

HVAC

EQUATIONS, DATA, AND RULES OF THUMB

THIRD EDITION

ARTHUR A. BELL, JR., P.E. • W. LARSEN ANGEL, P.E., LEED AP

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About the Author

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A. About the Author

Arthur A. Bell, Jr., PE, is a registered professional engineer and certified mechanical, plumbing, fire, and energy conservation code official in the Commonwealth of Pennsylvania with more than 31 years of experience in the design of HVAC systems. In addition, he has been involved in the design of plumbing systems, fire protection systems, and construction field engineering-mechanical systems. Mr. Bell is also the author of *HVAC Design Portfolio*, published by McGraw-Hill.

W. Larsen Angel, PE, is a registered professional engineer in the State of Maryland with more than 25 years of experience in the design of HVAC systems. In addition, he has been involved in the design of plumbing systems and electrical systems. Mr. Angel is also the author of *HVAC Design Sourcebook*, published by McGraw-Hill.

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Dedication

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B. Dedication

To Lisa, my lovely wife of twenty-five years, and to my two wonderful sons. *Soli Deo gloria*

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Part 1: Introduction

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1. Part 1: Introduction

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1.01. Background

- A. **The heating, ventilation, and air conditioning (HVAC) equations, data, rules of thumb, and other information contained within this reference manual were assembled to aid the beginning engineer and designer in the design of HVAC systems. In addition, the experienced engineer or designer may find this manual useful as a quick design reference guide, field manual, and teaching tool.**
- B. **The following pages compile information from various reference sources listed in Part 53 of this manual, from college HVAC class notes, from continuing education design seminars and classes, from engineers, and from personal experience. This document was put together as an encyclopedic type reference in contract specification outline format where information could be looked up quickly, in lieu of searching through volumes of textbooks, reference books and manuals, periodicals, trade articles, and product catalogs.**

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1.02. Rules of Thumb

- A. **Rules of thumb listed herein should be used considering the following:**
 - 1. Building loads are based on building gross square footage.
 - 2. Building loads generally include ventilation and make-up air requirements.

3. These rules of thumb may be used to estimate system loads during the preliminary design stages of a project.
 4. Building loads for construction documents should be calculated using the *ASHRAE Handbook of Fundamentals* or similar computational procedure in lieu of using these rules of thumb for final designs. When calculating heating and cooling loads, actual occupancy, lighting, and equipment information should be obtained from the owner, architect, electrical engineer, other design team members, or from technical publications such as ASHRAE.
- B. Many of the rules of thumb listed within this reference manual were developed many years ago. I have received many questions when conducting seminars regarding these rules of thumb. The most often asked question is "Are the cooling and heating load rules of thumb still accurate with the mandate of energy codes and tighter and improved building envelope construction?" The answer to this question is yes. The reason the cooling rules of thumb are still accurate is that the internal loads have increased substantially and cooling loads have switched from building-envelope-dependent, to lighting-dependent, and now to people-and-equipment-dependent (more people and equipment placed in the same area). The reason the heating load rules of thumb are still reasonably accurate is that the ventilation air (outdoor air load dictated by code) has increased.**

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1.03. Codes and Standards

- A. Code items contained herein were included more for comparison purposes than for use during design. All code items (i.e., ICC, ASHRAE, NFPA) are subject to change, and federal, state, and local codes should be consulted for applicable regulations and requirements.**
- B. The following codes were used unless otherwise noted.**
1. 2015 International Code Council Series of Codes (ICC):
 - a. 2015 International Building Code (herein referred to as 2015 IBC).
 - b. 2015 International Mechanical Code (herein referred to as 2015 IMC).
 - c. 2015 International Energy Conservation Code (herein referred to as 2015 IECC).

- d. 2015 International Plumbing Code (herein referred to as 2015 IPC).
 - e. 2015 International Fire Code (herein referred to as 2015 IFC).
 - f. 2015 International Fuel Gas Code (herein referred to as 2015 IFGC).
 - g. 2015 International Residential Code (herein referred to as 2015 IRC).
 - h. 2015 International Existing Building Code.
 - i. 2015 International Performance Code for Buildings and Facilities.
 - j. 2015 International Private Sewage Disposal Code.
 - k. 2015 International Property Maintenance Code.
 - l. 2015 International Zoning Code.
 - m. 2015 International Wildland-Urban Interface Code.
2. American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE):
- a. ASHRAE Standard 15—2013 (herein referred to as ASHRAE 15-2013).
 - b. ASHRAE Standard 55—2013 (herein referred to as ASHRAE 55-2013).
 - c. ASHRAE Standard 62.1—2013 (herein referred to as ASHRAE 62.1-2013).
 - d. ASHRAE Standard 62.2—2013 (herein referred to as ASHRAE 62.2-2013).
 - e. ASHRAE Standard 90.1—2013 (herein referred to as ASHRAE 90.1-2013).
 - f. ASHRAE Standard 90.2—2007 (herein referred to as ASHRAE 90.2-2007).
3. National Fire Protection Association Codes (NFPA):
- a. NFPA 90A—2015 Installation of Air-Conditioning and Ventilating Systems.
 - b. NFPA 96—2014 Ventilation Control and Fire Protection of Commercial Cooking Operations.

Citation

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Part 2: Definitions

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2. Part 2: Definitions

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2.01. General

A. *Furnish.* Except as otherwise defined in greater detail, the term *furnish* is used to mean "supply and deliver to the project site, ready for unloading, unpacking, assembly, installation, and similar operations" as applicable to each instance.

B. *Install.* Except as otherwise defined in greater detail, the term *install* is used to describe operations at the project site including actual "unloading, unpacking, assembly, erection, placing, anchoring, connecting, applying, working to dimension, finishing, curing, protecting, testing to demonstrate satisfactory operation, cleaning, and similar operations" as applicable in each instance.

C. *Provide.* Except as otherwise defined in greater detail, the term *provide* means to furnish and install, complete and ready for intended use and successfully tested to demonstrate satisfactory operation as applicable in each instance.

D. *Remove.* Except as otherwise defined in greater detail, the term *remove* means to disassemble, dismantle, and/or cut into pieces in order to remove the equipment from the site and to properly dispose of the removed equipment and pay for all associated costs incurred.

E. *Replace.* Except as otherwise defined in greater detail, the term *replace* means to remove the existing equipment and to provide new equipment of the same size, capacity, electrical characteristics,

function, etc., as the existing equipment.

F. *Relocate.* Except as otherwise defined in greater detail, the term *relocate* means to carefully remove without damaging item and to install where shown on the contract documents and/or as directed by the design professional and/or owner.

G. *Shall.* *Shall* indicates action that is mandatory on the part of the contractor.

H. *Will.* *Will* indicates action that is probable on the part of the contractor.

I. *Should.* *Should* indicates action that is probable on the part of the contractor.

J. *May.* *May* indicates action that is permissible on the part of the contractor.

K. *Indicated.* The term *indicated* is a cross-reference to graphic representations, details, notes, or schedules on the drawings; to other paragraphs or schedules in the specifications; and to similar means of recording requirements in the contract documents. Where terms such as *shown*, *noted*, *scheduled*, and *specified* are used in lieu of *indicated*, it is for the purpose of helping the reader locate the cross-reference, and no limitation is intended except as specifically noted.

L. *Shown.* The term *shown* is a cross-reference to graphic representations, details, notes, or schedules on the contract drawings and to similar means of recording requirements in the contract documents.

M. *Detailed.* The term *detailed* is a cross-reference to graphic representations, details, notes, or schedules on the contract drawings and to similar means of recording requirements in the contract documents.

N. *Specified.* The term *specified* is a cross-reference to paragraphs or schedules in the specifications and to similar means of recording requirements in the contract documents. The specifications include the general provisions, special provisions, and the technical specifications for the project.

O. *Including, Such as.* The terms *including* and *such as* shall always be taken in the most inclusive sense, namely "including, but not limited to" and "such as, but not limited to."

P. *Supply, Procurement.* The terms *supply* and *procurement* shall mean to purchase, procure, acquire, and deliver complete with related accessories.

Q. *At No Additional Cost.* The phrase "at no additional cost" shall mean at no additional cost to the owner and at no additional cost to the design professional or construction manager.

R. *Approved, Accepted.* Where used in conjunction with the design professional's response to submittals, requests, applications, inquiries, reports, and claims by the contractor, the meaning of the terms *approved* and *accepted* shall be held to the limitations of the design professional's responsibilities to fulfill requirements of the contract documents. The terms *approved* and *accepted* shall also mean to permit the use of material, equipment, or methods conditional upon compliance with the contract documents.

S. *Approved Equal, Approved Equivalent.* The terms *approved equal* and *approved equivalent* shall mean possessing the same performance qualities and characteristics and fulfilling the same utilitarian function and approved by the design professional.

T. *Directed, Requested, Required, etc.* Where not otherwise explained, terms such as *directed, requested, required, authorized, selected, approved, accepted, designated, prescribed, ordered, and permitted* mean "directed by the design professional," "requested by the design professional," "required by the design professional," and similar phrases. However, no such implied meaning will be interpreted to expand the design professional's responsibility into the contractor's area of construction supervision.

U. *Review.* The term *review* shall mean limited observation or checking to ascertain general conformance with the design concept of the work and with information given in the contract documents. Such action does not constitute a waiver or alteration of the contract document requirements.

V. *Suitable, Reasonable, Proper, Correct, and Necessary.* Such terms

shall mean as suitable, reasonable, proper, correct, or necessary for the purpose intended as required by the contract documents, subject to the judgment of the design professional or the construction manager.

W. *Option.* The term *option* shall mean a choice from the specified products, manufacturers, or procedures which shall be made by the contractor. The choice is not "whether" the work is to be performed, but "which" product, "which" manufacturer, or "which" procedure is to be used. The product or procedure chosen by the contractor shall be provided at no increase or additional cost to the owner, design professional, or construction manager, and with no lessening of the contractor's responsibility for its performance.

X. *Similar.* The term *similar* shall mean generally the same but not necessarily identical; details shall be worked out in relation to other parts of the work.

Y. *Submit.* The term *submit* shall mean, unless otherwise defined in greater detail, transmit to the design professional for approval, information, and record.

Z. *Project Site, Work Site.* The term *project site* shall be defined as the space available to the contractor for performance of the work, either exclusively or in conjunction with others performing other work as part of the project or another project. The extent of the project site is shown on the drawings or specified and may or may not be identical with the land upon which the project is to be built. The project site boundaries may include public streets, highways, roads, interstates, etc., public easements, and property under ownership of someone other than the client and are not available for performance of work.

AA. *Testing Laboratories.* The term *testing laboratories* shall be defined as an independent entity engaged to perform specific inspections or tests of the work, either at the project site or elsewhere, and to report and, if required, interpret the results of those inspections or tests.

BB. *Herein.* The term *herein* shall mean the contents of a particular section where this term appears.

CC. *Singular Number.* In all cases where a device or part of equipment

or system is herein referred to in the singular number (such as fan, pump, cooling system, heating system, etc.), it is intended that such reference shall apply to as many such items as are required by the contract documents and to complete the installation.

DD. *No Exception Taken.* The term *no exception taken* shall mean the same as *approved*.

EE. *Approved as Noted, Make Corrections Noted, or Revise—No Resubmittal Required.* The terms *approved as noted*, *make corrections noted*, and *revise—no resubmittal required* shall mean the submittal essentially complies with the contract documents except for a few minor discrepancies that have been annotated directly on the submittal that will have to be corrected on the submittal and the work correctly installed in the field by the contractor.

FF. *Revise and Resubmit.* The term *revise and resubmit* shall mean the contractor shall revise the submittal to conform with the contract documents by correcting moderate errors, omissions, and/or deviations from the contract documents and resubmit it for review prior to approval and before any material and/or equipment can be fabricated, purchased, or installed by the contractor.

GG. *Disapproved/Resubmit.* The term *disapproved/resubmit* shall mean the contractor shall revise the submittal to conform with the contract documents by correcting serious errors, omissions, and/or deviations from the contract documents and resubmit it for review prior to approval and before any material and/or equipment can be fabricated, purchased, or installed by the contractor.

HH. *Disapproved or Rejected.* The terms *disapproved* and *rejected* shall mean the contractor shall discard and replace the submittal because the submittal did not comply with the contract documents in a major way.

II. *Submit Specified Item.* The term *submit specified item* shall mean the contractor shall discard and replace the submittal with a submittal containing the specified items because the submittal contained improper manufacturer, model number, material, etc.

JJ. *Acceptance.* The formal acceptance by the owner or design professional of the work, as evidenced by the issuance of the

acceptance certificate.

KK. *Contract Item, Pay Item, Contract Fixed Price Item.* A specifically described item of work that is priced in the contract documents.

LL. *Contract Time, Time of Completion.* The number of calendar days (not working days) set forth in the contract documents for completion of the work.

MM. *Failure.* Any detected inability of material or equipment, or any portion thereof, to function or perform in accordance with the contract documents.

NN. *Substantial Completion.* *Substantial completion* shall be defined as the sufficient completion and accomplishment by the contractor of all work or designated portions thereof essential to fulfillment of the purpose of the contract, so the owner can occupy or utilize the work or designated portions thereof for the use for which it is intended.

OO. *Final Completion, Final Acceptance.* *Final completion* or *final acceptance* shall be defined as completion and accomplishment by the contractor of all work including contractual administrative demobilization work, all punch list items, and all other contract requirements essential to fulfillment of the purpose of the contract, so the owner can occupy or utilize the work for the use for which it is intended.

PP. *Pre-Final Inspection or Observation.* The term *pre-final inspection* or *observation* shall be held to the limitations of the design professional's responsibilities to fulfill the requirements of the contract documents and shall not relieve the contractor from contract obligations. The term *pre-final inspection* shall also mean all inspections conducted prior to the final inspection by the owner, the design professional, or both, verifying that all the work, with the exception of required contractual administrative demobilization work, inconsequential punch list items, and guarantees, has been satisfactorily completed in accordance with the contract documents.

QQ. *Final Inspection or Observation.* The term *final inspection* or *observation* shall be held to the limitations of the design professional's responsibilities to fulfill the requirements of the contract documents and shall not relieve the contractor from contract

obligations. The term *final inspection* shall also mean the inspection conducted by the owner, the design professional, or both, verifying that all the work, with the exception of required contractual administrative demobilization work, inconsequential punch list items, and guarantees, has been satisfactorily completed in accordance with the contract documents.

RR. *Reliability*. The probability that a system will perform its intended functions without failure and within design parameters under specified operating conditions for which it is designed and for a specified period of time.

SS. *Testing*. The term *testing* may be described as the inspection, investigation, analysis, and diagnosis of all systems and components to ensure that the systems are operable, meet the requirements of the contract documents, and are ready for operation. Included are such items as:

1. Verification that the system is filled with water and is not air bound.
2. Verification that expansion tanks of the proper size are connected at the correct locations and that they are not waterlogged.
3. Verification that all system components are in proper working order and properly installed. Check for proper flow directions.
4. Checking of all voltages for each motor in the system.
5. Checking that all motors rotate in the correct direction and at the correct speed.
6. Checking all motors for possible overload (excess amperage draw) on initial start-up.
7. Checking of each pump for proper alignment.
8. Checking all systems for leaks, etc.
9. Checking all systems and components to ensure they meet the contract document requirements as far as capacity, system operation, control function, and other items required by the contract documents.

TT. *Adjusting.* The term *adjusting* may be described as the final setting of balancing devices such as dampers and valves, establishing and setting minimum variable frequency controller speed, in addition to automatic control devices, such as thermostats and pressure/temperature controllers to achieve maximum system performance and efficiency during normal operation. Adjusting also includes final adjustments for pumps by regulation of motor speed, partial close-down of pump discharge valve or impeller trim (preferred over the partial close-down of pump discharge valve).

UU. *Balancing.* The term *balancing* is the methodical regulation of system fluid flow-rates (air and water) through the use of workable and industry-accepted procedures as specified to achieve the desired or specified flow rates (CFM or GPM) in each segment (main, branch, or subcircuit) of the system.

VV. *Commissioning.* The term *commissioning* is the methodical procedures and methods for documenting and verifying the performance of the building envelope, HVAC, plumbing, fire protection, electrical, life safety, and telecom/data systems so that the systems operate in conformity with the design intent. Commissioning will include testing; adjusting; balancing; documentation of occupancy requirements and design assumptions; documentation of design intent for use by contractors, owners, and operators; functional performance testing and documentation necessary for evaluating all systems for acceptance; and adjusting the building systems to meet actual occupancy needs within the capability of the systems. The purpose of commissioning of building systems is to achieve the end result of a fully functional, fine-tuned, and operational building.

WW. *Functional Performance Testing.* The term *functional performance testing* shall mean the full range of checks and tests carried out to determine if all components, subsystems, systems, and interfaces between systems function in accordance with the contract documents. In this context, *function* includes all modes and sequences of control operation, all interlocks and conditional control responses, and all specified responses to abnormal emergency conditions.

XX. *Confined Spaces.* *Confined spaces* (according to OSHA

regulations) are spaces which must have these three characteristics:

1. The space must be large enough and configured to permit personnel to enter and work.
2. The space is not designed for continuous human occupancy.
3. The space has limited or restricted means of entry and exit.
4. Two categories of confined spaces exist:
 - a. *Non-Permit Required Confined Spaces (NRCS)*. Spaces that contain no physical hazards that could cause death or serious physical harm, and cannot possibly contain any atmospheric hazards.
 - b. *Permit Required Confined Spaces (PRCS)*. Spaces that contain or may contain a hazardous atmosphere (atmospheric hazards—oxygen deficiency or enrichment 19.5 percent acceptable minimum and 23.5 percent acceptable maximum; flammable contaminants; and toxic contaminants—product, process, or reactivity); a liquid or finely divided solid material such as grain, pulverized coal, etc., that could surround or engulf a person; or some other recognized serious safety or health hazard such as temperature extremes or mechanical or electrical hazards (boilers, open transformers, tanks, vaults, sewers, manholes, pits, machinery enclosures, vats, silos, storage bins, rail tank cars, and process or reactor vessels).

YY. Hazardous Location Classifications

1. Hazardous locations are those areas where a potential for explosion and fire exist because of flammable gases, vapors, or dust in the atmosphere, or because of the presence of easily ignitable fibers or flyings in accordance with the National Electric Code (*NEC—NFPA 70*).
2. *Class I Locations*. Class I locations are those locations in which flammable gases or vapors are, or may be, present in the air in quantities sufficient to produce explosive or ignitable mixtures.
 - a. *Class I, Division 1 Locations*. These are Class I locations where the hazardous atmosphere is expected to be present during normal operations. It may be present continuously, intermittently, periodically, or during normal repair or maintenance operations. Division 1 locations are also those locations where a breakdown in the operation of processing equipment results in the release of hazardous vapors while providing a source of ignition with the simultaneous failure of electrical equipment.

- b. *Class I, Division 2 Locations.* These are Class I locations in which volatile flammable liquids or gases are handled, processed, or used, but in which they can escape only in the case of accidental rupture or breakdown of the containers or systems. The hazardous conditions will occur only under abnormal conditions.
3. *Class II Locations.* Class II locations are those locations that are hazardous because of the presence of combustible dust.
- a. *Class II, Division 1 Locations.* These are Class II locations where combustible dust may be in suspension in the air under normal conditions in sufficient quantities to produce explosive or ignitable mixtures. This may occur continuously, intermittently, or periodically. Division 1 locations also exist where failure or malfunction of machinery or equipment might cause a hazardous location to exist while providing a source of ignition with the simultaneous failure of electrical equipment. Included also are locations in which combustible dust of an electrically conductive nature may be present.
 - b. *Class II, Division 2 Locations.* These are Class II locations in which combustible dust will not normally be in suspension in the air, and normal operations will not put the dust in suspension, but where accumulation of the dust may interfere with the safe dissipation of heat from electrical equipment or where accumulations near electrical equipment may be ignited by arcs, sparks, or burning material from the equipment.
4. *Class III Locations.* Class III locations are those locations that are hazardous because of the presence of easily ignitable fibers or flyings, but in which the fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.
- a. *Class III, Division 1 Locations.* These are locations in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.
 - b. *Class III, Division 2 Locations.* These locations are where easily ignitable fibers are stored or handled.

2.02. Systems

A. *Mechanical Systems.* The term *mechanical systems* shall mean for the purposes of these contract documents all heating, ventilating, and air conditioning systems and all piping systems as specified and as shown on the mechanical drawings and all services and appurtenances incidental thereto.

B. *Plumbing Systems.* The term *plumbing systems* shall mean for the purposes of these contract documents all plumbing fixtures, plumbing systems, piping systems, medical vacuum, medical compressed air, medical gas, laboratory vacuum, laboratory compressed air, and all laboratory gas systems as specified and as shown on the plumbing drawings and all services and appurtenances incidental thereto.

C. *Fire Suppression Systems.* The term *fire suppression systems* shall mean for the purposes of these contract documents all fire protection piping systems, standpipe, wet-pipe, dry-pipe, preaction, foam suppression, and all fire protection systems as specified and as shown on the fire protection drawings and all services and appurtenances incidental thereto.

D. *Ductwork.* The term *ductwork* shall include ducts, fittings, flanges, dampers, insulation, hangers, supports, access doors, housings, and all other appurtenances comprising a complete and operable system.

1. *Supply Air Ductwork.* The term *supply air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a fan or air handling unit to the room, space, or area to which it is introduced. The air may be conditioned or unconditioned. Supply air ductwork extends from the fan or air handling unit to all the diffusers, registers, and grilles.
2. *Return Air Ductwork.* The term *return air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a room, space, or area to a fan or air handling unit. Return air ductwork extends from the registers, grilles, or other return openings to the return fan (if used) and the air handling unit.
3. *Exhaust Air Ductwork.* The term *exhaust air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a room, space, area, or equipment to a fan and then discharged to the outdoors. Exhaust air ductwork extends from the registers, grilles, equipment, or other exhaust openings to the fan, and from the fan to the outdoor discharge point.

4. *Relief Air Ductwork.* The term *relief air ductwork* shall mean for the purposes of these contract documents all ductwork carrying air from a room, space, or area without the use of a fan or with the use of a return fan to be discharged to the outdoors. Relief air ductwork extends from the registers, grilles, or other relief openings to the outdoor discharge point, or from the return fan discharge to the outdoor discharge point.
5. *Outside Air Ductwork.* The term *outside air ductwork* shall mean for the purposes of these contract documents all ductwork carrying unconditioned air from the outside to a fan or air handling unit. Outdoor air ductwork extends from the intake point or louver to the fan, air handling unit, or connection to the return air ductwork.
6. *Mixed Air Ductwork.* The term *mixed air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying a mixture of return air and outdoor air. Mixed air ductwork extends from the point of connection of the return air and outdoor air ductwork to the fan or air handling unit.
7. *Supply Air Plenum.* The term *supply air plenum* shall mean for the purposes of these contract documents all ductwork in which the discharges of multiple fans or air handling units connect forming a common supply header, or all ductwork or ceiling construction forming a common supply box where supply air ductwork discharges into the box at limited locations for air distribution to supply diffusers which are directly connected to the plenum.
8. *Return Air Plenum.* The term *return air plenum* shall mean for the purposes of these contract documents all ductwork in which the suctions of multiple return fans or the discharges of multiple return fans connect forming a common suction or discharge return header or the space above the architectural ceiling and below the floor or roof structure used as return air ductwork.
9. *Exhaust Air Plenum.* The term *exhaust air plenum* shall mean for the purposes of these contract documents all ductwork in which the suctions of multiple exhaust fans or the discharges of multiple exhaust fans connect forming a common suction or discharge exhaust header or the ductwork formed around single or multiple exhaust air discharge openings or louvers to create a connection point for exhaust air ductwork.

10. *Relief Air Plenum*. The term *relief air plenum* shall mean for the purposes of these contract documents all ductwork in which multiple relief air ductwork connections are made forming a common relief air header.
11. *Outdoor Air Plenum*. The term *outdoor air plenum* shall mean for the purposes of these contract documents all ductwork in which the suctions of multiple fans or air handling units connect to form a common outside air header or the ductwork formed around single or multiple outside air openings or louvers to create a connection point for outside air ductwork.
12. *Mixed Air Plenum*. The term *mixed air plenum* shall mean for the purposes of these contract documents all ductwork in which multiple return air and multiple outdoor air ductwork connections are made forming a common mixed air header.
13. *Vents, Flues, Stacks, and Breeching*. The terms *vents, flues, stacks, and breeching* shall mean for the purposes of these contract documents ductwork conveying the products of combustion to atmosphere for safe discharge.

E. *Piping*. The term *piping* shall include pipe, fittings, valves, flanges, unions, traps, drains, strainers, insulation, hangers, supports, and all other appurtenances comprising a complete and operable system.

F. *Wiring*. The term *wiring* shall include wire, conduit, raceways, bus duct, fittings, junction and outlet boxes, switches, cutouts, receptacles, and all other appurtenances comprising a complete and operable system.

G. *Product*. The term *product* shall include materials, equipment, and systems for a complete and operable system.

H. *Motor Controllers*. The term *motor controllers* shall be manual or magnetic starters (with or without switches), variable frequency controllers, individual push buttons, or hand-off-automatic (HOA) switches controlling the operation of motors.

I. *Control Devices*. The term *control devices* shall be automatic sensing and switching devices such as thermostats, float, and electro-pneumatic switches controlling the operations of mechanical and electrical equipment.

J. *Work, Project.* The terms *work* and *project* shall mean labor, operations, materials, supervision, services, machinery, equipment, tools, supplies, and facilities to be performed or provided including work normally done at the location of the project to accomplish the requirements of the contract including all alterations, amendments, or extensions to the contract made by change order.

K. *Extra Work.* The term *extra work* shall be any item of work not provided for in the awarded contract as previously modified by change order (change bulletin) or supplemental agreement, but which is either requested by the owner or found by the design professional to be necessary to complete the work within the intended scope of the Contract as previously modified.

L. *Concealed.* The term *concealed* shall mean hidden from normal sight; includes work in crawl spaces, above ceilings, in walls, in chases, and in building shafts.

M. *Exposed.* The term *exposed* shall mean not concealed.

N. *Below Ground.* The term *below ground* shall mean installed underground, buried in the earth, or buried below the ground floor slab.

O. *Above Ground.* The term *above ground* shall mean not installed underground, not buried in the earth, and not buried below the ground floor slab.

P. *Conditioned.* The term *conditioned* shall mean for the purposes of these contract documents rooms, spaces, or areas that are provided with mechanical heating and cooling.

Q. *Unconditioned and Nonconditioned.* The terms *unconditioned* and *nonconditioned* shall mean for the purposes of these contract documents rooms, spaces, or areas that are not provided with mechanical heating or cooling.

R. *Heated.* The term *heated* shall mean for the purposes of these contract documents rooms, spaces, or areas that are provided with mechanical heating only.

S. *Air Conditioned.* The term *air conditioned* shall mean for the purposes of these contract documents rooms, spaces, or areas that are provided with mechanical cooling only.

T. *Unheated.* The term *unheated* shall mean for the purposes of these contract documents rooms, spaces, or areas that are not provided with mechanical heating.

U. *Ventilated Spaces.* The term *ventilated spaces* shall mean for the purposes of these contract documents rooms, spaces, or areas supplied with outdoor air on a continuous or intermittent basis. The outdoor air may be conditioned, heated, unconditioned, or unheated.

V. *Indoor.* The term *indoor* shall mean for the purposes of these contract documents items or devices contained within the confines of a building, structure, or facility and items or devices that are not exposed to weather. The term *indoor* shall generally reference ductwork, piping, or equipment location (indoor ductwork, indoor piping, indoor equipment).

W. *Outdoor.* The term *outdoor* shall mean for the purposes of these contract documents items or devices not contained within the confines of a building, structure, or facility and items or devices that are exposed to weather. The term *outdoor* shall generally reference ductwork, piping, or equipment (outdoor ductwork, outdoor piping, outdoor equipment).

X. *Hot.* The term *hot* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that are above the surrounding ambient temperature or above 100°F (hot supply air ductwork, heating water piping).

Y. *Cold.* The term *cold* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that are below the surrounding ambient temperature or below 60°F (cold supply air ductwork, chilled water piping).

Z. *Warm.* The term *warm* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that are at the surrounding ambient temperature or between 60°F and 100°F (condenser water piping).

AA. *Hot/Cold.* The term *hot/cold* shall mean for the purposes of these contract documents the temperature of conveyed solids, liquids, or gases that can be either hot or cold depending on the season of the year (heating and air conditioning supply air ductwork, dual temperature piping systems).

BB. *Removable.* The term *removable* shall mean detachable from the structure or system without physical alteration or disassembly of the materials or equipment or disturbance to other construction.

CC. *Temporary Work.* Work provided by the contractor for use during the performance of the work, but which is to be removed prior to final acceptance.

DD. *Normally Closed (NC).* The term *normally closed* shall mean the valve, damper, or other control device shall remain in, or go to, the closed position when the control air pressure, the control power, or the control signal is removed. The position the device will assume when the control signal is removed.

EE. *Normally Open (NO).* The term *normally open* shall mean that the valve, damper, or other control device shall remain in, or go to, the open position when the control air pressure, the control power, or the control signal is removed. The position the device will assume when the control signal is removed.

FF. *Traffic Level or Personnel Level.* The term *traffic level or personnel level* shall mean for the purposes of these contract documents all areas, including process areas, equipment rooms, boiler rooms, chiller rooms, fan rooms, air handling unit rooms, and other areas where insulation may be damaged by normal activity and local personnel traffic. The area extends vertically from the walking surface to 8'0" above walking surface and extends horizontally 5'0" beyond the edge of the walking surface. The walking surface shall include floors, walkways, platforms, catwalks, ladders, and stairs.

2.03. Contract Documents

A. *Contract Drawings.* The terms *contract drawings* and *drawings* shall mean all drawings or reproductions of drawings pertaining to the construction or plans, sections, elevations, profiles, and details of the work contemplated and its appurtenances.

B. *Contract Specifications.* The terms *contract specifications* and *specifications* shall mean the description, provisions, and other requirements pertaining to the method and manner of performing the work and to the quantities and qualities of materials to be furnished under the contract. The specifications shall include the general provisions, the special provisions, and the technical specifications.

C. *Contract Documents.* The term *contract documents* shall include contract drawings, contract specifications, addenda, amendments, shop drawings, coordination drawings, general provisions, special provisions, the executed agreement and other items required for, or pertaining to, the contract, including the executed contract.

D. *Addenda.* Addenda are issued as changes, amendments, or clarifications to the original or previously issued contract documents. Addenda are issued in written and/or drawing form prior to acceptance or signing of the construction contract.

E. *Amendments (Change Orders, Change Bulletins).* Amendments (change orders, change bulletins) are issued changes or amendments to the contract documents. Amendments are issued in written and/or drawing form after acceptance or signing of the contract.

F. *Submittals or Shop Drawings.* The term *submittals* or *shop drawings* shall include drawings, coordination drawings, diagrams, schedules, performance characteristics, charts, brochures, catalog cuts, calculations, certified drawings, and other materials prepared by the contractor, subcontractor, manufacturer, or distributor that illustrate some portion of the work in accordance with the requirements of the contract documents used by the contractor to order, fabricate, and install the general construction, mechanical, plumbing, fire protection, and electrical equipment and systems in a building.

The corrections or comments annotated on a shop drawing during the design professional's review do not relieve the contractor from full compliance with the contract documents regarding the work. The

design professional's check is only a review of the shop drawing's general compliance with the information shown in the contract documents. The contractor remains responsible for continuing the correlation of all material and component quantities and dimensions, coordination of the contractor's work with that of other trades, selection of suitable fabrication and installation techniques, and performance of work in a safe and satisfactory manner.

G. *Product Data.* Illustrations, standard schedules, performance charts, instructions, brochures, diagrams, and other information furnished by the contractor to illustrate a material, product, or system for some portion of the work.

H. *Samples.* Physical examples that illustrate material, equipment, or workmanship and establish standards to which the work will be judged.

I. *Coordination Drawings.* The terms *coordination drawings* and *composite drawings* are drawings created by the respective contractors showing work of all contractors superimposed on the sepia or mylar of the basic shop drawing of one of the contractors to coordinate and verify that all work in a congested area will fit in an acceptable manner.

J. *Contract.* A set of documents issued by the owner for the work, which may include the contract documents, the advertisement, form of proposal, free competitive bidding affidavit, affidavit as to taxes, certification of bidder, buy America requirements, disadvantaged business enterprise forms, bid bond, agreement, waiver of right to file mechanics lien, performance bond, payment bond, maintenance bond(s), certification regarding lobbying, disclosure form to report lobbying, and other forms that form part of the contract as required by the owner and the contract documents.

K. *Payment Bond.* The approved form of security furnished by the contractor and its surety as a guarantee to pay promptly, or cause to be paid promptly, in full, such items as may be due for all material furnished, labor supplied or performed, rental of equipment used, and services rendered in connection with the work.

L. *Maintenance Bond.* The approved form of security furnished by the

contractor and its surety as a guarantee on the part of the contractor to remedy, without cost to the owner, any defects in the work that may develop during a period of twelve (12) months from the date of substantial completion.

M. *Performance Bond.* The approved form of security furnished by the contractor and its surety as a guarantee on the part of the contractor to execute the work.

N. *Working Drawings.* Drawings and calculations prepared by the contractor, subcontractor, supplier, distributor, etc., that illustrate work required for the construction of, but which will not become an integral part of, the work. These shall include, but are not limited to, drawings showing contractor's plans for temporary work such as decking, temporary bulkheads, support of excavation, support of utilities, groundwater control systems, forming and false-work, erection plans, and underpinning.

O. *Construction Drawings or Coordination Drawings.* Detailed drawings prepared by the contractor, subcontractor, supplier, distributor, etc., that illustrate in exact and intricate detail, work required for the construction contract. These drawings often show hanger locations, vibration isolators, ductwork and pipe fittings, sections, dimensions of ducts and pipes, and other items required to construct the work.

P. *Project Record Documents.* A copy of all contract drawings, shop drawings, working drawings, addenda, change orders, contract documents, and other data maintained by the contractor during the work. The contractor's recording, on a set of prints, of accurate information and sketches regarding the exact detail and location of the work as actually installed, recording such information as the exact location of all underground utilities, contract changes, and contract deviations. The contractor's information is then transferred to the original contract documents by the design professional for the owner's permanent record unless otherwise directed or specified.

Q. *Proposal Guarantee.* Cashier's check, certified check, or bid bond accompanying the proposal submitted by the bidder as a guarantee that the bidder will enter into a contract with the owner for the

performance of the work indicated and file acceptable bonds and insurance if the contract is awarded to it.

R. *Project Schedule.* The schedule for the work as prepared and maintained by the contractor in accordance with the contract documents.

S. *Certificate of Substantial Completion.* Certificate issued by the owner or design professional certifying that a substantial portion of the work has been completed in accordance with the contract documents with the exception of contractual administrative demobilization work, inconsequential punch list items, and guarantees. The certificate of substantial completion shall establish the date of substantial completion, shall state the responsibilities of the owner and the contractor for security, maintenance, heat, utilities, damage to the work, and insurance, and shall fix the time within which the contractor shall complete the items listed therein. Warranties required by the contract documents shall commence on the date of substantial completion of the work or a designated portion thereof unless otherwise provided in the certificate of substantial completion or the contract documents.

T. *Certificate of Final Completion (Final Acceptance).* Certificate issued by the owner or design professional certifying that all of the work has been completed in accordance with the contract documents to the best of the owner's or design professional's knowledge, information, and belief, and on the basis of that person's observations and inspections including contractual administrative demobilization work and all punch list items. The certificate of final completion shall establish the date of owner acceptance. Warranties required by the contract documents shall commence on the date of final completion of the work unless otherwise provided in the certificate of substantial completion or the contract documents.

U. *Acceptance Certificate.* Certificate to be issued by the owner or design professional certifying that all the work has been completed in accordance with the contract documents.

V. *Award.* The acceptance by the owner of the bid from the responsible bidder (sometimes the lowest responsible bidder) as evidenced by the written notice to award to the bidder tendering said

bid.

W. *Bid (Proposal)*. The proposal of the bidder for the work, submitted on the prescribed bid form, properly signed, dated, and guaranteed, including alternates, the unit price schedule, bonds, and other bidding requirements as applicable.

X. *Certificate of Compliance*. Certificate issued by the supplier certifying that the material or equipment furnished is in compliance with the contract documents.

Y. *Agreement*. The instrument executed by the owner and the contractor in conformance with the contract documents for the performance of the work.

Z. *Field Order*. A notice issued to the contractor by the design professional specifying an action required of the contractor.

AA. *Request for Information or Request for Interpretation (RFI)*. A notice issued by the contractor to the design professional or owner requesting a clarification of the contract documents.

BB. *Notice to Proceed*. A written notice from the owner to the contractor or design professional directing the contractor or design professional to proceed with the work.

CC. *Advertisement, Invitation to Bid*. The public or private announcement, as required by law or the owner, inviting bids for the work to be performed, material to be furnished, or both.

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2.04. Contractors/Manufacturers/Authorities

A. *Contractor*. The term *contractor* shall mean the individual, firm, partnership, corporation, joint venture, or any combination thereof or their duly authorized representatives who have executed a contract with the client for the proposed work.

B. *Subcontractor or Trade Contractor*. The terms *subcontractor* or *trade contractor* shall mean all the lower-tier contractors, material suppliers, and distributors that have executed a contract with the contractor for the proposed work.

C. *Furnisher or Supplier.* The terms *furnisher* or *supplier* shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the contractor, its subcontractor, or sub-subcontractor, to furnish a particular unit of material or equipment to the project site. It shall be a requirement that the furnisher or supplier be experienced in the manufacture of the material or equipment they are to furnish.

D. *Installer.* The term *installer* shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the contractor, its subcontractor, or sub-subcontractor to install a particular unit of work at the project site, including installation, erection, application, and similar required operations. It shall be a requirement that the installer be experienced in the operations they are engaged to perform.

E. *Provider.* The term *provider* shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the contractor, its subcontractor, or sub-subcontractor to provide a particular unit of material or equipment at the project site. It shall be a requirement that the provider be experienced in the operations they are engaged to perform.

F. *Bidder.* An individual, firm, partnership, corporation, joint venture, or any combination thereof submitting a bid for the work as a single business entity and acting directly or through a duly authorized representative.

G. *Authority Having Jurisdiction.* The term *authority having jurisdiction* shall mean federal, state, and/or local authorities or agencies thereof having jurisdiction over work to which reference is made and authorities responsible for "approving" equipment, installation, and/or procedures.

H. *Surety.* The corporate body that is bound with, and for, the contractor for the satisfactory performance of the work by the contractor, and the prompt payment in full for materials, labor, equipment, rentals, and services, as provided in the bonds.

I. *Acceptable Manufacturers.* The term *acceptable manufacturers* shall mean the specified list of manufacturers considered acceptable to bid the project for a specific piece of equipment. Only the equipment specified has been checked for spatial compatibility. If the contractor elects to use an optional manufacturer from the acceptable manufacturers list in the specifications, it shall be the contractor's responsibility to determine and ensure the spatial compatibility of the manufacturer's equipment selected.

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Part 3: Equations

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3. Part 3: Equations

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3.01. Airside System Equations and Derivations

A. Equations

$$H_S = 1.08 \times CFM \times \Delta T$$

$$H_L = 0.68 \times CFM \times \Delta W_{GR.}$$

$$H_L = 4840 \times CFM \times \Delta W_{LB.}$$

$$H_T = 4.5 \times CFM \times \Delta h$$

$$H_T = H_S + H_L$$

$$SHR = \frac{H_S}{H_T} = \frac{H_S}{H_S + H_L}$$

H_S	= sensible heat (Btu/h)
H_L	= latent heat (Btu/h)
H_T	= total heat (Btu/h)
ΔT	= temperature difference ($^{\circ}F$)
$\Delta W_{GR.}$	= humidity ratio difference (Gr.H ₂ O/lbs.DA)
$\Delta W_{LB.}$	= humidity ratio difference (lbs.H ₂ O/lbs.DA)
Δh	= enthalpy difference (Btu/lbs.DA)
CFM	= air flow rate (cubic feet per minute)
SHR	= sensible heat ratio
m	= mass flow (lbs.DA/h)
c_a	= specific heat of air (0.24 Btu/lbs.DA $^{\circ}F$)
DA	= dry air

B. Derivations

1. Standard air conditions:

- a. Temperature: 60 $^{\circ}F$
- b. Pressure: 14.7 psia (sea level)
- c. Specific volume: 13.33 ft.³/lbs.DA
- d. Density: 0.075 lbs./ft.³
- e. L_v = Latent heat of water @60 $^{\circ}F$: 1060 Btu/lbs.

2. Sensible heat equation:

H_S	$= m \times c_a \times \Delta T$
C_p	$= 0.24 \text{ (Btu/lbs.DA} \cdot \text{ }^\circ\text{F)} \times 0.075$ $\text{lbs.DA/ft.}^3 \times 60 \text{ min./h}$
	$= 1.08 \text{ Btu min./h ft.}^3 \text{ }^\circ\text{F}$
H_S	$= 1.08 \text{ (Btu min./h ft.}^3 \text{ }^\circ\text{F)} \times \text{CFM}$ $\text{(ft.}^3\text{/min.)} \times \Delta T \text{ (}^\circ\text{F)}$
H_S	$= 1.08 \times \text{CFM} \times \Delta T$

3. Latent heat equation:

H_L	$= m \times L_v \times \Delta W_{GR}$
L_v	$= 1060 \text{ Btu/lbs.H}_2\text{O} \times 0.075$ $\text{lbs.DA/ft.}^3 \times 60 \text{ min./h} \times 1.0$ $\text{lbs.H}_2\text{O/7,000 Gr.H}_2\text{O}$
	$= 0.68 \text{ Btu lbs.DA min./hft.}^3 \text{ Gr.H}_2\text{O}$
H_L	$= 0.68 \text{ (Btu lbs.DA min./hft.}^3 \text{ Gr.H}_2\text{O)}$ $\times \text{CFM (ft.}^3\text{/min.)} \times \Delta W_{GR}$ $\text{(Gr.H}_2\text{O/lbs.DA)}$
H_L	$= 0.68 \times \text{CFM} \times \Delta W_{GR}$

4. Total heat equation:

H_T	$= m \times \Delta h$
Factor	$= 0.075 \text{ lbs.DA/ft.}^3 \times 60 \text{ min./h} = 4.5$ $\text{lbs.DA min./hft.}^3$
H_T	$= 4.5 \text{ (lbs.DA min./hft.}^3) \times \text{CFM}$ $\text{(ft.}^3\text{/min.)} \times \Delta h \text{ (Btu/lbs.DA)}$
H_T	$= 4.5 \times \text{CFM} \times \Delta h$

3.02. Waterside System Equations and Derivations

A. Equations

$$H = 500 \times GPM \times \Delta T$$

$$GPM_{EVAP.} = \frac{TONS \times 24}{\Delta T}$$

$$GPM_{COND.} = \frac{TONS \times 30}{\Delta T}$$

H	= total heat (Btu/h)
GPM	= water flow rate (gallons per minute)
ΔT	= temperature difference ($^{\circ}F$)
TONS	= air conditioning load (tons)
$GPM_{EVAP.}$	= evaporator water flow rate (gallons per minute)
$GPM_{COND.}$	= condenser water flow rate (gallons per minute)
C_w	= specific heat of water (1.0 Btu/lbs.H ₂ O)

B. Derivations

1. Standard water conditions:
 - a. Temperature: 60 $^{\circ}F$
 - b. Pressure: 14.7 psia (sea level)
 - c. Density: 62.4 lbs./ft.³
2. Water equation

H	= $m \times c_w \times \Delta T$
C_w	= 1.0 Btu/Lb H ₂ O $^{\circ}F \times 62.4 \text{ lbs.H}_2\text{O/ft}^3 \times 1.0 \text{ ft}^3/7.48052 \text{ gal.} \times 60 \text{ min./h}$
	= 500 Btu min./h $^{\circ}F \text{ gal.}$
H	= 500 Btu min./h $^{\circ}F \text{ gal.} \times GPM \text{ (gal./min.)} \times \Delta T \text{ (}^{\circ}F)$
H	= 500 $\times GPM \times \Delta T$

3. Evaporator equation:

GPM_{EVAP}	$= H/(500 \times \Delta T)$
Factor	$= 12,000 \text{ Btu/h} / 1.0 \text{ tons} \div 500 \text{ Btu min./h } ^\circ\text{F gal.}$
	$= 24^\circ\text{F gal./tons min.}$
GPM_{EVAP}	$= \text{tons (tons)} \times 24 \text{ (}^\circ\text{F gal./tons min.)} / \Delta T \text{ (}^\circ\text{F)}$
GPM_{EVAP}	$= \text{tons} \times 24 / \Delta T$

4. Condenser equation:

GPM_{COND}	$= 1.25 \times GPM_{EVAP} = 1.25 \times \text{tons} \times 24 / \Delta T$
GPM_{COND}	$= \text{tons} \times 30 / \Delta T$

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3.03. Air Change Rate Equations

$$\frac{AC}{HR} = \frac{CFM \times 60}{VOLUME}$$

$$CFM = \frac{\frac{AC}{HR} \times VOLUME}{60}$$

AC/H	= air change rate per hour
CFM	= air flow rate (cubic feet per minute)
VOLUME	= space volume (cubic feet)

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3.04. English/Metric Airside System Equations Comparison

A. Sensible Heat Equations

$$H_s = 1.08 \frac{\text{Btu min.}}{\text{Hr ft}^3 \text{ } ^\circ\text{F}} \times CFM \times \Delta T$$

$$H_{SM} = 72.42 \frac{\text{kJ min.}}{\text{hr. m}^3 \text{ } ^\circ\text{C}} \times CMM \times \Delta T_M$$

B. Latent Heat Equations

$$H_L = 0.68 \frac{\text{Btu min. Lb DA}}{\text{hr. ft}^3 \text{ Gr H}_2\text{O}} \times \text{CFM} \times \Delta W$$

$$H_{LM} = 177,734.8 \frac{\text{kJ min. kg DA}}{\text{hr. m}^3 \text{ kg H}_2\text{O}} \times \text{CMM} \times \Delta W_M$$

C. Total Heat Equations

$$H_T = 4.5 \frac{\text{lb min.}}{\text{hr. ft.}^3} \times \text{CFM} \times \Delta h$$

$$H_{TM} = 72.09 \frac{\text{kg min.}}{\text{hr. m}^3} \times \text{CMM} \times \Delta h_M$$

$$H_T = H_S + H_L$$

$$H_{TM} = H_{SM} + H_{LM}$$

H_S	= sensible heat (Btu/h)
H_{SM}	= sensible heat (kJ/h)
H_L	= latent heat (Btu/h)
H_{LM}	= latent heat (kJ/h)
H_T	= total heat (Btu/h)
H_{TM}	= total heat (kJ/h)
ΔT	= temperature difference (°F)
ΔT_M	= temperature difference (°C)
ΔW	= humidity ratio difference (Gr.H ₂ O/lbs.DA)
ΔW_M	= humidity ratio difference (kg.H ₂ O/kg.DA)
Δh	= enthalpy difference (Btu/lbs.DA)
Δh_M	= enthalpy difference (kJ/lbs.DA)
CFM	= air flow rate (cubic feet per minute)
CMM	= air flow rate (cubic meters per minute)

3.05. English/Metric Waterside System Equation Comparison

$$H = 500 \frac{\text{Btu min.}}{\text{hr. gal. } ^\circ\text{F}} \times \text{GPM} \times \Delta T$$

$$H_M = 250.8 \frac{\text{kJ min.}}{\text{hr. Liters } ^\circ\text{C}} \times \text{LPM} \times \Delta T_M$$

H	= total heat (Btu/h)
H _M	= total heat (kJ/h)
ΔT	= temperature difference (°F)
ΔT _M	= temperature difference (°C)
GPM	= water flow rate (gallons per minute)
LPM	= water flow rate (liters per minute)

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3.06. English/Metric Air Change Rate Equation Comparison

$$\frac{AC}{HR} = \frac{CFM \times 60 \frac{\text{min.}}{h}}{VOLUME}$$

$$\frac{AC}{HR_M} = \frac{CMM \times 60 \frac{\text{min.}}{h}}{VOLUME_M}$$

AC/H	= air change rate per hour - English
AC/H _M	= air change rate per hour - Metric
AC/H	= AC/H _M
VOLUME	= space volume (cubic feet)
VOLUME _M	= space volume (cubic meters)
CFM	= air flow rate (cubic feet per minute)
CMM	= air flow rate (cubic meters per minute)

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3.07. English/Metric Temperature and Other Conversions

$$^{\circ}\text{F} = 1.8^{\circ}\text{C} + 32$$

$$^{\circ}\text{C} = \frac{^{\circ}\text{F} - 32}{1.8}$$

$^{\circ}\text{F}$	= degrees Fahrenheit
$^{\circ}\text{C}$	= degrees Celsius
kJ/h	= Btu/h \times 1.055
CMM	= CFM \times 0.02832
LPM	= GPM \times 3.785
kJ/kg	= Btu/lbs. \times 2.326
meters	= ft. \times 0.3048
sq. meters	= sq. ft. \times 0.0929
cu. meters	= cu. ft. \times 0.02832
kg	= lbs. \times 0.4536
1.0 GPM	= 500 lbs. steam/h
1.0 lbs. stm./h	= 0.002 GPM
1.0 lbs. H ₂ O/h	= 1.0 lbs. steam/h
kg/cu. meter	= lbs./cu. ft. \times 16.017 (Density)
cu. meters/kg	= cu. ft./lbs. \times 0.0624 (Specific Volume)
kg H ₂ O/kg DA	= Gr.H ₂ O/lbs.DA/7,000 = lbs.H ₂ O/lbs.DA

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3.08. Steam and Condensate Equations

A. General

$$LBS.STM./HR = \frac{BTU/HR}{H_{FG}} = \frac{BTU/HR}{960}$$

$$LBS.STM.COND./HR = \frac{EDR}{4}$$

$$EDR = \frac{BTU/HR}{240}$$

$$LBS.STM.COND./HR = \frac{GPM \times 500 \times SP.GR. \times C_w \times \Delta T}{H_{FG}}$$

$$LBS.STM.COND./HR = \frac{CFM \times 60 \times D \times C_a \times \Delta T}{H_{FG}}$$

B. Approximating Condensate Loads

$$LBS.STM.COND./HR = \frac{GPM(WATER) \times \Delta T}{2}$$

$$LBS.STM.COND./HR = \frac{GPM(FUEL OIL) \times \Delta T}{4}$$

$$LBS.STM.COND./HR = \frac{CFM(AIR) \times \Delta T}{900}$$

stm.	= steam
GPM	= quantity of liquid (gallons per minute)
CFM	= quantity of gas or air (cubic feet per minute)
SP.GR.	= specific gravity
D	= density (lbs./cubic feet)
C _a	= specific heat of air (0.24 Btu/lbs.)
C _w	= specific heat of water (1.00 Btu/lbs.)
H _{FG}	= latent heat of steam (Btu/lbs.) at steam design pressure (ASHRAE Fundamentals)
ΔT	= final temperature minus initial temperature
EDR	= equivalent direct radiation

3.09. Building Envelope Heating Equation and R-Values/U-Values

$$H = U \times A \times \Delta T$$

$$R = \frac{1}{C} = \frac{1}{K} \times \text{Thickness (in.)}$$

$$R = \frac{1}{\Sigma R}$$

H	= heat flow (Btu/h)
ΔT	= temperature difference (°F)
A	= area (sq.ft.)
U	= U-Value (Btu./h sq.ft. °F): See Part 35 for definitions.
R	= R-Value (h sq.ft. °F/Btu.): See Part 35 for definitions.
C	= conductance (Btu./h sq.ft. °F): See Part 35 for definitions.
K	= conductivity (Btu. in./h sq.ft. °F): See Part 35 for definitions.
ΣR	= sum of the individual R-Values

3.10. Fan Laws

$$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{SP_2}{SP_1} = \left[\frac{CFM_2}{CFM_1} \right]^2 = \left[\frac{RPM_2}{RPM_1} \right]^2$$

$$\frac{BHP_2}{BHP_1} = \left[\frac{CFM_2}{CFM_1} \right]^3 = \left[\frac{RPM_2}{RPM_1} \right]^3 = \left[\frac{SP_2}{SP_1} \right]^{1.5}$$

$$BHP = \frac{CFM \times SP \times SP.GR.}{6356 \times FAN_{EFF.}}$$

$$MHP = \frac{BHP}{M/D_{EFF.}}$$

CFM	= cubic feet/minute
RPM	= revolutions/minute
SP	= static pressure, in. W.G.
BHP	= brake horsepower
Fan Size	= constant
Air Density	= constant
SP.GR.(Air)	= 1.0
FAN _{EFF}	= 65-85%
M/D _{EFF}	= 80-95%
M/D	= motor/drive

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3.11. Pump Laws

$$\frac{GPM_2}{GPM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{HD_2}{HD_1} = \left[\frac{GPM_2}{GPM_1} \right]^2 = \left[\frac{RPM_2}{RPM_1} \right]^2$$

$$\frac{BHP_2}{BHP_1} = \left[\frac{GPM_2}{GPM_1} \right]^3 = \left[\frac{RPM_2}{RPM_1} \right]^3 = \left[\frac{HD_2}{HD_1} \right]^{1.5}$$

$$BHP = \frac{GPM \times HD \times SP.GR.}{3960 \times PUMP_{EFF.}}$$

$$MHP = \frac{BHP}{M/D_{EFF.}}$$

$$VH = \frac{V^2}{2g}$$

$$HD = \frac{P \times 2.31}{SP.GR.}$$

GPM	= gallons/minute
RPM	= revolutions/minute
HD	= head in ft. H ₂ O
BHP	= brake horsepower
Pump Size	= constant
Water Density	= constant
SP.GR.	= specific gravity of liquid with respect to water
SP.GR.(Water)	= 1.0
PUMP _{EFF}	= 60–80%
M/D _{EFF}	= 85–95%
M/D	= motor/drive
P	= pressure (psi)
VH	= velocity head in ft. H ₂ O
V	= velocity (ft./sec.)
g	= acceleration due to gravity (32.16 ft./sec. ²)

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3.12. Pump Net Positive Suction Head (NPSH) Calculations

$$NPSH_{AVAIL} > NPSH_{REQ'D}$$

$NPSH_{AVAIL}$	$= H_A \pm H_S - H_F - H_{VP}$
$NPSH_{AVAIL}$	= net positive suction available at pump (feet)
$NPSH_{REQ'D}$	= net positive suction required at pump (feet)
H_A	= pressure at liquid surface (feet - 34 feet for water at atmospheric pressure)
H_S	= height of liquid surface above (+) or below (-) pump (feet)
H_F	= friction loss between pump and source (feet)
H_{VP}	= absolute pressure of water vapor at liquid temperature (feet - ASHRAE Fundamentals)
Note: Calculations may also be performed in psig, provided that all values are in psig.	

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3.13. Mixed Air Temperature

$$T_{MA} = \left(T_{ROOM} \times \frac{CFM_{RA}}{CFM_{SA}} \right) + \left(T_{OA} \times \frac{CFM_{OA}}{CFM_{SA}} \right)$$

$$T_{MA} = \left(T_{RA} \times \frac{CFM_{RA}}{CFM_{SA}} \right) + \left(T_{OA} \times \frac{CFM_{OA}}{CFM_{SA}} \right)$$

CFM _{SA}	= supply air CFM
CFM _{RA}	= return air CFM
CFM _{OA}	= outside air CFM
T _{MA}	= mixed air temperature (°F)
T _{ROOM}	= room design temperature (°F)
T _{RA}	= return air temperature (°F)
T _{OA}	= outside air temperature (°F)

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3.14. Psychrometric Equations

$$W = 0.622 \times \frac{P_W}{P - P_W}$$

$$RH \equiv \frac{W_{ACTUAL}}{W_{SAT}} \times 100\%$$

$$RH = \frac{P_W}{P_{SAT}} \times 100\%$$

$$H_S = m \times c_p \times \Delta T$$

$$H_L = L_v \times m \times \Delta W$$

$$H_T = m \times \Delta h$$

$$W = \frac{(2501 - 2.381 T_{WB})(W_{SAT WB}) - (T_{DB} - T_{WB})}{(2501 + 1.805 T_{DB} - 4.186 T_{WB})}$$

$$W = \frac{(1093 - 0.556 T_{WB})(W_{SAT WB}) - (0.240)(T_{DB} - T_{WB})}{(1093 + 0.444 T_{DB} - T_{WB})}$$

W	= specific humidity, lbs.H ₂ O/lbs.DA or Gr.H ₂ O/lbs.DA
W _{ACTUAL}	= actual specific humidity, lbs.H ₂ O/lbs.DA or Gr.H ₂ O/lbs.DA
W _{SAT}	= saturation specific humidity at the dry bulb temperature
W _{SAT WB}	= saturation specific humidity at the wet bulb temperature

P_W	= partial pressure of water vapor, lbs./sq.ft.
P	= total absolute pressure of air/water vapor mixture, lbs./sq.ft.
P_{SAT}	= saturation partial pressure of water vapor at the dry bulb temperature, lbs./sq.ft.
RH	= relative humidity, %
H_S	= sensible heat, Btu/h
H_L	= latent heat, Btu/h
H_T	= total heat, Btu/h
m	= mass flow rate, lbs.DA/h or lbs.H ₂ O/h
C_P	= specific heat, Air—0.24 Btu/lbs.DA, Water—1.0 Btu/lbs.H ₂ O
T_{DB}	= dry bulb temperature, °F
T_{WB}	= wet bulb temperature, °F
ΔT	= temperature difference, °F
ΔW	= specific humidity difference, lbs.H ₂ O/lbs.DA or Gr.H ₂ O/lbs.DA
Δh	= enthalpy difference, Btu/lbs.DA
L_V	= latent heat of vaporization, Btu/lbs.H ₂ O

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3.15. Ductwork Equations

$$TP = SP + VP$$

$$VP = \left[\frac{V}{4005} \right]^2 = \frac{(V)^2}{(4005)^2}$$

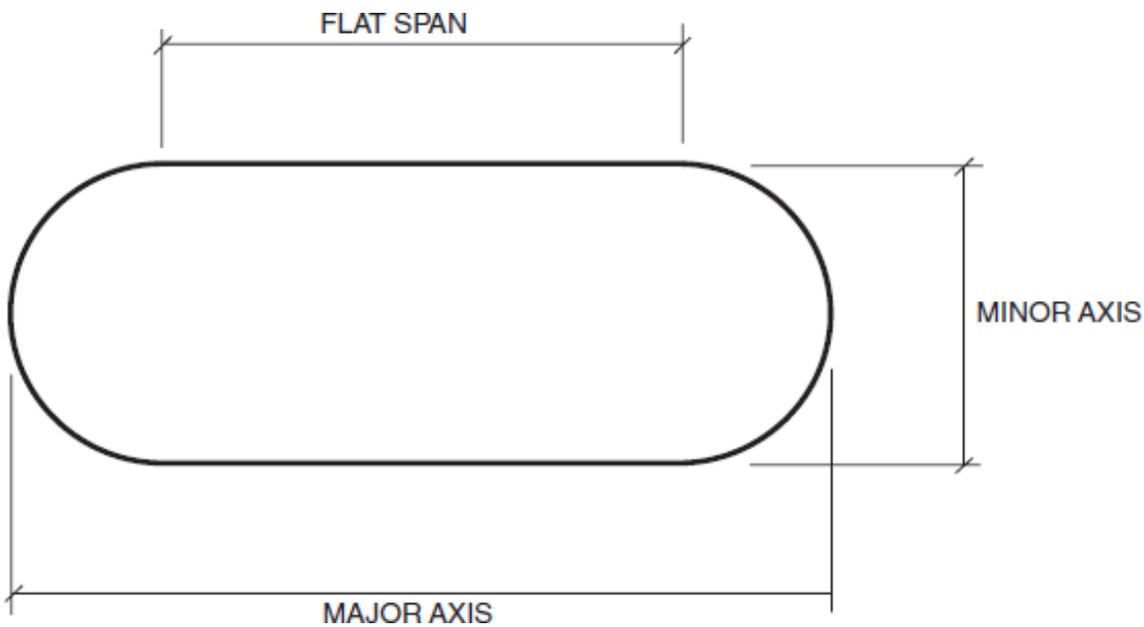
$$V = \frac{Q}{A} = \frac{Q \times 144}{W \times H}$$

$$D_{EQ} = \frac{1.3 \times (A \times B)^{0.625}}{(A + B)^{0.25}}$$

TP	= total pressure
SP	= static pressure, friction losses
VP	= velocity pressure, dynamic losses
V	= velocity, ft./min.
Q	= air flow rate through duct, CFM
A	= area of duct, sq.ft.
W	= width of duct, in.
H	= height of duct, in.
D _{EQ}	= equivalent round duct size for rectangular duct, in.
A	= one dimension of rectangular duct, in.
B	= adjacent side of rectangular duct, in.

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3.16. Equations for Flat Oval Ductwork



$$FS = MAJOR - MINOR$$

$$A = \frac{(FS \times MINOR) + \frac{(\pi \times MINOR^2)}{4}}{144}$$

$$P = \frac{(\pi \times MINOR) + (2 \times FS)}{12}$$

$$D_{EQ} = \frac{1.55 \times (A)^{0.625}}{(P)^{0.25}}$$

FS	= flat span dimension in inches
MAJOR	= major axis dimension in inches (larger dimension)
MINOR	= minor axis dimension in inches (smaller dimension)
A	= cross-sectional area in square feet
P	= perimeter or surface area in square feet per lineal feet
D _{EQ}	= equivalent round duct diameter

3.17. Steel Pipe Equations

A	$= 0.785 \times ID^2$
W_P	$= 10.6802 \times T \times (OD - T)$
W_W	$= 0.3405 \times ID^2$
OSA	$= 0.2618 \times OD$
ISA	$= 0.2618 \times ID$
A_M	$= 0.785 \times (OD^2 - ID^2)$
A	$=$ cross sectional area (sq.in.)
W_P	$=$ weight of pipe per foot (lbs.)
W_W	$=$ weight of water per foot (lbs.)
T	$=$ pipe wall thickness (in.)
ID	$=$ inside diameter (in.)
OD	$=$ outside diameter (in.)
OSA	$=$ outside surface area per foot (sq.ft.)
ISA	$=$ inside surface area per foot (sq.ft.)
A_M	$=$ area of the metal (sq.in.)

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3.18. Steam and Steam Condensate Pipe Sizing Equations

A. Steam Pipe Sizing Equations

$$\Delta P = \frac{(0.01306) \times W^2 \times \left(1 + \frac{3.6}{ID}\right)}{3600 \times D \times ID^5}$$

$$W = 60 \times \sqrt{\frac{\Delta P \times D \times ID^5}{0.01306 \times \left(1 + \frac{3.6}{ID}\right)}}$$

$$W = 0.41667 \times V \times A_{INCHES} \times D = 60 \times V \times A_{FEET} \times D$$

$$V = \frac{2.4 \times W}{A_{INCHES} \times D} = \frac{W}{60 \times A_{FEET} \times D}$$

ΔP	= pressure drop per 100 ft. of pipe, psig/100 ft.
W	= steam flow rate, lbs./h
ID	= actual inside diameter of pipe, in.
D	= average density of steam at system pressure, lbs./cu.ft.
V	= velocity of steam in pipe, ft./min.
A_{INCHES}	= actual cross-sectional area of pipe, sq.in.
A_{FEET}	= actual cross-sectional area of pipe, sq.ft.

B. Steam Condensate Pipe Sizing Equations

$$FS = \frac{H_{SS} - H_{SCR}}{H_{LCR}} \times 100$$

$$W_{CR} = \frac{FS}{100} \times W$$

FS	= flash steam, percentage %
H_{SS}	= sensible heat at steam supply pressure, Btu/lbs.
H_{SCR}	= sensible heat at condensate return pressure, Btu/lbs.
H_{LCR}	= latent heat at condensate return pressure, Btu/lbs.
W	= steam flow rate, lbs./h
W_{CR}	= condensate flow based on percentage of flash steam created during condensing process, lbs./h. Use this flow rate in the preceding steam equations to determine the condensate return pipe size.

3.19. Air Conditioning Condensate

$$GPM_{AC\ COND} = \frac{CFM \times \Delta W_{LB.}}{SpV \times 8.33}$$

$$GPM_{AC\ COND} = \frac{CFM \times \Delta W_{GR.}}{SpV \times 8.33 \times 7000}$$

$GPM_{AC\ COND}$	= air conditioning condensate flow (gal./min.)
CFM	= air flow rate (cu.ft./min.)
SpV	= specific volume of air (cu.ft./lbs.DA) = 13.33 ft ³ /lbs. DA at 60°F
$\Delta W_{LB.}$	= specific humidity (lbs.H ₂ O/lbs.DA)
$\Delta W_{GR.}$	= specific humidity (Gr.H ₂ O/lbs.DA)

3.20. Humidification

$$GRAINS_{REQ'D} = \left(\frac{W_{GR.}}{SpV} \right)_{ROOM\ AIR} - \left(\frac{W_{GR.}}{SpV} \right)_{SUPPLY\ AIR}$$

$$POUNDS_{REQ'D} = \left(\frac{W_{LB.}}{SpV} \right)_{ROOM\ AIR} - \left(\frac{W_{LB.}}{SpV} \right)_{SUPPLY\ AIR}$$

$$LBS.STM. / HR = \frac{CFM \times GRAINS_{REQ'D} \times 60}{7000} = CFM \times POUNDS_{REQ'D} \times 60$$

$GRAINS_{REQ'D}$	= grains of moisture required (Gr.H ₂ O/cu.ft.)
$POUNDS_{REQ'D}$	= pounds of moisture required (lbs.H ₂ O/cu.ft.)
CFM	= air flow rate (cu.ft./min.)
SpV	= specific volume of air (cu.ft./lbs.DA)
$W_{GR.}$	= specific humidity (Gr.H ₂ O/lbs.DA)
$W_{LB.}$	= specific humidity (lbs.H ₂ O/lbs.DA)

3.21. Humidifier Sensible Heat Gain

$$H_s = (0.244 \times Q \times \Delta T) + (L \times 380)$$

H_s	= sensible heat gain (Btu/h)
Q	= steam flow (lbs. steam/h)
ΔT	= steam temperature - supply air temperature (°F)
L	= length of humidifier manifold (ft.)

3.22. Expansion Tanks

$$\text{CLOSED } V_T = V_s \times \frac{\left[\left(\frac{v_2}{v_1} \right) - 1 \right] - 3\alpha\Delta T}{\left[\frac{P_A}{P_1} - \frac{P_A}{P_2} \right]}$$

$$\text{OPEN } V_T = 2 \times \left\{ \left[V_s \times \left[\left(\frac{v_2}{v_1} \right) - 1 \right] \right] - 3\alpha\Delta T \right\}$$

$$\text{DIAPHRAGM } V_T = V_s \times \frac{\left[\left(\frac{v_2}{v_1} \right) - 1 \right] - 3\alpha\Delta T}{1 - \left(\frac{P_1}{P_2} \right)}$$

V_T	= volume of expansion tank (gallons)	
V_s	= volume of water in piping system (gallons)	
ΔT	= $T_2 - T_1$ (°F)	
T_1	= lower system temperature (°F)	
	Heating Water	$T_1 = 45\text{-}50^\circ\text{F}$ temperature at fill condition
	Chilled Water	$T_1 =$ supply water temperature
	Dual Temperature	$T_1 =$ chilled water supply temperature

		supply temperature
T_2	= higher system temperature (°F)	
	Heating Water	T_2 = supply water temperature
	Chilled Water	T_2 = 95°F ambient temperature (design weather data)
	Dual Temperature	T_2 = heating water supply temperature
P_A	= atmospheric pressure (14.7 psia)	
P_1	= system fill pressure/minimum system pressure (psia)	
P_2	= system operating pressure/maximum operating pressure (psia)	
v_1	= SpV of H ₂ O at T_1 (cu.ft./lbs.H ₂ O) ASHRAE Fundamentals	
v_2	= SpV of H ₂ O at T_2 (cu.ft./lbs.H ₂ O) ASHRAE Fundamentals	
α	= linear coefficient of expansion	
	$\alpha_{STEEL} = 6.5 \times 10^{-6}$	
	$\alpha_{COPPER} = 9.5 \times 10^{-6}$	
System Volume Estimate:		
	12 gal./ton	
	35 gal./BHP	
System Fill Pressure/Minimum System Pressure Estimate:		
	Height of System + 5 to 10 psi OR 5-10 psi, whichever is greater.	
System Operating Pressure/Maximum Operating Pressure Estimate:		
	150 lbs. Systems	45-125 psi
	250 lbs. Systems	125-225 psi

3.23. Air Balance Equations

SA	= Supply Air
RA	= Return Air
OA	= Outside Air
EA	= Exhaust Air
RFA	= Relief Air
SA	= RA + OA = RA + EA + RFA
If minimum OA (ventilation air) is greater than EA, then	
OA = EA + RFA	
If EA is greater than minimum OA (ventilation air), then	
OA = EA	RFA = 0
For Economizer Cycle:	
OA = SA = EA + RFA	RA = 0

3.24. Efficiencies

$$COP = \frac{BTU\ OUTPUT}{BTU\ INPUT} = \frac{EER}{3.413}$$

$$EER = \frac{BTU\ OUTPUT}{WATTS\ INPUT} = COP \times 3.413$$

$$KW/TON = \frac{12,000\ BTU/HR\ TON}{COP \times 3,517\ BTU/HR\ KW}$$

Turndown Ratio = Maximum Firing Rate: Minimum Firing Rate (e.g., 5:1, 10:1, 25:1)

$$OVERALL\ THERMAL\ EFF. = \frac{GROSS\ BTU\ OUTPUT}{GROSS\ BTU\ INPUT} \times 100\%$$

$$COMBUSTION\ EFF. = \frac{BTU\ INPUT - BTU\ STACK\ LOSS}{BTU\ INPUT} \times 100\%$$

Overall Thermal Efficiency Range 75–90%

Combustion Efficiency Range 85–95%

3.25. Cooling Towers and Heat Exchangers

$$APPROACH_{CT'S} = LWT - AWB$$

$$APPROACH_{HE'S} = EWT_{HS} - LWT_{CS}$$

$$RANGE = EWT - LWT$$

EWT	= entering water temperature (°F)
LWT	= leaving water temperature (°F)
AWB	= ambient wet bulb temperature (Design WB - °F)
HS	= hot side
CS	= cold side

3.26. Cooling Tower/Evaporative Cooler Blowdown Equations

$$C = \frac{(E + D + B)}{(D + B)}$$

$$B = \frac{E - [(C - 1) \times D]}{(C - 1)}$$

<i>E</i>	= $GPM_{COND.} \times R \times 0.0008$
<i>D</i>	= $GPM_{COND.} \times 0.0002$
<i>R</i>	= $EWT - LWT$
B	= blowdown, GPM
C	= cycles of concentration
D	= drift, GPM
E	= evaporation, GPM
EWT	= entering water temperature, °F
LWT	= leaving water temperature, °F
R	= range, °F

3.27. Electricity

A. General

KVA	$= KW + KVAR$
PF	$= KW/KVA$

B. Single-Phase Power

$$KW_{1\phi} = \frac{V \times A \times PF}{1000}$$

$$KVA_{1\phi} = \frac{V \times A}{1000}$$

$$BHP_{1\phi} = \frac{V \times A \times PF \times DEVICE_{EFF.}}{746}$$

$$MHP_{1\phi} = \frac{BHP_{1\phi}}{M / D_{EFF.}}$$

C. Three-Phase Power

$$KW_{3\phi} = \frac{\sqrt{3} \times V \times A \times PF}{1000}$$

$$KVA_{3\phi} = \frac{\sqrt{3} \times V \times A}{1000}$$

$$BHP_{3\phi} = \frac{\sqrt{3} \times V \times A \times PF \times DEVICE_{EFF.}}{746}$$

$$MHP_{3\phi} = \frac{BHP_{3\phi}}{M / D_{EFF.}}$$

KVA	= total power (kilovolt amps)
KW	= real power, electrical energy (kilowatts)
KVAR	= reactive power or "imaginary" power (kilovolt amps reactive)
V	= voltage (volts)
A	= current (amps)
PF	= power factor (0.75–0.95)
BHP	= brake horsepower
MHP	= motor horsepower
EFF	= efficiency
M/D	= motor drive

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3.28. Moisture Condensation on Glass

$$T_{GLASS} = T_{ROOM} - \left[\frac{R_{IA}}{R_{GLASS}} \times (T_{ROOM} - T_{OA}) \right]$$

$$T_{GLASS} = T_{ROOM} - \left[\frac{U_{GLASS}}{U_{IA}} \times (T_{ROOM} - T_{OA}) \right]$$

If $T_{GLASS} < DP_{ROOM}$ condensation occurs

T	= temperature (°F)
R	= R-Value (h sq.ft. °F/Btu)
U	= U-Value (Btu./h sq.ft. °F)
IA	= inside airfilm
	= design outside air temperature
DP	= dewpoint

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3.29. Calculating Heating Loads for Loading Docks, Heavily Used Vestibules and Similar Spaces

- A. **Find volume of space to be heated (cu.ft.).**
- B. **Determine acceptable warm-up time for space (min.).**
- C. **Divide volume by time (CFM).**
- D. **Determine inside and outside design temperatures—assume inside space temperature has dropped to the outside design temperature because doors have been open for an extended period of time.**
- E. **Use sensible heat equation to determine heating requirement using CFM and inside and outside design temperatures determined earlier in this Part.**

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3.30. Ventilation of Mechanical Rooms with Refrigeration Equipment

- A. **For a more detailed description of ventilation requirements for mechanical rooms with refrigeration equipment, see ASHRAE Standard 15 and Part 8.**
- B. **Completely Enclosed Equipment Rooms**

<i>CFM</i>	= $100 \times G^{0.5}$
CFM	= exhaust air flow rate required (cu.ft./minute)
<i>G</i>	= mass of refrigerant of largest system (pounds)

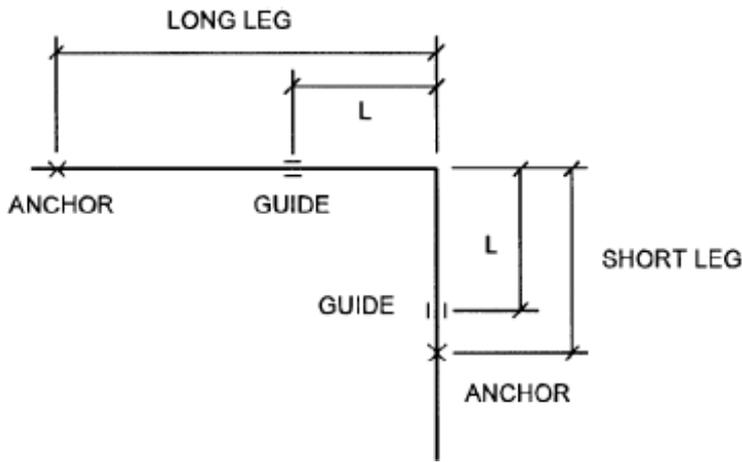
- C. **Partially Enclosed Equipment Rooms**

<i>FA</i>	= $G^{0.5}$
FA	= ventilation free opening Area (sq.ft.)
<i>G</i>	= mass of refrigerant of largest system (pounds)

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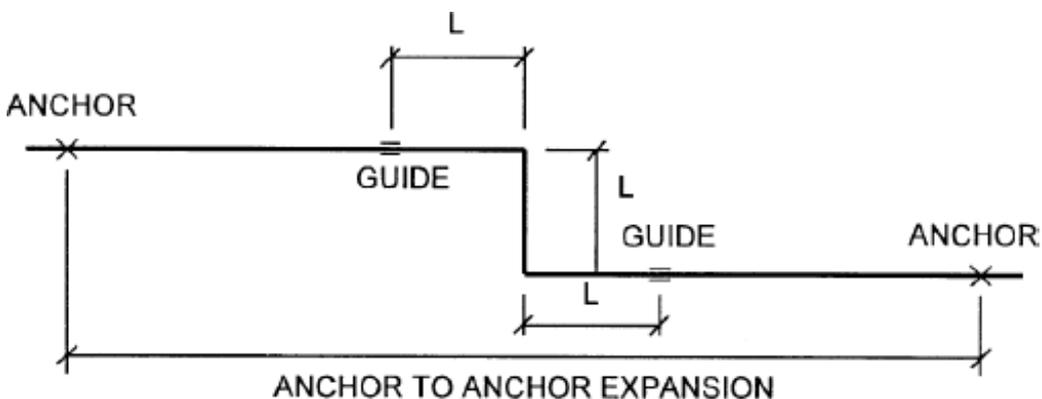
3.31. Pipe Expansion Equations

A. L-Bends



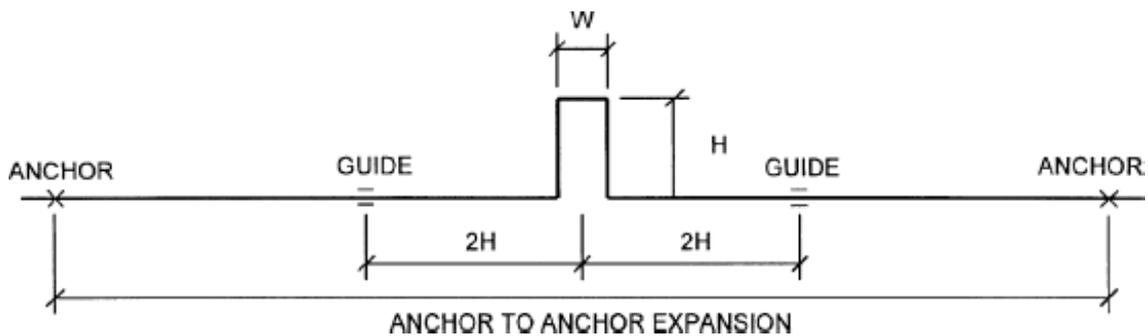
L	$= 6.225 \times \sqrt{\Delta D}$
F	$= 500 \text{ LB./PIPE DIA.} \times \text{PIPE DIA.}$
L	$= \text{length of leg required to accommodate thermal expansion or contraction, feet}$
Δ	$= \text{thermal expansion or contraction of long leg, inches}$
D	$= \text{pipe outside diameter, inches}$
F	$= \text{force exerted by pipe expansion or contraction on anchors and supports, lbs. See Tables in Part 18 for solved equations.}$

B. Z-Bends



L	$= 4 \times \sqrt{\Delta D}$
F	$= 200 - 500 \text{ LB./PIPE DIA.} \times \text{PIPE DIA.}$
L	= length of offset leg required to accommodate thermal expansion or contraction, feet
Δ	= anchor to anchor expansion or contraction, inches
D	= pipe outside diameter, inches
F	= force exerted by pipe expansion or contraction on anchors and supports, lbs. See Tables in Part 18 for solved equations.

C. U-Bends or Expansion Loops



L	$= 6.225 \times \sqrt{\Delta D}$
F	$= 200 \text{ LB./PIPE DIA.} \times \text{PIPE DIA.}$
L	$= 2H + W$
H	$= 2W$
L	$= 5W$
L	$=$ length of loop required to accommodate thermal expansion or contraction, ft.
D	$=$ anchor to anchor expansion or contraction, in.
D	$=$ pipe outside diameter, in.
F	$=$ force exerted by pipe expansion or contraction on anchors and supports, lbs.

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3.32. Relief Valve Vent Line Maximum Length

$$L = \frac{9 \times P_1^2 \times D^5}{C^2} = \frac{9 \times P_2^2 \times D^5}{16 \times C^2}$$

P_1	$= 0.25 \times [(\text{PRESSURE SETTING} \times 1.1) + 14.7]$
P_2	$= [(\text{PRESSURE SETTING} \times 1.1) + 14.7]$
L	$=$ maximum length of relief vent line in feet
D	$=$ inside diameter of pipe in inches
C	$=$ minimum discharge of air in lbs./min.

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3.33. Relief Valve Sizing

A. Liquid System Relief Valves—Spring-Style Relief Valves

$$A = \frac{GPM \times \sqrt{G}}{28.14 \times K_B \times K_V \times \sqrt{\Delta P}}$$

B. Liquid System Relief Valves—Pilot-Operated Relief Valves

$$A = \frac{GPM \times \sqrt{G}}{36.81 \times K_V \times \sqrt{\Delta P}}$$

C. Steam System Relief Valves

$$A = \frac{W}{51.5 \times K \times P \times K_{SH} \times K_N \times K_B}$$

D. Gas and Vapor System Relief Valves—lbs./h

$$A = \frac{W \times \sqrt{TZ}}{C \times K \times P \times K_B \times \sqrt{M}}$$

E. Gas and Vapor System Relief Valves—SCFM

$$A = \frac{SCFM \times \sqrt{TGZ}}{1.175 \times C \times K \times P \times K_B}$$

F. Relief Valve Equation Definitions

1. A	= Minimum required effective relief valve discharge area (sq.in.)
2. GPM	= Required relieving capacity at flow conditions (gal./min.)
3. W	= Required relieving capacity at flow conditions (lbs./h)
4. SCFM	= Required relieving capacity at flow conditions (standard cu.ft./min.)
5. G	= Specific gravity of liquid, gas, or vapor at flow conditions Water = 1.0 for most HVAC applications Air = 1.0
6. C	= Coefficient determined from expression of ratio of specific heats C = 315 if value is unknown
7. K	= Effective coefficient of discharge

7. K	= Effective coefficient of discharge K = 0.975
8. K _B	= Capacity correction factor due to back pressure K _B = 1.0 for atmospheric discharge systems
9. K _V	= Flow correction factor due to viscosity K _V = 0.9 to 1.0 for most HVAC applications with water
10. K _N	= Capacity correction factor for dry saturated steam at set pressures above 1500 psia and up to 3200 psia K _N = 1.0 for most HVAC applications
11. K _{SH}	= Capacity correction factor due to the degree of superheat K _{SH} = 1.0 for saturated steam
12. Z	= Compressibility factor Z = 1.0 if value is unknown
13. P	= Relieving pressure (psia) P = Set pressure (psig) + over pressure (10% psig) + atmospheric pressure (14.7 psia)
14. ΔP	= Differential pressure (psig) ΔP = Set pressure (psig) + over pressure (10% psig) - back pressure (psig)
15. T	= Absolute temperature (°R = °F + 460)
16. M	= Molecular weight of the gas or vapor

G. Relief Valve Sizing Notes

1. When multiple relief valves are used, one valve shall be set at or below the maximum allowable working pressure, and the remaining valves may be set up

to 5 percent over the maximum allowable working pressure.

2. When sizing multiple relief valves, the total area required is calculated on an over pressure of 16 percent or 4 psi, whichever is greater.
3. For superheated steam, the following correction factor values may be used:

a. Superheat up to 400°F:	0.97	(range 0.979–0.998)
b. Superheat up to 450°F:	0.95	(range 0.957–0.977)
c. Superheat up to 500°F:	0.93	(range 0.930–0.968)
d. Superheat up to 550°F:	0.90	(range 0.905–0.974)
e. Superheat up to 600°F:	0.88	(range 0.882–0.993)
f. Superheat up to 650°F:	0.86	(range 0.861–0.988)
g. Superheat up to 700°F:	0.84	(range 0.841–0.963)
h. Superheat up to 750°F:	0.82	(range 0.823–0.903)
i. Superheat up to 800°F:	0.80	(range 0.805–0.863)
j. Superheat up to 850°F:	0.78	(range 0.786–0.836)
k. Superheat up to 900°F:	0.75	(range 0.753–0.813)
l. Superheat up to 950°F:	0.72	(range 0.726–0.792)
m. Superheat up to 1000°F:	0.70	(range 0.704–0.774)

4. Gas and vapor properties:

Gas and vapor properties

Gas or Vapor	Molecular Weight	Ratio of Specific Heats	Coefficient C	Specific Gravity
Acetylene	26.04	1.25	342	0.899
Air	28.97	1.40	356	1.000
Ammonia (R-717)	17.03	1.30	347	0.588
Argon	39.94	1.66	377	1.379
Benzene	78.11	1.12	329	2.696
N-Butane	58.12	1.18	335	2.006
Iso-Butane	58.12	1.19	336	2.006
Carbon Dioxide	44.01	1.29	346	1.519
Carbon Disulphide	76.13	1.21	338	2.628
Carbon Monoxide	28.01	1.40	356	0.967
Chlorine	70.90	1.35	352	2.447
Cyclohexane	84.16	1.08	325	2.905
Ethane	30.07	1.19	336	1.038
Ethyl Alcohol	46.07	1.13	330	1.590
Ethyl Chloride	64.52	1.19	336	2.227
Ethylene	28.03	1.24	341	0.968
Helium	4.02	1.66	377	0.139
N-Heptane	100.20	1.05	321	3.459
Hexane	86.17	1.06	322	2.974
Hydrochloric Acid	36.47	1.41	357	1.259

Gas or Vapor	Molecular Weight	Ratio of Specific Heats	Coefficient C	Specific Gravity
Hydrogen	2.02	1.41	357	0.070
Hydrogen Chloride	36.47	1.41	357	1.259
Hydrogen Sulphide	34.08	1.32	349	1.176
Methane	16.04	1.31	348	0.554
Methyl Alcohol	32.04	1.20	337	1.106
Methyl Butane	72.15	1.08	325	2.491
Methyl Chloride	50.49	1.20	337	1.743
Natural Gas	19.00	1.27	344	0.656
Nitric Oxide	30.00	1.40	356	1.036
Nitrogen	28.02	1.40	356	0.967
Nitrous Oxide	44.02	1.31	348	1.520
N-Octane	114.22	1.05	321	3.943
Oxygen	32.00	1.40	356	1.105
N-Pentane	72.15	1.08	325	2.491
Iso-Pentane	72.15	1.08	325	2.491
Propane	44.09	1.13	330	1.522
R-11	137.37	1.14	331	4.742
R-12	120.92	1.14	331	4.174
R-22	86.48	1.18	335	2.985
R-114	170.93	1.09	326	5.900
R-123	152.93	1.10	327	5.279
R-134a	102.03	1.20	337	3.522
Sulfur Dioxide	64.04	1.27	344	2.211

Toluene	92.13	1.09	326	3.180
Gas or	Molecular	Ratio of	Coefficient	Specific

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3.34. Motor Drive Formulas

$$D_{FP} \times RPM_{FP} = D_{MP} \times RPM_{MP}$$

$$BL = [(D_{FP} + D_{MP}) \times 1.5708] + (2 \times L)$$

D_{FP}	= fan pulley diameter
D_{MP}	= motor pulley diameter
RPM_{FP}	= fan pulley RPM
RPM_{MP}	= motor pulley RPM
BL	= belt length
L	= center to center distance of fan and motor pulleys

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3.35. Domestic Water Heater Sizing

$$H_{OUTPUT} = GPH \times 8.34 \text{ LBS./GAL.} \times \Delta T \times 1.0$$

$$H_{INPUT} = \frac{GPH \times 8.34 \text{ LBS./GAL.} \times \Delta T}{\%EFFICIENCY}$$

$$GPH = \frac{H_{INPUT} \times \%EFFICIENCY}{\Delta T \times 8.34 \text{ LBS./GAL.}} = \frac{KW \times 3413 \text{ BTU / KW}}{\Delta T \times 8.34 \text{ LBS./GAL.}}$$

$$\Delta T = \frac{H_{INPUT} \times \%EFFICIENCY}{GPH \times 8.34 \text{ LBS./GAL.}} = \frac{KW \times 3413 \text{ BTU / KW}}{GPH \times 8.34 \text{ LBS./GAL.}}$$

$$KW = \frac{GPH \times 8.34 \text{ LBS./GAL.} \times \Delta T \times 1.0}{3413 \text{ BTU / KW}}$$

$$\%COLD \text{ WATER} = \frac{T_{HOT} - T_{MIX}}{T_{HOT} - T_{COLD}}$$

$$\%HOT \text{ WATER} = \frac{T_{MIX} - T_{COLD}}{T_{HOT} - T_{COLD}}$$

H_{OUTPUT}	= heating capacity - output
H_{INPUT}	= heating capacity - input
GPH	= recovery rate - gallons per hour
ΔT	= temperature rise - °F
KW	= kilowatts
T_{COLD}	= temperature - cold water - °F
T_{HOT}	= temperature - hot water - °F
T_{MIX}	= temperature - mixed water - °F

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3.36. Domestic Hot Water Recirculation Pump/Supply Sizing

- A. **Determine the approximate total length of all hot water supply and return piping.**
- B. **Multiply this total length by 30 Btu/ft. for insulated pipe and 60 Btu/ft. for uninsulated pipe to obtain the approximate heat loss.**
- C. **Divide the total heat loss by 10,000 to obtain the total pump capacity in GPM.**
- D. **Select a circulating pump to provide the total required GPM and obtain the head created at this flow.**
- E. **Multiply the head by 100 and divide by the total length of the longest run of the hot water return piping to determine the allowable friction loss per 100 feet of pipe.**
- F. **Determine the required GPM in each circulating loop and size the hot water return pipe based on this GPM and the allowable friction loss as determined earlier.**

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3.37. Swimming Pools

A. Sizing Outdoor Pool Heater

1. Determine pool capacity in gallons - obtain from architect if available.

Length × Width × Depth × 7.5 gal./cu.ft. (If depth is not known, assume an average depth of 5.5 feet.)

2. Determine heat pick-up time in hours from owner.
3. Determine pool water temperature in °F from the owner. If owner does not specify temperature, assume 80°F.
4. Determine the average air temperature on the coldest month in which the pool will be used.
5. Determine the average wind velocity in miles per hour. For pools less than 900 square feet and where the pool is sheltered by nearby buildings, fences, shrubs, etc., from the prevailing wind, an average wind velocity of less than 3.5 mph may be assumed. The surface heat loss factor of 5.5 Btuh/sq.ft. °F in the following equation assumes a wind velocity of 3.5 mph. If a wind velocity of less than 3.5 mph is used, multiply the equation by 0.75; for 5.0 mph, multiply the equation by 1.25; and for 10 mph, multiply the equation by 2.0.

6. Pool heater equations:

$$H_{\text{POOLHEATER}} = H_{\text{HEAT-UP}} + H_{\text{SURFACE LOSS}}$$

$$H_{\text{HEAT-UP}} = \frac{\text{GAL.} \times 8.34 \text{ LBS./GAL.} \times \Delta T_{\text{WATER}} \times 1.0 \text{ BTU/LBS.}^\circ\text{F}}{\text{HEAT PICK-UP TIME}}$$

$$H_{\text{SURFACELOSS}} = 5.5 \text{ BTU/HRSQ. FT.}^\circ\text{F} \times \Delta T_{\text{WATER/AIR}} \times \text{POOL AREA}$$

$$\Delta T_{\text{WATER}} = T_{\text{FINAL}} - T_{\text{INITIAL}}$$

$$T_{\text{FINAL}} = \text{POOL WATER TEMPERATURE}$$

$$T_{\text{INITIAL}} = 50^\circ\text{F}$$

$$\Delta T_{\text{WATER/AIR}} = T_{\text{FINAL}} - T_{\text{AVERAGEAIR}}$$

H	= heating capacity (Btu/h)
ΔT	= temperature difference (°F)

Citation

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Part 4: Conversion Factors

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4. Part 4: Conversion Factors

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4.01. Length

1 mile	= 1760 yds. = 5280 ft. = 63,360 in. = 1.609 km
1 ft.	= 0.3048 m = 30.48 cm = 304.8 mm
1 in.	= 2.54 cm = 25.4 mm
1 cm	= 0.3937 in.
1 m	= 39.37 in. = 3.2808 ft. = 1.094 yds.
1 km	= 3281 ft. = 0.6214 miles = 1094 yds.
1 fathom	= 6 feet = 1.828804 meters
1 furlong	= 660 feet

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4.02. Weight

1 gal.H ₂ O	= 8.33 lbs.H ₂ O
1 lb.	= 16 oz. = 7000 grains = 0.4536 kg
1 ton	= 2000 lbs. = 907 kg
1 kg	= 2.205 lbs.
1 lb.steam	= 1 lb.H ₂ O

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4.03. Area

1 sq.ft.	= 144 sq.in.
1 acre	= 43,560 sq.ft. = 4840 sq.yds. = 0.4047 hectares
1 sq.mile	= 640 acres
1 sq.yd.	= 9 sq.ft. = 1296 sq.in.
1 hectare	= 2.417 acres
1 sq.m	= 1,550 sq.in. = 10.7639 sq.ft. = 1.1968 sq.yds.

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4.04. Volume

1 cu.yd.	= 27 cu.ft. = 46,656 cu.in. = 1616 pints = 807.9 quarts = 764.6 liters
1 cu.ft.	= 1,728 cu.in.
1 liter	= 0.2642 gallons = 1.057 quarts = 2.113 pints
1 gallon	= 4 quarts = 8 pints = 3.785 liters
1 cu.m	= 61,023 cu.in. = 35.3134 cu.ft. = 1.3093 cu.yds.
1 barrel oil	= 42 gallons oil
1 barrel beer	= 31.5 gallons beer
1 barrel wine	= 31.0 gallons wine
1 bushel	= 1.2445 cu.ft. = 32 quarts (dry) = 64 pints (dry) = 4 pecks
1 hogshead	= 63 gallons = 8.42184 cu.ft.

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4.05. Velocity

1 mph	= 5280 ft./h = 88 ft./min. = 1.467 ft./sec. = 0.8684 knot
1 knot	= 1.1515 mph = 1.8532 km/hr. = 1.0 nautical mile/h
1 league	= 3.0 miles (approx.)

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4.06. Speed of Sound in Air

1128.5 ft./sec.	= 769.4 mph
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4.07. Pressure

14.7 psi	= 33.95 ft. H ₂ O = 29.92 in. Hg = 407.2 in. W.G. = 2116.8 lbs./sq.ft.
1 psi	= 2.307 ft. H ₂ O = 2.036 in. Hg = 16 oz = 27.7 in. WC
1 ft. H ₂ O	= 0.4335 psi = 62.43 lbs./sq.ft.
1 oz	= 1.73 in. WC

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4.08. Density

A. Water

62.43 lbs./cu.ft.	= 8.33 lbs./gal. = 0.1337 cu.ft./gal.
1 cu.ft.	= 7.48052 gallons = 29.92 quarts = 62.43 lbs.H ₂ O

B. Standard Air @ 60°F, 14.7 psi

13.329 cu.ft./lbs.	= 0.0750 lbs./cu.ft.
1 lb./cu.ft.	= 177.72 cu.ft./lb.
1 cu.ft./lb.	= 0.00563 lbs./cu.ft.
1 kg/cu.m	= 16.017 lbs./cu.ft.
1 cu.m/kg	= 0.0624 cu.ft./lb

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4.09. Energy

1 hp	= 0.746 kW = 746 watts = 2,545 Btuh. 1.0 kva
1 kW	= 1,000 watts = 3413 Btuh = 1.341 hp
1 watt	= 3.413 Btuh
1 ton AC	= 12,000 Btuh cooling = 15,000 Btuh heat rejection

1 Btuh	= 1 Btu/h
1 bhp	= 34,500 Btuh (33,472 Btuh) = 34.5 lbs.stm/h = 34.5 lbs.H ₂ O/h = 0.069 gpm = 4.14 gph = 140 edr (sq.ft. of equivalent direct radiation)
1 therm	= 100,000 Btuh
1 mbh	= 1,000 Btuh
1 lb.stm/h	= 0.002 gpm
1 gpm	= 500 lbs.stm./h
1 edr (equivalent direct radiation)	= 0.000496 gpm = 0.25 lbs.stm.cond./h
1,000 edr	= 0.496 gpm
1 edr hot water	= 150 Btu/h
1 edr steam	= 240 Btu/h
1 edr	= 240 Btu/h (up to 1,000 ft. above sea level)
1 edr	= 230 Btu/h (1,000 ft.-3,000 ft. above sea level)
1 edr	= 223 Btu/h (3,000 ft. -5,000 ft. above sea level)
1 edr	= 216 Btu/h (5,000 ft.-7,000 ft. above sea level)
1 edr	= 209 Btu/h (7,000 ft.-10,000 ft. above sea level)

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4.10. Flow

1 mgd (million gal./day)	= 1.547 cu.ft./sec. = 694.4 gpm
1 cu.ft./min.	= 62.43 lbs.H ₂ O/min. = 448.8 gph

4.11. HVAC Metric Conversions

kJ/h	= Btu/h × 1.055
cmm	= cfm × 0.02832
lpm	= gpm × 3.785
kJ/kg	= Btu/lb. × 2.326
meters	= ft. × 0.3048
sq. meters	= sq. ft. × 0.0929
cu. meters	= cu. ft. × 0.02832
kg	= lbs. × 0.4536
1.0 gpm	= 500 lbs.steam/h
1.0 lb.stm./h	= 0.002 gpm
1.0 lb.H ₂ O/h	= 1.0 lb.steam/h
kg/cu.m	= lbs./cu.ft. × 16.017 (density)
cu.m/kg	= cu.ft./lb. × 0.0624 (specific volume)
kg H ₂ O/kg DA	= Gr H ₂ O/lb. DA/7000 = lb. H ₂ O/lb. DA

4.12. Fuel Conversion Factors

A. Electric Baseboard to Hydronic Baseboard

1. KWH × 1.19 = KWH for electric boiler
2. KWH × 0.033 = gal. for oil-fired boiler
3. KWH × 0.046 = therms for gas-fired boiler

B. Electric Furnace to Hydronic Baseboard

1. KWH × 1.0 = KWH for electric boiler
2. KWH × 0.028 = gal. for oil-fired boiler
3. KWH × 0.038 = therms for gas-fired boiler

C. Ceiling Cable to Hydronic Baseboard

1. $\text{KWH} \times 1.06 = \text{KWH}$ for electric boiler
2. $\text{KWH} \times 0.03 = \text{gal.}$ for oil-fired boiler
3. $\text{KWH} \times 0.041 = \text{therms}$ for gas-fired boiler

D. Heat Pump to Hydronic Baseboard

1. $\text{KWH} \times 1.88 = \text{KWH}$ for electric boiler
2. $\text{KWH} \times 0.052 = \text{gal.}$ for oil-fired boiler
3. $\text{KWH} \times 0.073 = \text{therms}$ for gas-fired boiler

E. Electric Baseboard to Warm Air Furnace

1. $\text{KWH} \times 1.19 = \text{KWH}$ for electric furnace
2. $\text{KWH} \times 0.039 = \text{gal.}$ for oil-fired furnace
3. $\text{KWH} \times 0.054 = \text{therms}$ for gas-fired furnace

F. Electric Furnace to Fuel-Fired Furnace

1. $\text{KWH} \times 0.032 = \text{gal.}$ for oil-fired furnace
2. $\text{KWH} \times 0.045 = \text{therms}$ for gas-fired furnace

G. Ceiling Cable to Warm Air Furnace

1. $\text{KWH} \times 1.06 = \text{KWH}$ for electric furnace
2. $\text{KWH} \times 0.034 = \text{gal.}$ for oil-fired furnace
3. $\text{KWH} \times 0.048 = \text{therms}$ for gas-fired furnace

H. Heat Pump to Warm Air Furnace

1. $\text{KWH} \times 1.88 = \text{KWH}$ for electric furnace
2. $\text{KWH} \times 0.061 = \text{gal.}$ for oil-fired furnace
3. $\text{KWH} \times 0.085 = \text{therms}$ for gas-fired furnace

I. Warm Air Systems to Hydronic Baseboard System

1. $\text{gal. oil for W.A.} \times 0.857 = \text{gal. for hydronics}$
2. $\text{therms gas for W.A.} \times 0.857 = \text{therms for hydronics}$
3. $\text{gal. oil for W.A.} \times 1.2 = \text{therms for hydronics}$

4. therms gas for W.A. $\times 0.612 =$ gal. for hydronics

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Part 5: Cooling Load Rules of Thumb

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5. Part 5: Cooling Load Rules of Thumb

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5.01. Offices, Commercial

A. General

1. Total Heat	300–400 sq.ft./ton	(Range 230–520)
2. Total Heat	30–40 Btuh/sq.ft.	(Range 23–52)
3. Room Sens. Heat	25–28 Btuh/sq.ft.	(Range 19–37)
4. SHR	0.75–0.93	
5. Perimeter Spaces	1.0–3.0 cfm/sq.ft.	
6. Interior Spaces	0.5–1.5 cfm/sq.ft.	
7. Building Block cfm	1.0–1.5 cfm/sq.ft.	
8. Air Change Rate	4–10 AC/h	

B. Large, Perimeter

1. Total Heat	225–275 sq.ft./ton
2. Total Heat	43–53 Btuh/sq.ft.

C. Large, Interior

1. Total Heat	300-350 sq.ft./ton
2. Total Heat	34-40 Btuh/sq.ft.

D. Small

1. Total Heat	325-375 sq.ft./ton
2. Total Heat	32-37 Btuh/sq.ft.

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5.02. Banks, Court Houses, Municipal Buildings, Town Halls

A. Total Heat	200-250 sq.ft./ton	(Range 160-340)
B. Total Heat	48-60 Btuh/sq.ft.	(Range 35-75)
C. Room Sens. Heat	28-38 Btuh/sq.ft.	(Range 21-48)
D. SHR	0.75-0.90	
E. Air Change Rate	4-10 AC/h	

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5.03. Police Stations, Fire Stations, Post Offices

A. Total Heat	250-350 sq.ft./ton	(Range 200-400)
B. Total Heat	34-48 Btuh/sq.ft.	(Range 30-60)
C. Room Sens. Heat	25-35 Btuh/sq.ft.	(Range 20-40)
D. SHR	0.75-0.90	
E. Air Change Rate	4-10 AC/h	

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5.04. Precision Manufacturing

A. Total Heat	50-300 sq.ft./ton
B. Total Heat	40-240 Btuh/sq.ft.
C. Room Sens. Heat	32-228 Btuh/sq.ft.
D. SHR	0.80-0.95
E. Air Change Rate	10-50 AC/h

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5.05. Computer Rooms

A. Total Heat	50-150 sq.ft./ton
B. Total Heat	80-240 Btuh/sq.ft.
C. Room Sens. Heat	64-228 Btuh/sq.ft.
D. SHR	0.80-0.95
E. Air Flow	2.0-4.0 cfm/sq.ft.
F. Air Change Rate	15-20 AC/h

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5.06. Restaurants

A. Total Heat	100-250 sq.ft./ton	(Range 75-300)
B. Total Heat	48-120 Btuh/sq.ft.	(Range 40-155)
C. Room Sens. Heat	21-62 Btuh/sq.ft.	(Range 20-80)
D. SHR	0.65-0.80	
E. Air Flow	1.5-4.0 cfm/sq.ft.	
F. Air Change Rate	8-12 AC/h	

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5.07. Kitchens (Depends Primarily on Kitchen Equipment)

A. Total Heat	150-350 sq.ft./ton	(at 85°F space)
B. Total Heat	34-80 Btuh/sq.ft.	(at 85°F space)
C. Room Sens. Heat	20-56 Btuh/sq.ft.	(at 85°F space)
D. SHR	0.60-0.70	
E. Air Flow	1.5-2.5 cfm/sq.ft.	
F. Air Change Rate	12-15 AC/h	

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5.08. Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

A. Total Heat	150-200 sq.ft./ton	(Range 75-300)
B. Total Heat	60-80 Btuh/sq.ft.	(Range 40-155)
C. Room Sens. Heat	27-40 Btuh/sq.ft.	(Range 20-80)
D. SHR	0.65-0.80	
E. Spaces	1.5-4.0 cfm/sq.ft.	
F. Air Change Rate	15-20 AC/h	Cocktail Lounges, Bars, Taverns, Clubhouses
G. Air Change Rate	20-30 AC/h	Night Clubs

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5.09. Hospital Patient Rooms, Nursing Home Patient Rooms

A. Total Heat	250-300 sq.ft./ton	(Range 200-400)
B. Total Heat	40-48 Btuh/sq.ft.	(Range 30-60)
C. Room Sens. Heat	32-46 Btuh/sq.ft.	(Range 25-50)
D. SHR	0.75-0.85	

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5.10. Buildings w/100 percent OA Systems (e.g., Laboratories, Hospitals)

A. Total Heat	100-300 sq.ft./ton
B. Total Heat	40-120 Btuh/sq.ft.

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5.11. Medical/Dental Centers, Clinics, and Offices

A. Total Heat	250-300 sq.ft./ton	(Range 200-400)
B. Total Heat	40-48 Btuh/sq.ft.	(Range 30-60)
C. Room Sens. Heat	32-46 Btuh/sq.ft.	(Range 25-50)
D. SHR	0.75-0.85	
E. Air Change Rate	8-12 AC/h	

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5.12. Residential

A. Total Heat	500-700 sq.ft./ton
B. Total Heat	17-24 Btuh/sq.ft.
C. Room Sens. Heat	12-20 Btuh/sq.ft.
D. SHR	0.80-0.95

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5.13. Apartments (Eff., One-Room, Two-Room)

A. Total Heat	350-450 sq.ft./ton	(Range 300-500)
B. Total Heat	27-34 Btuh/sq.ft.	(Range 24-40)
C. Room Sens. Heat	22-30 Btuh/sq.ft.	(Range 20-35)
D. SHR	0.80-0.95	

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5.14. Motel and Hotel Public Spaces

A. Total Heat	250-300 sq.ft./ton	(Range 160-375)
B. Total Heat	40-48 Btuh/sq.ft.	(Range 32-74)
C. Room Sens. Heat	32-46 Btuh/sq.ft.	(Range 25-60)
D. SHR	0.75-0.90	

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5.15. Motel and Hotel Guest Rooms, Dormitories

A. Total Heat	400-500 sq.ft./ton	(Range 300-600)
B. Total Heat	24-30 Btuh/sq.ft.	(Range 20-40)
C. Room Sens. Heat	20-25 Btuh/sq.ft.	(Range 15-35)
D. SHR	0.80-0.95	

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5.16. School Classrooms

A. Total Heat	225-275 sq.ft./ton	(Range 150-350)
B. Total Heat	43-53 Btuh/sq.ft.	(Range 35-80)
C. Room Sens. Heat	25-42 Btuh/sq.ft.	(Range 20-65)
D. SHR	0.65-0.80	
E. Air Change Rate	4-12 AC/h	

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5.17. Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

A. Total Heat	100-250 sq.ft./ton	(Range 75-300)
B. Total Heat	48-120 Btuh/sq.ft.	(Range 40-155)
C. Room Sens. Heat	21-62 Btuh/sq.ft.	(Range 20-80)
D. SHR	0.65-0.80	
E. Spaces	1.5-4.0 cfm/sq.ft.	
F. Air Change Rate	12-15 AC/h	

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5.18. Libraries, Museums

A. Total Heat	250-350 sq.ft./ton	(Range 160-400)
B. Total Heat	34-48 Btuh/sq.ft.	(Range 30-75)
C. Room Sens. Heat	22-32 Btuh/sq.ft.	(Range 20-50)
D. SHR	0.80-0.90	
E. Air Change Rate	8-12 AC/h	

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5.19. Retail, Department Stores

A. Total Heat	200-300 sq.ft./ton	(Range 200-500)
B. Total Heat	40-60 Btuh/sq.ft.	(Range 24-60)
C. Room Sens. Heat	32-43 Btuh/sq.ft.	(Range 16-43)
D. SHR	0.65-0.90	
E. Air Change Rate	6-10 AC/h	

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5.20. Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

A. Total Heat	175-225 sq.ft./ton	(Range 100-350)
B. Total Heat	53-69 Btuh/sq.ft.	(Range 35-115)
C. Room Sens. Heat	23-54 Btuh/sq.ft.	(Range 15-90)
D. SHR	0.65-0.90	
E. Air Change Rate	6-10 AC/h	

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5.21. Supermarkets

A. Total Heat	250-350 sq.ft./ton	(Range 150-400)
B. Total Heat	34-48 Btuh/sq.ft.	(Range 30-80)
C. Room Sens. Heat	25-40 Btuh/sq.ft.	(Range 22-67)
D. SHR	0.65-0.85	
E. Air Change Rate	4-10 AC/h	

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5.22. Malls, Shopping Centers

A. Total Heat	150-350 sq.ft./ton	(Range 150-400)
B. Total Heat	34-80 Btuh/sq.ft.	(Range 30-80)
C. Room Sens. Heat	25-67 Btuh/sq.ft.	(Range 22-67)
D. SHR	0.65-0.85	
E. Air Change Rate	6-10 AC/h	

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5.23. Jails

A. Total Heat	350-450 sq.ft./ton	(Range 300-500)
B. Total Heat	27-34 Btuh/sq.ft.	(Range 24-40)
C. Room Sens. Heat	22-30 Btuh/sq.ft.	(Range 20-35)
D. SHR	0.80-0.95	

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5.24. Auditoriums, Theaters

A. Total Heat	0.05-0.07 tons/seat
B. Total Heat	600-840 Btuh/seat
C. Room Sens. Heat	325-385 Btuh/seat
D. SHR	0.65-0.75
E. Air Flow	15-30 cfm/seat
F. Air Change Rate	8-15 AC/h

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5.25. Churches

A. Total Heat	0.04-0.06 tons/seat
B. Total Heat	480-720 Btuh/seat
C. Room Sens. Heat	260-330 Btuh/seat
D. SHR	0.65-0.75
E. Air Flow	15-30 cfm/seat
F. Air Change Rate	8-15 AC/h

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5.26. Bowling Alleys

A. Total Heat	1.5-2.5 tons/alley
B. Total Heat	18,000-30,000 Btuh/alley
C. Air Change Rate	10-15 AC/h

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5.27. All Spaces

A. Total Heat	300-500 cfm/ton@20°F ΔT
B. Total Heat	400 cfm/ton ± 20%@20°F ΔT
C. Perimeter Spaces	1.0-3.0 cfm/sq.ft.
D. Interior Spaces	0.5-1.5 cfm/sq.ft.
E. Building Block cfm	1.0-1.5 cfm/sq.ft.
F. Air Change Rate	4 AC/h minimum
G. Total heat includes ventilation. Room sensible heat does not include ventilation.	

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5.28. Cooling Load Calculation Procedure

A. Obtain Building Characteristics

1. Construction materials.
2. Construction material properties: U-values, R-values, shading coefficients, solar heat gain coefficients.
3. Size.
4. Color.
5. Shape.
6. Location.
7. Orientation, N, S, E, W, NE, SE, SW, NW, etc.
8. External/internal shading.
9. Occupancy type and time of day.

B. Select Outdoor Design Weather Conditions

1. Temperature.
2. Wind direction and speed.
3. Conditions in selecting outdoor design weather conditions:
 - a. Type of structure, heavy, medium, or light.
 - b. Is structure insulated? If the structure is heated or cooled, the structure must be insulated by code.
 - c. Is structure exposed to high winds?
 - d. Infiltration or ventilation load.
 - e. Amount of glass.
 - f. Time of building occupancy.
 - g. Type of building occupancy.
 - h. Length of reduced indoor temperature.
 - i. What is daily temperature range, minimum/maximum?
 - j. Are there significant variations from ASHRAE weather data?
 - k. What type of heating devices will be used?
 - l. Expected cost of fuel.
4. See Part 15 for code restrictions on the selection of outdoor design conditions.

C. Select the indoor design temperature to be maintained in each space. See Part 15 for code restrictions on the selection of indoor design conditions.

D. Estimate temperatures in unconditioned spaces.

E. Select and/or compute U-values for walls, roof, windows, doors, partitions, etc.

F. Determine the area of walls, windows, floors, doors, partitions, etc.

- G. Compute the conduction heat gains for all walls, windows, floors, doors, partitions, skylights, etc.**
- H. Compute the solar heat gains for all walls, windows, floors, doors, partitions, skylights, etc.**
- I. Infiltration heat gains are generally ignored unless space temperature and humidity tolerance are critical.**
- J. Compute the ventilation heat gain required.**
- K. Compute the internal heat gains from lights, people, and equipment.**
- L. Compute the sum of all heat gains indicated in items G, H, I, J, and K earlier in this list.**
- M. Include morning cool-down for buildings with intermittent use and night setup. See Part 15 for code restrictions on the excess HVAC system capacity permitted for morning cool-down.**
- N. Consider equipment and materials that will be brought into the building above the inside design temperature.**
- O. Cooling load calculations should be conducted using industry-accepted methods to determine the actual cooling load requirements.**
- P. Cooling load calculations are often performed using computer simulation programs. These programs greatly simplify the calculation process; however, the basic procedures and input information required are the same.**

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5.29. Cooling Load Peak Time Estimate (for Calculating Cooling Loads by Hand)

MONTH OF PEAK ROOM COOLING LOAD FOR VARIOUS EXPOSURES

Window Characteristics**Probable Month of Peak Room Cooling Load**

% Glass	Shade Coef.	Overhang	Probable Month of Peak Room Cooling Load						
			N	S	E	W	NE	SE	SW
25	0.4	0	July	Sept.	July	July	July	Sept.	Sept.
25	0.4	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.
25	0.4	1:1	July	Oct.	July	July	July	Sept.	Oct.
25	0.6	0	July	Sept.	July	July	July	Sept.	Sept.
25	0.6	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.
25	0.6	1:1	July	Dec.	July	Sept.	July	Sept.	Oct.
50	0.4	0	July	Sept.	July	July	July	Sept.	Sept.
50	0.4	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.
50	0.4	1:1	July	Dec.	July	Sept.	July	Sept.	Oct.
50	0.6	0	July	Oct.	July	July	July	Sept.	Sept.
50	0.6	1:2	July	Dec.	July	Aug.	July	Sept.	Oct.
50	0.6	1:1	July	Dec.	July	Sept.	July	Sept.	Dec.

Notes:

- 1. Percent glass is the percent of gross wall area for the particular exposure.**
- 2. The shading coefficient refers to the overall shading coefficient. A shading coefficient of 0.4 is approximately equal to double-pane glass with the heat-absorbing plate out and the regular plate in, combined with medium-color Venetian blinds.**
- 3. Although the room peak for south, southeast, and southwest exposure is September or later, the system peak will likely be in July.**
- 4. The value for the overhang is the ratio of the depth of the overhang to the height of the window with the overhang at the same elevation as top of the window.**
- 5. The roof will peak in June or July.**

Citation

EXPORT

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Part 6: Heating Load Rules of Thumb

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6. Part 6: Heating Load Rules of Thumb

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6.01. All Buildings and Spaces

- A. **20-60 Btuh/sq.ft.**
- B. **25-40 Btuh/sq.ft. Average**

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6.02. Buildings w/100 Percent OA Systems (i.e., Laboratories, Hospitals)

- A. **40-120 Btuh/sq.ft.**

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6.03. Buildings w/Ample Insulation, Few Windows

- A. **AC tons × 12,000 Btuh/ton × 1.2**

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6.04. Buildings w/Limited Insulation, Many Windows

- A. **AC tons × 12,000 Btuh/ton × 1.5**

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6.05. Walls Below Grade (Heat Loss at Outside Air Design Condition)

- A. **-30°F - 6.0 Btuh/sq.ft.**

- B. **-25°F - 5.5 Btuh/sq.ft.**
- C. **-20°F - 5.0 Btuh/sq.ft.**
- D. **-15°F - 4.5 Btuh/sq.ft.**
- E. **-10°F - 4.0 Btuh/sq.ft.**
- F. **-5°F - 3.5 Btuh/sq.ft.**
- G. **0°F - 3.0 Btuh/sq.ft.**
- H. **5°F - 2.5 Btuh/sq.ft.**
- I. **10°F - 2.0 Btuh/sq.ft.**
- J. **15°F - 1.9 Btuh/sq.ft.**
- K. **20°F - 1.8 Btuh/sq.ft.**
- L. **25°F - 1.7 Btuh/sq.ft.**
- M. **30°F - 1.5 Btuh/sq.ft.**

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6.06. Floors Below Grade (Heat Loss at Outside Air Design Condition)

- A. **-30°F - 3.0 Btuh/sq.ft.**
- B. **-25°F - 2.8 Btuh/sq.ft.**
- C. **-20°F - 2.5 Btuh/sq.ft.**
- D. **-15°F - 2.3 Btuh/sq.ft.**
- E. **-10°F - 2.0 Btuh/sq.ft.**
- F. **-5°F - 1.8 Btuh/sq.ft.**
- G. **0°F - 1.5 Btuh/sq.ft.**
- H. **5°F - 1.3 Btuh/sq.ft.**
- I. **10°F - 1.0 Btuh/sq.ft.**
- J. **15°F - 0.9 Btuh/sq.ft.**

K. **20°F - 0.8 Btuh/sq.ft.**

L. **25°F - 1.7 Btuh/sq.ft.**

M. **30°F - 0.5 Btuh/sq.ft.**

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6.07. Heating System Selection Guidelines

- A. **If heat loss exceeds 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.**
- B. **If heat loss is between 250 and 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, blanketing the exposed wall and window areas.**
- C. **If heat loss is less than 250 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away from, the exposed wall and window areas.**

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6.08. Heating Load Calculation Procedure

A. Obtain Building Characteristics

1. Construction materials.
2. Construction material properties: U-values, R-values, shading coefficients, solar heat gain coefficients.
3. Size.
4. Color.
5. Shape.
6. Location.
7. Orientation, N, S, E, W, NE, SE, SW, NW, etc.

8. External/internal shading.
9. Occupancy type and time of day.

B. Select Outdoor Design Weather Conditions

1. Temperature.
2. Wind direction and speed.
3. Conditions in selecting outdoor design weather conditions:
 - a. Type of structure: heavy, medium, or light.
 - b. Is structure insulated? If the structure is heated or cooled, it must be insulated according to code.
 - c. Is structure exposed to high wind?
 - d. Infiltration or ventilation load.
 - e. Amount of glass.
 - f. Time of building occupancy.
 - g. Type of building occupancy.
 - h. Length of reduced indoor temperature.
 - i. What is daily temperature range, minimum/maximum?
 - j. Are there significant variations from ASHRAE weather data?
 - k. What type of heating devices will be used?
 - l. Expected cost of fuel.
4. See Part 15 for code restrictions on selection of outdoor design conditions.

C. Select indoor design temperature to be maintained in each space. See Part 15 for code restrictions on selection of indoor design conditions.

D. Estimate temperatures in unheated spaces.

E. Select and/or compute U-values for walls, roof, windows, doors, partitions, etc.

F. Determine area of walls, windows, floors, doors, partitions, etc.

- G. Compute heat transmission losses for all walls, windows, floors, doors, partitions, etc.**
- H. Compute heat losses from basement and/or grade level slab floors.**
- I. Compute infiltration heat losses.**
- J. Compute ventilation heat loss required.**
- K. Compute sum of all heat losses indicated in items G, H, I, and J shown earlier.**
- L. For a building with sizable and steady internal heat release, a credit may be taken, but only a portion of the total. Use extreme caution!!! For most buildings, credit for heat gain should not be taken.**
- M. Include morning warm-up for buildings with intermittent use and night set-back. See Part 15 for code restrictions on excess HVAC system capacity permitted for morning warm-up.**
- N. Consider equipment and materials that will be brought into the building below the inside design temperature.**
- O. Heating load calculations should be conducted using industry accepted methods to determine actual heating load requirements.**
- P. Heating load calculations are often performed using computer simulation programs. These programs greatly simplify the calculation process; however, the basic procedures and input information required are the same.**

Citation

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Part 7: Infiltration Rules of Thumb

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7. Part 7: Infiltration Rules of Thumb

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7.01. General

- A. **Below Grade or Interior Spaces—No infiltration losses or gains are taken for rooms located below grade or interior spaces.**
- B. **Buildings that are not humidified have no latent infiltration heating load.**
- C. **Winter sensible infiltration loads will generally be 1/2 to 3 times the conduction heat losses (average 1.0 to 2.0 times).**

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7.02. Heating Infiltration (15-mph wind)

- A. **Air Change Rate Method**
 - 1. Range 0 to 10 AC/h
 - 2. Commercial buildings:
 - a. 1.0 AC/h one exterior wall
 - b. 1.5 AC/h two exterior walls
 - c. 2.0 AC/h three or four exterior walls
 - 3. Vestibules 3.0 AC/h
- B. **CFM/sq.ft. of Wall Method**
 - 1. Range 0 to 1.0 CFM/sq.ft.

2. Tight buildings 0.1 CFM/sq.ft.
3. Average buildings 0.3 CFM/sq.ft.
4. Leaky buildings 0.6 CFM/sq.ft.

C. Crack Method

1. Range 0.12 to 2.8 CFM/ft. of crack
2. Average 1.0 CFM/ft. of crack

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7.03. Cooling Infiltration (7.5-mph wind)

- A. **Cooling load infiltration is generally ignored unless close tolerances in temperature and humidity control are required.**
- B. **Cooling infiltration values are generally taken as 1/2 of the values listed earlier for heating infiltration.**

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Part 8: Ventilation Rules of Thumb

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8. Part 8: Ventilation Rules of Thumb

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8.01. 2015 IMC and ASHRAE Standard 62.1-2013

MINIMUM VENTILATION RATES

Occupancy Classification	Occupant Density People/1,000 SF ^a	CFM per Person	CFM per SF ^a	Exhaust Airflow Rate CFM/SF ^a
Correctional Facilities				
Booking/waiting	50	7.5	0.06	–
Cell—with plumbing fixtures ^b	25	5	0.12	1.0
Cell—without plumbing fixtures	25	5	0.12	–
Day room	30	5	0.06	–
Dining halls (see food and beverage service)	–	–	–	–
Guard Stations	15	5	0.06	–
Dry Cleaners, Laundries				
Notes: Operated dry cleaner ^c	20	15	–	–

^a Based on net occupiable floor area

Occupancy Classification	Occupant Density People/1,000 SF	7.5 CFM per Person	0.06^d, 0.12^e per SF	20 Exhaust Airflow Rate CFM/SF
Coin-operated laundries	20	7.5	0.06 ^d , 0.12 ^e	20
Commercial dry cleaner ^c	30	30	-	-
Commercial laundry ^c	10	25	-	-
Storage, pick-up ^c	30	7.5	0.12	-
Education				
Art classroom ^b	20	10	0.18	0.7
Auditoriums	150	5	0.06	-
Classrooms (ages 5 to 8)	25	10	0.12	-
Classrooms (ages 9 plus)	35	10	0.12	-
Computer lab	25	10	0.12	-
Corridors (see public spaces)	-	-	-	-
Daycare (through age 4)	25	10	0.18	-
Daycare sickroom ^g	25	10	0.18	-
Lecture classroom	65	7.5	0.06	-
Lecture hall (fixed seats)	150	7.5	0.06	-
Locker/dressing rooms ^b	-	-	-	0.25
Media center	25	10	0.12	-
Multiuse assembly	100	7.5	0.06	-
Music/theater/dance	35	10	0.06	-
Science laboratories ^b	25	10	0.18	1.0
Smoking lounges ^{c,f}	70	60	-	-

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Sports locker rooms ^b	-	-	-	0.5
University/college laboratories	25	10	0.18	-
Wood/metal shops ^b	20	10	0.18	0.5
Food and Beverage Service				
Bars, cocktail lounges	100	7.5	0.18	-
Cafeteria, fast food	100	7.5	0.18	-
Dining rooms	70	7.5	0.18	-
Kitchens (cooking) ^f	20 ^g	7.5 ^g	0.12 ^g	0.7 ^c
Hospitals, Nursing and Convalescent Homes				
Autopsy rooms ^f	-	-	-	0.7
Medical procedure rooms	20	15	-	-
Operating rooms	20	30	-	-
Patient rooms	10	25	-	-
Physical therapy	20	15	-	-
Recovery and ICU	10	15	-	-
Hotel, Motels, Resorts, and Dormitories				
Barracks sleeping areas ^g	20	5	0.06	-
Bathrooms/toilet—private ^b	-	-	-	25/50 ^h
Bedroom/living room	10 ^g	5	0.06	-
Conference/meeting ^c	-	5	0.06	-
Dormitory sleeping areas ^c	-	5	0.06	-
Gambling casinos	-	7.5	0.18	-
Notes: ^a By rooms, central ^g	10	5	0.12	-

^a Based on net occupiable floor area

Occupancy Classification	Occupant Density People/1,000 SF	5 CFM per Person	0.12 CFM per SF	- Exhaust Airflow Rate CFM/SF
Laundry rooms, with in-unit laundry units ⁹	10	5	0.12	-
Lobbies/prefunction	30 ⁹	7.5	0.06	-
Multipurpose assembly	120 ⁹	5	0.06	-
Miscellaneous spaces ⁹				
Banks or bank lobbies ⁹	15	7.5	0.06	-
Freezer and refrigerated spaces (<50°F) ⁹	-	10	-	-
General manufacturing (excludes heavy industrial and processes using chemicals) ⁹	7	10	0.18	-
Janitor closets, trash rooms, recycling ⁹	-	-	-	1.00
Kitchenettes ⁹	-	-	-	0.30
Shipping/receiving ⁹	2	10	0.12	-
Sorting, packing, light assembly ⁹	7	7.5	0.12	-
Transportation waiting ⁹	100	7.5	0.06	-
Offices				
Breakrooms ⁹	50	5	0.12	-
Conference rooms	50	5	0.06	-
Main entry lobbies	10	5	0.06	-
Notes: a. Based on net occupiable floor area.	2	5	0.06	-

materials ^g	Occupant			Exhaust
Occupancy	Density	CFM per	CFM	Airflow
Classification	People/1,000	Person	per SF	Rate
	SF			CFM/SF
Office	5	5	0.06	-
Reception areas	30	5	0.06	-
Telephone/data entry	60	5	0.06	-
Private Dwellings, Single and Multiple				
Common corridors ^g	-	-	0.06	-
Garages, common for multiple units ^{c,f}	-	-	-	0.75
Garages, separate for each dwelling ^f	-	-	-	100 cfm per car
Kitchens ^f	-	-	-	25/100 ^h
Living areas ^{c,i}	Based upon number of bedrooms. First bedroom, 2; each additional bedroom, 1	0.35 ACH but not less than 15 cfm/person ^d , 5 ^e	- ^d , 0.06 ^e	-
Toilet rooms and bathrooms ^{b,c}	-	-	-	20/50 ^h
Public Spaces				
Breakrooms ^g	25	5	0.06	-
Corridors	-	-	0.06	-
Courtrooms	70	5	0.06	-
Elevator car ^c	-	-	-	1.0
Legislative chambers	50	5	0.06	-
Libraries	10	5	0.12	-
Lobbies ^g	150	5	0.06	-
Museums (children's)	40	7.5	0.12	-

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
Museums/galleries	40	7.5	0.06	-
Occupiable storage rooms for records or gels ^g	2	5	0.12	-
Places of religious worship	120	5	0.06	-
Shower room (per shower head) ^{b,c}	-	-	-	50/20 ^h
Smoking lounges ^{c,f}	70	60	-	-
Toilet rooms—public ^b	-	-	-	50/70 ^j
Retail Stores, Sales Floors and Showroom Floors				
Dressing rooms	-	-	-	0.25
Mall common areas	40	7.5	0.06	-
Sales (except as below)	15	7.5	0.12	-
Shipping and receiving ^c	-	-	0.12	-
Smoking lounges ^{c,k}	70	60	-	-
Storage rooms ^c	-	-	0.12	-
Warehouses (see storage)	-	-	-	-
Specialty Shops				
Automotive motor-fuel dispensing stations ^f	-	-	-	1.5
Auto repair rooms ^g	-	-	-	1.50
Barber	25	7.5	0.06	0.5
Beauty salons ^f	25	20	0.12	0.6
Embalming rooms ^{c,f}	-	-	-	2.0
Notes ^{f,k}	25	20	0.12	0.6

Occupancy Classification	Occupant Density People/1,000 SF	7.5 CFM per Person	0.18 CFM per SF	Exhaust Airflow Rate CFM/SF
Pet shops (animal areas)	10 ^a	7.5	0.18	0.9
Supermarkets	8	7.5	0.06	-
Sports and Amusement				
Bowling alleys (seating area)	40	10	0.12	-
Disco/dance floors	100	20	0.06	-
Game arcades	20	7.5	0.18	-
Gym, stadium (play area)	- ^d , 7 ^e	- ^d , 20 ^e	0.30 ^d , 0.18 ^e	-
Health club/aerobics room	40	20	0.06	-
Health club/weight room	10	20	0.06	-
Ice arenas without combustion engines	-	-	0.30 ^c	0.5
Spectator areas	150	7.5	0.06	-
Swimming pools (pool and deck area)	-	-	0.48	-
Storage				
Repair garages, enclosed parking garages ^{f,l}	-	-	-	0.75
Soiled laundry storage rooms ^g	-	-	-	1.00
Storage rooms, chemical ^g	-	-	-	1.50
Warehouses	-	10 ^g	0.06	-
Theaters				
auditoriums (see education)	-	-	-	-

Notes:
a. Based on net occupiable floor area.

Occupancy Classification	Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate -CFM/SF
Lobbies ^c	150	5	0.06	-
Stages, studios	70	10	0.06	-
Ticket booths ^c	60	5	0.06	-
Transportation				
Platforms ^c	100	7.5	0.06	-
Transportation waiting ^c	100	7.5	0.06	-
Workrooms				
Bank vaults/safe deposit	5	5	0.06	-
Computer (without printing)	4	5	0.06	-
Copy, printing rooms	4 ^c	5 ^c	0.06 ^c	0.5
Darkrooms	-	-	-	1.0
Meat processing ^{c,i}	10	15	-	-
Pharmacy (prep. area)	10	5	0.18	-
Photo studios	10	5	0.12	-

Notes:

- a. Based on *net occupiable floor area*.
- b. Mechanical exhaust is required and recirculation from such spaces is prohibited except that recirculation shall be permitted where the resulting supply airstream consists of not more than 10 percent air recirculated from these spaces. Recirculation of air that is contained completely within such spaces shall not be prohibited (see 2015 IMC Section 403.2.1, Items 2 and 4).
- c. 2015 IMC only.
- d. 2015 IMC.
- e. ASHRAE Standard 62.1-2013.
- f. Mechanical exhaust required and the recirculation of air from such

i. Mechanical exhaust required and the recirculation of air from such spaces is prohibited. Recirculation of air that is contained completely within such spaces shall not be prohibited (see 2015 IMC Section 403.2.1, Item 3).

Occupant Density People/1,000 SF	CFM per Person	CFM per SF	Exhaust Airflow Rate CFM/SF
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- g. ASHRAE Standard 62.1-2013 only.
- h. Rates are per room unless otherwise indicated. The higher rate shall be provided where the exhaust system is designed to operate intermittently. The lower rate shall be permitted only where the exhaust system is designed to operate continuously while occupied.
- i. Spaces unheated or maintained below 50°F are not covered by these requirements unless the occupancy is continuous.
- j. Rates are per water closet or urinal. The higher rate shall be provided where the exhaust system is designed to operate intermittently. The lower rate shall be permitted only where the exhaust system is designed to operate continuously while occupied.
- k. For nail salons, each manicure and pedicure station shall be provided with a *source capture system* capable of exhausting not less than 50 cfm per station. Exhaust inlets shall be located in accordance with Section 502.20. Where one or more required source capture systems operate continuously during occupancy, the exhaust rate from such systems shall be permitted to be applied to the exhaust flow rate required by Table 403.3.1.1 for the nail salon.
- l. Ventilation systems in enclosed parking garages shall comply with 2015 IMC Section 404.

A. **Breathing zone outdoor airflow volumes must be corrected as follows:**

$$V_{BZ} = R_p P_Z + R_A A_Z$$

Breathing zone outdoor airflow for each zone.

where:

A_Z = area of the zone.

P_Z = people per zone.

R_p = outdoor airflow rate for people.

R_A = outdoor airflow rate per area.

B. Single Zone Systems:

$V_{OT} = V_{OZ} = V_{BZ}/E_Z$ Outdoor air intake flow rate for single zone systems.

where:

V_{OT} = system outdoor air intake flow rate

V_{OZ} = zone outdoor airflow rate

E_Z = zone air distribution effectiveness factor from the table below.

C. 100-Percent Outdoor Air Systems:

$V_{OT} = V_{OZ1} + V_{OZ2} + \dots$ Outdoor air intake flow rate for 100-percent outdoor air systems.

D. Multiple Zone Recirculating Systems:

$Z_p = V_{OZ}/V_{PZ}$ Primary outdoor air fraction for each zone—OA corrected for zone air distribution effectiveness divided by the primary airflow rate supplied to the zone (zone with highest primary outdoor air fraction shall be used in selection of E_V).

where:

V_{PZ} = primary airflow rate supplied to the zone. For variable volume supply, V_{PZ} shall be the lowest expected primary airflow rate to the zone when it is fully occupied.

E_V = system ventilation efficiency from table below.

E. Uncorrected Outdoor Air Intake for Multiple Zone Recirculating Systems:

$V_{OU} = D \sum_{\text{all zones}} R_P P_Z + \sum_{\text{all zones}} R_A A_Z$

where:

D = Occupant diversity: the ratio of the system population to the sum of the zone populations, determined in accordance with the following equation:

$$D = P_S / \sum_{\text{all zones}} P_Z$$

where:

P_S = System population: the total number of occupants in the area served by the system. For design purposes, P_S shall be the maximum number of occupants expected to be concurrently in all zones served by the system.

F. Corrected Outdoor Air Intake for Multiple Zone Recirculating Systems:

$V_{OT} = V_{OU}/E_V$ Outdoor air intake flow rate for multiple zone systems corrected for ventilation effectiveness.

Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air.	1.0
Ceiling supply of warm air and floor return.	1.0
Ceiling supply of warm air at least 15°F above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F above space temperature and ceiling return provided that the 150 fpm supply air jet reaches to within 4.5 feet of the floor level.	1.0
Ceiling supply of warm air less than 15°F above space temperature and ceiling return provided that the supply air jet is less than 150 fpm.	0.8
Floor supply of cool air and ceiling return provided that the 150 fpm supply jet reaches at least 4.5 feet above the floor. <i>Note:</i> Most underfloor air distribution systems comply with this provision.	1.0
Floor supply of cool air and ceiling return, provided low velocity displacement ventilation achieves unidirectional flow and thermal stratification.	1.2
Floor supply of warm air and floor return.	1.0
Floor supply of warm air and ceiling return.	0.7
Makeup supply drawn in on the	0.8

Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.0
Zone Air Distribution Effectiveness	E
Air Distribution Configuration	
Makeup supply drawn in near to the exhaust and/or return location.	0.5

System Ventilation Efficiency Table

Max Z_p Zone with Max % OA	E_v
≤ 0.15	1
≤ 0.25	0.9
≤ 0.35	0.8
≤ 0.45	0.7
≤ 0.55	0.6
≤ 0.65	0.5
≤ 0.75	0.4
> 0.75	0.3

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8.02. ASHRAE Standard 62.1-2013: Return Air, Transfer Air, or Exhaust Air Classifications

A. **Class 1: Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor. Class 1 air may be recirculated or transferred to any space. This includes:**

1. Offices.
2. Reception/waiting areas.
3. Telephone/data entry.
4. Lobbies.
5. Conference/meeting rooms.
6. Corridors.

7. Storage rooms.
8. Break rooms.
9. Coffee stations.
10. Equipment rooms.
11. Mechanical rooms.
12. Electrical/telephone closets.
13. Elevator machine rooms.
14. Laundry rooms within dwelling units.
15. Sports arena.
16. Correctional facility day room and guard station.
17. Educational facilities: classrooms, lecture classrooms, lecture halls, computer lab, media center, music/theater/dance studios, multiuse assembly.
18. Hotels, motels, resorts, dormitories: bedrooms, living rooms, barracks, sleeping quarters, lobbies, prefunction spaces, multipurpose assembly.
19. Computer rooms.
20. Photo studios.
21. Shipping/receiving rooms.
22. Transportation waiting rooms.
23. Public assembly spaces: auditorium seating area, places of religious worship, courtrooms, legislative chambers, libraries, lobbies, museums/galleries (all types).
24. Mall common areas.
25. Supermarkets.
26. Sports and entertainment: sports arena (play area), spectator areas, disco/dance floors, bowling alleys, gambling casinos, game arcades, stages, studios.

B. Class 2: Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odors. Air that is not harmful or objectionable but is inappropriate for transfer or recirculation to spaces used for different purposes. Class 2 air may be recirculated within the space of origin but may not be recirculated or transferred to Class 1 spaces. Class 2 air may be recirculated or transferred to other Class 2 or Class 3 spaces with the same occupancy and use, or where contaminants are from similar sources and will not react to form more hazardous contaminants. Class 2 air may be recirculated or transferred to Class 4 spaces. This includes:

1. Kitchens (commercial) and kitchenettes.
2. Toilet/bath rooms (public and private).
3. Locker rooms.
4. Locker/dressing rooms.
5. Central laundry rooms.
6. Science laboratories.
7. University and college laboratories.
8. Art classrooms.
9. Retail sales areas.
10. Barber shops.
11. Beauty and nail salons.
12. Prison cells with toilets.
13. Darkrooms.
14. Pet shops (animal areas).
15. Copy printing rooms.
16. Wood/metal shop classrooms.
17. Correctional facility booking/waiting areas.
18. Food and beverage services: restaurant dining rooms, cafeterias, fast food establishments, bars, cocktail lounges.

19. Bank vaults/safe deposit vaults.
20. Pharmacy preparation areas.
21. Warehouses.
22. Coin-operated laundries.
23. Gym/stadium (play areas).
24. Swimming pools and decks.
25. Health club/aerobics rooms.
26. Health club/weight rooms.
27. Hydraulic elevator machine rooms.

C. Class 3: Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor. Class 3 air may be recirculated within the space of origin only and cannot be recirculated to any other space. This includes:

1. Commercial kitchen hoods other than grease hoods.
2. Residential kitchen vented hoods.
3. Refrigeration machinery rooms.
4. Boiler rooms.
5. Soiled laundry storage areas.
6. Janitor closets.
7. Trash/recycle rooms.
8. General chemical/biological laboratories.
9. Daycare sick rooms.

D. Class 4: Air with highly objectionable fumes or gases or with potentially dangerous particles, bio-aerosols, or gases, at such high concentrations as to pose a health hazard. Class 4 air shall not be recirculated or transferred to any space or recirculated within the space of origin. This includes:

1. Commercial kitchen grease hoods.
2. Laboratory hoods.
3. Paint spray booths.
4. Diazo printing equipment discharges.
5. Chemical storage rooms.
6. Auto repair rooms.
7. Parking garages.

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8.03. ASHRAE Standard 62.2-2013

A. Outdoor air must be provided to each dwelling unit in accordance with the following table:

Floor Area Square Feet	Number of Bedrooms				
	1	2	3	4	5
<500	30	38	45	53	60
501-1,000	45	53	60	68	75
1,001-1,500	60	68	75	83	90
1,501-2,000	75	83	90	98	105
2,001-2,500	90	98	105	113	120
2,501-3,000	105	113	120	128	135
3,001-3,500	120	128	135	143	150
3,501-4,000	135	143	150	158	165

4,001- 4,500 Floor Area	150	158	165	173	180
	1	2	3	4	5
4,501- 5,000 Square Feet	165	173	180	188	195

Notes:

1. In lieu of the preceding table, the following equation may be used to determine the minimum outdoor air quantity.

$$Q_{OA} = 0.03 \times A_{FLOOR} + 7.5 \times (N_{BR} + 1).$$

Q_{OA} = Quantity of Outdoor Air—CFM.

A_{FLOOR} = Floor Area of Residence—Square Feet.

N_{BR} = Number of Bedrooms—Minimum of 1.

2. Exhaust requirements:

a. Intermittent:

1. Kitchen: 100 CFM.
2. Bathroom: 50 CFM.

b. Continuous:

1. Kitchen: 5.0 AC/h
2. Bathroom: 20 CFM.

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8.04. ASHRAE Standard 170-2013 *Ventilation of Health Care Facilities* (incorporated as Part 4 of the 2014 Facility Guidelines Institute *Guidelines for Design and Construction of Hospitals and Outpatient Facilities*)

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Surgery and Critical Care			
Operating room (Classes B and C)	Pos	4	20

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Operating/surgical cystoscopic rooms	Pos	4	20
Delivery room (Caesarean)	Pos	4	20
Substerile service area	NR	2	6
Recovery room	NR	2	6
Critical and intensive care	NR	2	6
Intermediate care	NR	2	6
Wound intensive care (burn unit)	NR	2	6
Newborn intensive care	Pos	2	6
Treatment room	NR	2	6
Trauma room (crisis or shock)	Pos	3	15
Medical/anesthesia gas storage	Neg	NR	8
Laser eye room	Pos	3	15
ER waiting rooms	Neg	2	12
Triage	Neg	2	12
ER decontamination	Neg	2	12
Radiology waiting rooms	Neg	2	12
Procedure room (Class A surgery)	Pos	3	15
Emergency department exam/treatment room	NR	2	6
Inpatient Nursing			
Patient room	NR	2	4
Nourishment area or room	NR	NR	2
Toilet room	Neg	NR	10
Newborn nursery suite	NR	2	6
Protective environment room	Pos	2	12
Airborne Infectious Isolation (All) room	Neg	2	12
Notes: Isolation All/Protective	Pos	2	12

Environment (PE) room			Minimum
Area Designation	Pressure Relationship	Minimum NR OA AC/h	Total AC/h
All anterooms	Neg	NR	10
PE anteroom	Neg	NR	10
Combination All/PE anteroom	Neg	NR	10
Labor/delivery/recovery/postpartum (LDRP)	NR	2	6
Labor/delivery/recovery (LDR)	NR	2	6
Patient Corridor	NR	NR	2
Nursing Facility			
Resident room	NR	2	2
Resident gathering/activity/dining	NR	4	4
Resident unit corridor	NR	NR	4
Physical therapy	Neg	2	6
Occupational therapy	NR	2	6
Bathing room	Neg	NR	10
Radiology			
X-ray (diagnostic and treatment)	NR	2	6
X-ray (surgery/critical care and catheterization)	Pos	3	15
Darkroom	Neg	2	10
Diagnostic and Treatment			
Bronchoscopy, sputum collection, and pentamidine administration	Neg	2	12
Laboratory, general	Neg	2	6
Laboratory, bacteriology	Neg	2	6
Laboratory, biochemistry	Neg	2	6
Laboratory, cytology	Neg	2	6
Laboratory, glass washing	Neg	2	10
Laboratory, histology	Neg	2	6

Laboratory, histology	Neg	2	6
Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Laboratory, microbiology	Neg	2	6
Laboratory, nuclear medicine	Neg	2	6
Laboratory, pathology	Neg	2	6
Laboratory, serology	Neg	2	6
Laboratory, sterilizing	Neg	2	10
Laboratory, media transfer	Pos	2	4
Nonrefrigerated body-holding room	Neg	NR	10
Autopsy room	Neg	2	12
Pharmacy	Pos	2	4
Examination room	NR	2	6
Medication room	NR	2	4
Gastrointestinal endoscopy procedure room	NR	2	6
Endoscope cleaning	Neg	2	10
Treatment room	NR	2	6
Hydrotherapy	Neg	2	6
Physical therapy	Neg	2	6
Dialysis treatment area	NR	2	6
Dialyzer reprocessing room	Neg	NR	10
Nuclear medicine hot lab	Neg	NR	6
Nuclear medicine treatment room	Neg	2	6
Sterilizing			
Sterilizer equipment room	Neg	NR	10
Central Medical and Surgical Supply			
Soiled or decontamination room	Neg	2	6
Clean workroom	Pos	2	4
Sterile storage	Pos	2	4

Service

Area Designation	Pressure Relationship	Minimum OA AC/h	Minimum Total AC/h
Food preparation center	NR	NR	10
Warewashing	Neg	NR	10
Dietary storage	NR	NR	2
Laundry, general	Neg	2	10
Soiled linen sorting and storage	Neg	NR	10
Clean linen storage	Pos	NR	2
Linen and trash chute room	Neg	NR	10
Bedpan room	Neg	NR	10
Bathroom	Neg	NR	10
Janitor's closet	Neg	NR	10
Support Space			
Soiled workroom or soiled holding	Neg	2	10
Clean workroom or clean holding	Pos	2	4
Hazardous material storage	Neg	2	10

Notes:

Pos = Positive Pressure Relationship

Neg = Negative Pressure Relationship

NR = No Requirement



8.05. Enclosed Parking Garages

A. 2015 IMC

1. Ventilation rates:
 - a. Minimum: 0.05 CFM/SF.
 - b. Design: 0.75 CFM/SF.

- c. Mechanical ventilation systems may reduce the 0.75 CFM/SF ventilation requirement when the system operates automatically by means of carbon monoxide detectors applied in conjunction with nitrogen dioxide detectors. Such detectors shall be installed in accordance with their manufacturers' recommendations.

B. Enclosed Parking Garage Design Recommendations

1. Exhaust 0.75 CFM/SF at one end of the garage on each floor using a masonry plenum or ductwork (a floor-to-floor exhaust plenum is normally easier because floor-to-floor heights are generally limited in a garage and ductwork does not fit). Exhaust 1/2 of the air high and 1/2 of the air low. This will remove contaminants that are heavier than air (flammable vapors) and contaminants that are lighter than air (carbon monoxide).
2. Supply approximately 0.75 CFM/SF at the other end of the garage on each floor using a masonry plenum or ductwork (a floor-to-floor supply plenum is normally easier because floor-to-floor heights are generally limited in a garage and ductwork does not fit). Supply 1/2 of the air high and 1/2 of the air low. This exhaust and supply design will provide a sweeping air motion through the garage. Depending on the location of the entrances and exits to the garage, the supply quantity may be reduced to allow air to enter through the entrances and exits provided that short circuiting of the supply air is prevented.
3. Utilize VFDs to control the speed and the airflow of the fan based on vehicle operation and the presence of occupants, or carbon monoxide detectors applied in conjunction with nitrogen dioxide detectors. Note that the minimum garage ventilation rate is only 8 percent of the design airflow (0.05 CFM/SF divided by 0.75 CFM/SF). A single fan operated by a VFD will only turn down to about 25 percent. Use at least two fans with VFDs; this will permit a turndown of 12.5 percent and will allow for partial capacity in the event of fan failure.
4. Garages should not be heated. The volume of air, even under code minimum airflow requirements, has a substantial impact and is a waste of energy.

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8.06. Outside Air Intake and Exhaust Locations

A. 2015 IMC

1. Intakes or exhausts—10 feet from lot lines, buildings on same lot or center line of street or public way.
2. Intakes—10 feet horizontally from any hazardous or noxious contaminant (plumbing vents, chimneys, vents, stacks, alleys, streets, parking lots, loading docks). When within 10 feet horizontally, intake must be a minimum of 3 feet below or 25 feet above any source of contaminant.
3. Exhausts—shall not create a public nuisance or be directed onto walkways. For environmental air exhaust systems, outlets shall be 3 feet from property lines, 3 feet from operable openings into buildings for all occupancies other than Group U, and 10 feet from mechanical air intakes.
4. Opening protection:
 - a. Protect intake and exhaust openings with corrosion resistant screens, louvers, or grilles.
 - b. Exhaust openings: between 1/4" and 1/2" opening screens.
 - c. Intake openings—residential: between 1/4" and 1/2" opening screens.
 - d. All other intake openings: between 1/4" and 1" opening screens.

B. NFPA 90A-2015

1. Outside air intakes shall be located to avoid drawing in combustible materials and toxic or hazardous vapors.
2. Outside air intakes shall be protected with corrosion resistant screens not larger than 1/2" mesh.
3. Outside air intakes shall be located to minimize the hazard from fires in other structures. Intakes shall be equipped with a fire damper when protection from fire hazards is required.
4. Outside air intake shall be located so as to minimize the introduction of smoke into the building. Intakes shall be equipped with a smoke damper when protection from smoke hazards is required.

C. ASHRAE Standard 62.1-2013—Air Intake Minimum Separation Distances

1. Significantly contaminated exhaust (high contaminant concentration, significant sensory-irritation intensity, offensive odor): 15 feet.
2. Noxious or dangerous exhaust air with highly objectionable fumes or gases

and or exhaust air with potentially dangerous contaminants (laboratory exhaust, fumes, gases, potentially dangerous particles, bio-aerosols, gases at high concentrations to be harmful): 30 feet.

3. Plumbing vents terminating less than 3 feet above the level of the outdoor air intake: 10 feet.
4. Plumbing vents terminating at least 3 feet above the level of the outdoor air intake: 3 feet.
5. Vents, chimneys, flues, and other combustion appliance discharge: 15 feet.
6. Garage entry, automobile loading area, drive-in queue: 15 feet.
7. Truck loading area or dock, bus parking/idling area: 25 feet.
8. Driveway, street, or parking area: 5 feet.
9. Street or thoroughfare with high traffic volume: 25 feet.
10. Roof, landscaped grade or other surface directly below intake: 1 foot (or expected average snow depth, whichever is greater).
11. Garbage storage/pickup area, dumpsters: 15 feet.
12. Cooling tower intake or basin: 15 feet.
13. Cooling tower exhaust: 25 feet.
14. Class 1 air: 10 feet (the author's interpretation of Class 1 air).
15. Class 2 air: 15 feet (the author's interpretation of Class 2 air).
16. Class 3 air: 15 feet (see item number 1 preceding the definition of Class 3 air).
17. Class 4 air: 30 feet (see item number 2 preceding the definition of Class 4 air).

D. ASHRAE Standard 170-2013 *Ventilation of Health Care Facilities*

(incorporated as Part 4 of the 2014 Facility Guidelines Institute

Guidelines for Design and Construction of Hospitals and Outpatient Facilities

1. Outdoor air intakes shall be located at least 25 feet from cooling towers and all exhaust outlets of ventilating systems, combustion equipment stacks, medical-surgical vacuum systems, plumbing vents, or areas that may collect

vehicular exhaust or other noxious fumes. Prevailing winds and/or proximity to other structures may require greater clearances.

2. The bottom of outdoor air intakes serving central systems shall be as high as practical, but at least 6 feet above ground level, or if installed above the roof, 3 feet above roof level.
3. Relief air is exempt from the 25 foot separation requirement. Relief air is defined as air that otherwise could be returned to an air handling unit from the occupied space but is being discharged to the outdoors to maintain building pressure, such as during outside air economizer operation.
4. Exhaust outlets from areas that may be contaminated shall discharge in a vertical direction at least 10 feet above roof level and shall be located not less than 10 feet horizontally from air intakes, openable windows/doors, or areas that are normally accessible to the public or maintenance personnel and that are higher in elevation than the exhaust discharge.
5. Exhaust outlets from areas that may be contaminated shall be arranged to minimize recirculation of exhaust air into the building.

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8.07. Indoor Air Quality (IAQ)

A. Causes of Poor IAQ

1. Inadequate ventilation—50 percent of all IAQ problems are due to lack of ventilation.
2. Poor intake/exhaust locations.
3. Inadequate filtration or dirty filters.
4. Intermittent airflow.
5. Poor air distribution.
6. Inadequate operation.
7. Inadequate maintenance.

B. IAQ Control Methods

1. Control temperature and humidity.
2. Ventilation—dilution.

3. Remove pollution source.

4. Filtration.

C. IAQ Factors

1. Thermal environment.

2. Smoke.

3. Odors.

4. Irritants—dust.

5. Stress problems (perceptible, nonperceptible).

6. Toxic gases—carbon monoxide, carbon dioxide.

7. Allergens—pollen.

8. Biological contaminants—bacteria, mold, pathogens, legionella, micro-organisms, fungi.

D. CO₂ Levels and IAQ

1. Outdoor background level:	500–700 PPM CO ₂ avg.
2. <i>ASHRAE Standard 62.1</i> recommends:	1000–1200 PPM CO ₂ max.
3. OSHA and U.S. Air Force standard:	650 PPM CO ₂ max.
4. Human discomfort begins:	800–1000 PPM CO ₂ .
5. Long-term health effects:	>12,000 PPM CO ₂ .

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8.08. Effects of Carbon Monoxide

A. **Effects of Various Concentrations of Carbon Monoxide with Respect to Time are shown in the following table.**

Concentration of Carbon Monoxide in PPM ±

Hours of Exposure	Barely Perceptible	Sickness	Deadly
0.5	600	1000	2000
1.0	200	600	1600
2	100	300	1000
3	75	200	700
4	50	150	400
5	35	125	300
6	25	120	200
7	25	100	200
8	25	100	150

B. Carbon Monoxide Concentration versus Time versus Symptoms are shown in the following table.

Concentration of CO in the Air	Inhalation Time	Toxic Symptoms Developed
9 PPM	Short-term exposure	ASHRAE recommended maximum allowable concentration for short term exposure in living area.
35 PPM	8 hours	The maximum allowable concentration for a continuous exposure, in any 8-hour period, according to federal law.
200 PPM	2-3 hours	Slight headache, tiredness, dizziness, nausea; maximum CO concentration exposure at any time as

Concentration of CO in the Air	Inhalation Time	Toxic Symptoms
400 PPM	1-2 hours	Frontal headaches Developed
	after 3 hours	Life threatening
	-	Maximum PPM in flue gas (on a free air basis) according to EPA and AGA
800 PPM	45 minutes	Dizziness, nausea, and convulsions
	2 hours	Unconscious
	2-3 hours	Death
1,600 PPM	20 minutes	Headache, dizziness, nausea
	1 hour	Death
3,200 PPM	5-10 minutes	Headache, dizziness, nausea
	30 minutes	Death
6,400 PPM	1-2 minutes	Headache, dizziness, nausea
	10-15 minutes	Death
12,800 PPM	1-3 minutes	Death

C. Carbon monoxide is lighter than air (specific gravity is 0.968).

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8.09. Toilet Rooms

A. ASHRAE Standard 62.1-2013

1. Private: 50 CFM/room for intermittent operation, 25 CFM/room for continuous operation. For toilet rooms intended to be occupied by one person at a time.
2. Public: 70 CFM/water closet and urinal where periods of heavy use are expected to occur, 50 CFM/water closet and urinal otherwise.

B. 2015 IMC

1. Private: 50 CFM/room for intermittent operation, 25 CFM/room for continuous operation. For toilet rooms intended to be occupied by one person at a time.
2. Public: 70 CFM/water closet and urinal for intermittent operation, 50 CFM/water closet and urinal for continuous operation.

C. **Recommended Design Requirements**

1. 2.0 CFM/sq.ft.
2. 10 AC/h
3. 100 CFM/water closet and urinal.
4. Toilet room ventilation:
 - a. For toilet rooms with high fixture densities (stadiums, auditoriums), the 50 CFM/water closet and urinal dictates.
 - b. For toilet rooms with ceiling heights over 12 feet, the 10 AC/h dictates.
 - c. For toilet rooms with ceiling heights 12 feet and under, the 2.0 CFM/sq.ft. dictates.
 - d. If toilet rooms are designed for a 100 CFM/water closet or urinal, you will always meet the 2.0 CFM/sq.ft. and the 10 AC/h recommended airflow requirements.

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8.10. Electrical Rooms

A. **Recommended Minimum Ventilation Rate**

1. 2.0 CFM/sq.ft.
2. 10.0 AC/h
3. 5 CFM/KVA of transformer.

B. **Electrical Room Design Guidelines**

1. Determine heat gain from transformers, panelboards, and other electrical equipment contained in the electrical room. Then, determine required airflow for ventilation or tempering of space.
2. Generally, electrical equipment rooms only require ventilation to keep equipment from overheating. Most electrical rooms are designed for 95°F to 104°F; however, consult the electrical engineer for equipment temperature

tolerances. If space temperatures 90°F and below are required by equipment, air conditioning (tempering) of the space will be required.

3. If outside air is used to ventilate the electrical room, the electrical room design temperature will be 10°F to 15°F above outside summer design temperatures.
4. If conditioned air from an adjacent space is used to ventilate the electrical room, the electrical room temperature can be 10°F to 20°F above the adjacent spaces.

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8.11. Mechanical Rooms

A. Recommended Minimum Ventilation Rate

1. 2.0 CFM/sq.ft.
2. 10.0 AC/h

B. Mechanical Equipment Room Design Guidelines

1. Determine heat gain from motors, pumps, fans, transformers, panelboards, and other mechanical and electrical equipment contained in the mechanical room. Then, determine the required airflow for the ventilation or tempering of space.
2. Generally, mechanical equipment rooms only require ventilation. Most mechanical rooms are designed for 95°F to 104°F; however, verify mechanical equipment temperature tolerances. If space temperatures below 90°F are required by mechanical equipment, air conditioning (tempering) of the space will be required.
3. A number of products (DDC control panels, variable frequency drives, other electronic components) will perform better if the mechanical room is tempered in lieu of just ventilating the room.
4. If outside air is used to ventilate the mechanical room, the mechanical room design temperature will be 10°F to 15°F above outside summer design temperatures.
5. If conditioned air from an adjacent space is used to ventilate the mechanical room, the mechanical room temperature can be 10°F to 20°F above the adjacent spaces.

C. Boiler Rooms—Cleaver Brooks 10 CFM/BHP

1. 8 CFM/BHP combustion air.
2. 2 CFM/BHP ventilation.
3. 1 BHP = 33,500 Btuh.

D. Chiller Rooms—ASHRAE Standard 15-2013 and ASHRAE Standard 34-2013

1. See *ASHRAE Standard 15-2013* and *ASHRAE Standard 34-2013* for complete refrigeration system requirements.
2. Scope:
 - a. To establish safeguards for life, limb, health, and property.
 - b. To define practices that are consistent with safety.
 - c. To prescribe safety standards.
3. Application: The standard applies to all mechanical and absorption refrigerating systems and heat pumps used in institutional, public assembly, residential, commercial, large mercantile, industrial, and mixed-use occupancies; to parts and components added after adoption of this code; and to substitutions of refrigerant having a different designation.
4. Refrigerant classification is shown in the following table:

Safety Group

Higher Flammability	A3	B3
Lower Flammability	A2	B2 Ammonia
No Flame Propagation	A1 R-11, R-12, R-22, R-134a, R-410a	B1 R-123
	Lower toxicity	Higher toxicity

5. Requirements for refrigerant use:
 - a. Requirements for refrigerant use are based on the probability that the refrigerant will enter an occupied space and on the type of occupancy (institutional, public assembly, residential, commercial, large mercantile, industrial, and mixed-use).

- b. The total amount of refrigerant permitted to be installed in a system is determined by the type of occupancy, the refrigerant group, and the probability that refrigerant will enter the occupied space.
 - c. Refrigerant piping shall not be installed in an enclosed stairways, stair landings, or means of egress.
 - d. Refrigeration system components shall not interfere with free passage through public hallways, and limitations regarding size are based on refrigerant type.
6. Service provisions:
- a. All serviceable components of refrigerating systems shall be safely accessible.
 - b. Properly located stop valves, liquid and vapor transfer valves, refrigerant storage tanks, and adequate venting are required when needed for safe servicing of equipment.
 - c. Refrigerant systems with more than 6.6 lbs. of refrigerant require stop valves at:
 - 1. The suction inlet of each compressor, compressor unit, or condensing unit.
 - 2. The discharge outlet of each compressor, compressor unit, or condensing unit.
 - 3. The outlet of each liquid receiver.
 - d. Refrigerant systems with more than 110 lbs. of refrigerant require stop valves at:
 - 1. The suction inlet of each compressor, compressor unit, or condensing unit.
 - 2. The discharge outlet of each compressor, compressor unit, or condensing unit.
 - 3. The inlet of each liquid receiver, except for self-contained systems or where the receiver is an integral part of the condenser or condensing unit.
 - 4. The outlet of each liquid receiver.
 - 5. The inlet and outlet of condensers when more than one condenser is

used in parallel.

e. Stop valves shall be suitably labeled.

7. Installation requirements:

a. Air ducts passing through machinery rooms shall be of tight construction and shall have no openings in such rooms. Access doors and panels in ductwork and air handling units shall be gasketed and tight fitting.

b. Refrigerant piping crossing an open space that affords passageway in any building shall not be less than 7'-3" above the floor.

c. Passages shall not be obstructed by refrigerant piping.

d. Refrigerant piping shall not be placed in, or pass through, any elevator, dumbwaiter, or other shaft containing moving objects or in any shaft that has openings to living quarters or main exits.

e. Refrigerant piping shall not be installed vertically through floors from one story to another except as follows:

1. Basement to first floor, top floor to mechanical equipment penthouse or roof.

2. Adjacent floors served by the refrigerating system.

3. Where the refrigerant concentration does not exceed that listed in Table 4-1 or Table 4-2 of ASHRAE Standard 34 for the smallest occupied space through which the refrigerant piping passes.

4. For the purpose of interconnecting separate pieces of equipment in other than industrial occupancies and where the refrigerant concentration exceeds that listed in Table 4-1 or Table 4-2 of ASHRAE Standard 34 for the smallest occupied space. The piping may be carried in an approved, rigid and tight, continuous fire-resistive pipe, duct, or shaft having no openings into floors not served by the refrigerating system or carried exposed on the outer wall of the building. Or the piping may be located on the exterior wall of a building when vented to the outdoors or to the space served by the system and not used as an air shaft, closed court, or similar space.

8. Refrigeration equipment room requirements:

a. Provide proper space for service, maintenance, and operation.

- b. Minimum clear headroom shall be 7'-3".
- c. Doors shall be outward opening, self-closing, fire-rated, tight fitting, and adequate in number to ensure freedom for persons to escape in an emergency. No other openings shall be permitted in equipment rooms that will permit passage of refrigerant to other parts of the building.
- d. Refrigeration equipment rooms require a refrigerant detector located in the equipment room in an area where refrigerant from a leak will concentrate, set to alarm and start the ventilation system when the level reaches the refrigerant's toxicity level. The alarm shall annunciate visual and audible alarms inside the refrigerating machinery room and outside each entrance to the refrigerating machinery room. The alarm shall be of the manual reset type with the reset located inside the refrigeration equipment room.
- e. Periodic test of alarm and sensors are required.
- f. Mechanical rooms shall be vented to the outdoors.
- g. Mechanical ventilation shall be capable of exhausting the air quantity determined by the formula in Section 8.11.5. The exhaust quantity depends on the amount of refrigerant contained in the system. To obtain a reduced airflow for normal ventilation, multiple fans, multispeed fans, or fans with variable frequency drives may be used. Provision shall be made for inlet air to replace that being exhausted. Openings for inlet air shall be positioned to avoid recirculation.
- h. Minimum ventilation rate shall be 0.5 CFM per square foot of machine room area or 20 CFM per person.
- i. No open flames that use combustion air from the machinery room shall be installed where any refrigerant other than carbon dioxide (R-744), water (R-718), or ammonia (R-717) is used. A sealed air duct may be used to supply combustion air to fuel-burning appliances in the machinery room, or a refrigerant detector may be used to automatically shut down the combustion process in the event of refrigerant leakage.
- j. There shall be no flame-producing device or continuously operating hot surface over 800°F permanently installed in the room.

- k. Walls, floors, and ceilings shall be tight and of non-combustible construction with a minimum 1-hour fire resistance rating.
- l. The machinery room shall have a door that opens directly to the outside or through a vestibule equipped with self-closing, tight-fitting doors.
- m. All machinery room wall, floor, and ceiling penetrations shall be sealed.
- n. Where Groups A2, A3, B2, and B3 refrigerants are used, the machinery room shall conform to Class I, Division 2 of the National Electric Code. Groups A1 and B1 are exempt from this requirement.
- o. Emergency shutdown of the refrigeration equipment shall be provided immediately outside the machinery room door.
- p. Ventilation fans shall be on a separate electrical circuit and shall have a control switch located immediately outside the machinery room door so they can be activated in an emergency.
- q. Refrigeration compressors, piping, equipment, valves, switches, ventilation equipment, and associated appurtenances shall be labeled in accordance with *ANSI/ASME A13.1*.

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8.12. Combustion Air

A. 2015 IMC

- 1. Oil-fired appliances shall be provided with combustion air in accordance with NFPA 31.
- 2. The requirements for combustion and dilution air for gas-fired appliances shall be in accordance with the *International Fuel Gas Code*.

B. NFPA 54—2015 National Fuel Gas -Code

- 1. Inside air:
 - a. Minimum required space volume: 50 ft.³ per 1,000 Btu/h of the combined fuel-burning appliance input capacity.
 - b. Number of openings: Two openings are required—one within 1 foot of the ceiling of the room, and one within 1 foot of the floor.

- c. Opening size on the same story: The net free area of each opening shall be equal to 1.0 square inch for each 1,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room), 100 square inches minimum. The minimum dimension of air openings shall not be less than 3 inches.
- d. Opening size on the different stories: The net free area of each opening shall be equal to 2.0 square inches for each 1,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

2. Outdoor air:

a. Two permanent opening methods:

- 1. Number of openings: Two openings are required—one within 1 foot of the ceiling of the room and one within 1 foot of the floor.
- 2. Direct opening size: The net free area of each opening shall be equal to 1.0 square inch for each 4,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
- 3. Horizontal duct opening size: The net free area of each opening shall be equal to 1.0 square inch for each 2,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
- 4. Vertical opening size: The net free area of each opening shall be equal to 1.0 square inch for each 4,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).

b. One permanent opening method:

- 1. Number of openings: One opening is required—one within 1 foot of the ceiling.
- 2. The appliance will have at least 1 inch clearance on the sides and back of the appliance, and 6 inches in front of the appliance.
- 3. The opening shall directly communicate with the outdoors or shall communicate through vertical or horizontal ducts to the outdoors.
- 4. Opening size: The net free area of each opening shall be equal to 1.0 square inch for each 3,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room). Not

less than the sum of the areas of all vent connectors in the space.

3. Combination indoor and outdoor combustion air:
 - a. Indoor openings shall comply with the indoor air requirements listed above.
 - b. Outdoor openings shall comply with the outdoor air requirements listed above.
 - c. The outdoor opening shall be sized to compensate for the deficiency in available volume of all communicating interior spaces. The minimum size of outdoor opening(s) shall be the full size of the outdoor opening(s) calculated in accordance with the requirements listed above, multiplied by 1 minus the ratio of available interior volume divided by the required interior volume.
4. Forced combustion air supply:
 - a. Where combustion air is provided by mechanical means, the system shall deliver a minimum of 0.35 CFM per 1,000 Btu/h of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
 - b. Appliances shall be interlocked with a makeup air unit to prevent operation if the makeup air unit is not operating.
5. Direct vent appliances:
 - a. Appliances must be listed and labeled for a direct combustion air connection.
 - b. Appliances must be installed in accordance with the manufacturers' installation instructions.
6. Combustion air ducts:
 - a. Galvanized steel construction.
 - b. Unobstructed termination.
 - c. Same cross-sectional area as the free area of the openings.
 - d. Serves a single appliance enclosure.
 - e. Separate ducts must be provided for the upper and lower combustion air openings. The separation between these ducts shall be maintained from source to discharge.

- f. Ducts that serve the upper combustion air opening cannot slope downward toward the source of the combustion air.
 - g. The bottom of the combustion air opening shall be a minimum of 12 inches above grade.
 - h. Ducts shall not be screened where terminating in an attic space.
 - i. The remaining space within a chimney surrounding a chimney liner, gas vent, special gas vent, or plastic piping shall not be used to supply combustion air.
7. Opening protection:
- a. Metal louver: Maximum 75 percent free area.
 - b. Wood louvers: Maximum 25 percent free area.
 - c. Dampers (fire, smoke, control): Dampers shall be interlocked to operate with the appliance. Manually operated dampers are not permitted.

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8.13. Hazardous Locations

A. Hazardous location requirements for electrical and electronic equipment are defined in the *2014 National Electrical Code (NEC NFPA 70)*, Articles 500 through 510.

B. Hazardous Classifications

- 1. Class I: Class I locations are those spaces where flammable gases or vapors are, or where they may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.
 - a. Class I locations are subdivided into four groups based on the type of flammable gases or vapors:
 - 1. Group A: Acetylene.
 - 2. Group B: Flammable gas (hydrogen, ethylene oxide, propylene oxide); flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value less than or equal to 0.45 mm or a minimum igniting current ratio (MIC ratio) less than or equal to 0.40.

3. Group C: Flammable gas (Ethyl Ether, Ethylene); flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value greater than 0.45 mm and less than or equal to 0.75 mm, or a minimum igniting current ratio (MIC ratio) greater than 0.40 and less than or equal to 0.80.
 4. Group D: Flammable gas (Acetone, Ammonia, Butane, Gasoline, Propane); flammable liquid-produced vapor, or combustible liquid-produced vapor mixed with air that may burn or explode, having either a maximum experimental safe gap (MESG) value greater than 0.75 mm or a minimum igniting current ratio (MIC ratio) greater than 0.80.
- b. Class I locations are also subdivided into two divisions:
1. Class I, Division 1:
 - a. Locations where ignitable concentrations of flammable gases or vapors can exist under normal operating conditions; or
 - b. Locations where ignitable concentrations of flammable gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or
 - c. Locations where breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might cause the simultaneous failure of electric equipment.
 2. Class I, Division 2:
 - a. Locations where volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems where they can escape only in case of an accidental rupture or breakdown of such containers or systems, or in the case of abnormal operation or equipment; or
 - b. Locations where ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and have the potential to become hazardous through failure or abnormal operation of the ventilating equipment; or
 - c. Locations that are adjacent to Class I, Division 1 locations, and to which ignitable concentrations of gases or vapors might occasionally

be communicated unless such communication is prevented by adequate positive pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

2. Class II: Class II locations are spaces or areas that contain combustible dusts.
 - a. Class II locations are subdivided into three groups based on the type of combustible dusts:
 1. Group E: Atmospheres containing combustible metal dusts, including aluminum, magnesium, and their commercial alloys, or other combustible dusts whose particle size, abrasiveness, and conductivity present similar hazards in the use of electrical equipment.
 2. Group F: Atmospheres containing combustible carbonaceous dusts that have more than 8 percent total entrapped volatiles or have been sensitized by other materials so that they present an explosion hazard (coal, carbon black, charcoal, and coke dust).
 3. Group G: Atmospheres containing combustible dusts not included in Group E or F, such as flour, grain, wood, plastic, and chemicals.
 - b. Class II, Division 1:
 1. Locations in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures; or
 2. Locations where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through the simultaneous failure of electrical equipment, through the operation of protection devices, or from other causes; or
 3. Locations in which Group E combustible dusts may be present in quantities sufficient to be hazardous.
 - c. Class II, Division 2:
 1. Locations in which combustible dust due to abnormal operations may be present in the air in quantities sufficient to produce explosive or ignitable mixtures; or
 2. Locations where combustible dust accumulations are present but are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus, but could as a result of infrequent

malfunctioning of handling or processing equipment become suspended in the air; or

3. Locations in which combustible dust accumulations on, in, or in the vicinity of the electrical equipment could be sufficient to interfere with the safe dissipation of heat from electrical equipment, or could be ignitable by abnormal operation or the failure of electrical equipment.

3. Class III: Class II locations are spaces or areas that contain easily ignitable fibers or flyings, but where such fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.
 - a. Class III, Division 1: Locations in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.
 - b. Class III, Division 2: Locations in which easily ignitable fibers are stored or handled other than in the process of manufacturing.

C. Hazardous Location Protection Techniques

1. Purged and pressurized systems: Spaces and equipment are pressurized at pressures above the external atmosphere with noncontaminated air or other nonflammable gas to prevent explosive gases or vapors from entering the enclosure.
2. Intrinsically safe systems: Electrical circuits are designed so that they do not release sufficient energy to ignite an explosive atmosphere.
3. Explosion-proof equipment: Explosion-proof equipment is designed and built to withstand an internal explosion without igniting the surrounding atmosphere.
4. Nonincendive circuits, components, and equipment: Circuits designed to prevent any arc or thermal effect produced, under intended operating conditions of the equipment or produced by opening, shorting, or grounding of the field wiring, is not capable, under specified test conditions, of igniting the flammable gas, vapor, or dust-air mixtures.
5. Oil immersed equipment: The arcing portions of the equipment are immersed in an oil at a depth that the arc will not set off any hazardous gases or vapors above the surface of the oil.
6. Hermetically sealed equipment: The equipment is sealed against the external atmosphere to prevent the entry of hazardous gases or vapors.

7. Dust-ignition-proof equipment: Dust-ignition-proof equipment is designed and built to exclude dusts and, where installed and protected, will not permit arcs, sparks, or heat generated or liberated inside the enclosure to cause ignition of the exterior accumulations or atmospheric suspensions of a specified dust on or in the enclosure.
8. Dust-tight equipment: Dust-tight equipment is designed to prevent the entrance of dust into equipment.
9. Combustible gas detection system: Gas detection equipment shall be listed for detection of the specific gas or vapor to be encountered.
10. Classification versus Protection Techniques is shown in the following table:

Protection Techniques	Class I		Class II		Class III	
	Div 1	Div 2	Div 1	Div 2	Div 1	Div 2
Purged and Pressurized	X	X	X	X	X	X
Intrinsically Safe Systems	X	X	X	X	X	X
Explosion-Proof Equipment	X	X	N/A	N/A	N/A	N/A
Nonincendive Circuits, Components, and Equipment	N/A	X	N/A	X	X	X
Hermetically Sealed Equipment	N/A	X	N/A	X	X	X
Oil Immersed Equipment	N/A	X	N/A	N/A	N/A	N/A
Dust-Ignitionproof Equipment	N/A	N/A	X	X	N/A	N/A
Dusttight Equipment	N/A	N/A	N/A	X	X	X
Combustible Gas Detection Systems	X	X	N/A	N/A	N/A	N/A

Notes:

X = Appropriate to the classification.

N/A = Not acceptable to the classification.

D. **Ventilation Requirements**

1. Ventilation, natural or mechanical, must be sufficient to limit the concentrations of flammable gases or vapors to a maximum level of 25 percent of their Lower Flammable Limit/Lower Explosive Limit (LFL/LEL).
2. Minimum ventilation required: 1.0 CFM/sq.ft. of floor area or 6.0 air changes per hour, whichever is greater. If a reduction in the classification is desired, the airflow must be four times the airflow just specified.
3. Recommendation: Ventilate all hazardous locations with 2.0 CFM/sq.ft. of floor area or 12 air changes per hour minimum with half the airflow supplied and exhausted high (within 6 inches of the ceiling or structure) and half the airflow supplied and exhausted low (within 6 inches of the floor).
4. A ventilation rate that is a minimum of four times the ventilation rate required to prevent the space from exceeding the maximum level of 25 percent LFL/LEL using fugitive emissions calculations.
5. Ventilate the space so accumulation pockets for lighter-than-air or heavier-than-air gases or vapors are eliminated.
6. Monitoring of the space is recommended to ensure that the 25 percent LFL/LEL is not exceeded.

E. **Hazardous Location Definitions**

1. *Boiling Point.* The temperature at which the vapor pressure of a liquid equals the atmospheric pressure of 14.7 pounds per square inch absolute.
2. *Combustible Liquids.* Liquids having flash points at or above 100°F. Combustible liquids shall be subdivided as Class II or Class III liquids as follows:
 - a. Class II. Liquids having flash points at or above 100°F and below 140°F.
 - b. Class IIIA. Liquids having flash points at or above 140°F and below 200°F.
 - c. Class IIIB. Liquids having flash points at or above 200°F.
3. *Explosion.* An effect produced by the sudden violent expansion of gases, which can be accompanied by a shockwave or disruption, or both, of enclosing materials or structures. An explosion might result from chemical changes such as rapid oxidation, deflagration, or detonation; decomposition of molecules, and runaway polymerization; or physical changes such as pressure tank ruptures.

4. *Explosive*. Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion.
5. *Flammable*. Any material capable of being ignited from common sources of heat or at a temperature of 600°F or less.
6. *Flammable Compressed Gas*. An air/gas mixture that is flammable when the gas is 13 percent or less by volume or when the flammable range of the gas is wider than 12 percent regardless of the lower limitation determined at atmospheric temperature and pressures.
7. *Flammable Liquids*. Liquids having flash points below 100°F and having vapor pressures not exceeding 40 pounds per square inch absolute at 100°F. Flammable liquids shall be subdivided as Classes IA, IB, and IC as follows:
 - a. Class IA. Liquids having flash points below 73°F and having boiling points below 100°F.
 - b. Class IB. Liquids having flash points below 73°F and having boiling points above 100°F.
 - c. Class IC. Liquids having flash points at or above 73°F and below 100°F.
8. *Flammable Solids*. A solid, other than a blasting agent or explosive, that is capable of causing a fire through friction, absorption of moisture, spontaneous chemical change, or retaining heat from manufacturing or processing, or which has an ignition temperature below 212°F, or which burns so vigorously and persistently when ignited as to create a serious hazard.
9. *Flash Point*. The minimum temperature in °F at which a flammable liquid will give off sufficient vapors to form an ignitable mixture with air near the surface or in the container, but will not sustain combustion.
10. *Noncombustible*. A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subject to fire or heat.
11. *Pyrophoric*. A material that will spontaneously ignite in air at or below 130°F.

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Part 9: Humidification Rules of Thumb

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9. Part 9: Humidification Rules of Thumb

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9.01. Window Types and Space Humidity Values

A. Single Pane Windows	±10 percent RH Maximum
B. Double Pane Windows	±30 percent RH Maximum
C. Triple Pane Windows	±40 percent RH Maximum

D. The preceding numbers are based on the following:

1. 0°F, outside design temperature.
2. 72°F, inside design temperature.
3. $R_{\text{INSIDE AIR FILM}} = 0.680$ $U_{\text{INSIDE AIR FILM}} = 1.471$
4. $R_{\text{SINGLE GLASS}} = 0.909$ $U_{\text{SINGLE GLASS}} = 1.100$
5. $R_{\text{DOUBLE GLASS}} = 1.667$ $U_{\text{DOUBLE GLASS}} = 0.600$
6. $R_{\text{TRIPLE GLASS}} = 2.000$ $U_{\text{TRIPLE GLASS}} = 0.500$
7. Standard air at sea level.
8. The relative humidity numbers presented earlier in this list are rounded for ease of remembrance.
9. The glass R-values and U-values are for average glass construction. Modern glass construction can achieve higher R-values/lower U-values.

10. For additional information on moisture condensation on glass, see the tables at the end of this chapter.

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9.02. Proper Vapor Barriers

- A. **Proper vapor barriers and moisture control must be provided to prevent moisture condensation in walls and to prevent mold, fungi, bacteria, and other plant and micro-organism growth.**

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9.03. Human Comfort

- A. **30-60 percent RH**

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9.04. Electrical Equipment, Computers

- A. **35-55 percent RH**

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9.05. Winter Design Relative Humidities

- A. **Outdoor Air Below 32°F**

1. 70-80 percent RH
2. Design Wet Bulb Temperatures 2 to 4°F below Design Dry Bulb Temperatures

- B. **Outdoor Air 32-60°F: 50 percent RH**

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9.06. Optimum Relative Humidity Ranges for Health

**Optimum Relative Humidity
Range
for Controlling Health Aspect**

Health Aspect	Optimum Relative Humidity Range for Controlling Health Aspect
Bacteria	20-70%
Viruses	40-78%
Fungi	0-70%
Mites	0-60%
Respiratory Infections (1)	40-50%
Allergic Rhinitis and Asthma	40-60%
Chemical Interactions	0-40%
Ozone Production	75-100%
Combined Health Aspects	40-60%
Note: (1) Insufficient data above 50 percent RH.	

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9.07. Moisture Condensation on Glass

The subsequent moisture condensation tables are based on the following:

1. $R_{\text{INSIDE AIR FILM}} = 0.680$	$U_{\text{INSIDE AIR FILM}} = 1.471$
2. $R_{\text{SINGLE GLASS}} = 0.909$	$U_{\text{SINGLE GLASS}} = 1.100$
3. $R_{\text{DOUBLE GLASS}} = 1.818$	$U_{\text{DOUBLE GLASS}} = 0.550$
4. $R_{\text{TRIPLE GLASS}} = 2.500$	$U_{\text{TRIPLE GLASS}} = 0.400$
5. Standard air at sea level.	

The glass surface temperatures, which are also the space dewpoint temperatures, listed in the moisture condensation tables that follow, were developed using the equations in Part 3.

**Single Pane
Glass**

**Double Pane
Glass**

**Triple Pane
Glass**

Temp. Room Temp. °F	Temp. Outside Temp. °F	Single Pane		Double Pane		Triple Pane	
		T _{GLASS}	% R.H.	T _{GLASS}	% R.H.	T _{GLASS}	% R.H.
		T _{DEWPOINT}		T _{DEWPOINT}		T _{DEWPOINT}	
65	-30	6.1	4.5	29.5	25.9	39.2	38.5
	-25	-2.3	5.6	31.3	27.9	40.5	40.5
	-20	1.4	6.9	33.2	30.2	41.9	42.8
	-15	5.2	8.4	35.1	32.6	43.2	45.0
	-10	8.9	10.1	36.9	35.1	44.6	47.5
	-5	12.6	12.1	38.8	37.9	46.0	50.1
	0	16.4	14.5	40.7	40.8	47.3	52.7
	5	20.1	17.2	42.6	44.0	48.7	55.5
	10	23.9	20.3	44.4	47.1	50.0	58.3
	15	27.6	23.9	46.3	50.7	51.4	61.4
	20	31.3	27.9	48.2	54.5	52.8	64.7
	25	35.1	32.6	50.0	58.3	54.1	67.9
	30	38.8	37.9	51.9	62.6	55.5	71.4
	35	42.6	44.0	53.8	67.1	56.8	74.9
	40	46.3	50.7	55.6	71.7	58.2	78.3
66	-30	-5.8	4.4	30.1	25.6	39.9	38.2
	-25	-2.1	5.5	32.0	27.7	41.2	40.2
	-20	1.7	6.7	33.8	29.9	42.6	42.5
	-15	5.4	8.2	35.7	32.3	44.0	44.8
	-10	9.1	9.9	37.6	34.9	45.3	47.1
	-5	12.9	11.8	39.4	37.4	46.7	49.7
	0	16.6	14.1	41.3	40.4	48.0	52.2
	5	20.4	16.8	43.2	43.5	49.4	55.1
	10	24.1	19.8	45.1	46.8	50.8	58.0
	15	27.8	23.3	46.9	50.1	52.1	60.9
	20	31.6	27.3	48.8	53.8	53.5	64.1
	25	35.3	31.8	50.7	57.8	54.8	67.2
	30	39.1	37.0	52.5	61.8	56.2	70.8
	35	42.8	42.8	54.4	66.3	57.6	74.4
	40	46.6	49.5	56.3	71.0	58.9	78.0
67	-30	-5.6	4.3	30.7	25.4	40.6	37.9
	-25	-1.8	5.4	32.6	27.5	42.0	40.1
	-20	1.9	6.6	34.5	29.7	43.3	42.2

	-15 -10	5.7 9.4	8.0 9.7	36.3 38.2	32.0 34.5	44.7 46.1	44.5 46.9
		Single Pane Glass		Double Pane Glass		Triple Pane Glass	
Temp. Room °F	Temp. Outside °F	T 13.1 16.9 20.6	R.H. 11.6 13.8 16.4	T 40.1 41.9 43.8	R.H. 37.2 39.9 43.0	T 47.4 48.8 50.1	R.H. 49.3 52.0 54.6
	15	28.1	22.7	47.6	49.7	52.9	60.6
	20	31.8	26.6	49.4	53.2	54.2	63.5
	25	35.6	31.1	51.3	57.1	55.6	66.9
	30	39.3	36.0	53.2	61.3	56.9	70.1
	35	43.1	41.8	55.0	65.4	58.3	73.7
	40	46.8	48.2	56.9	70.1	59.7	77.5
68	-30	-5.3	4.3	31.3	25.1	41.3	37.7
	-25	-1.6	5.3	33.2	27.2	42.7	39.8
	-20	2.2	6.5	35.1	29.4	44.1	42.0
	-15	5.9	7.8	37.0	31.8	45.4	44.2
	-10	9.7	9.5	38.8	34.1	46.8	46.6
	-5	13.4	11.3	40.7	36.8	48.1	48.9
	0	17.1	13.5	42.6	39.6	49.5	51.6
	5	20.9	16.0	44.4	42.5	50.9	54.4
	10	24.6	18.9	46.3	45.7	52.2	57.0
	15	28.4	22.2	48.2	49.1	53.6	60.1
	20	32.1	26.0	50.0	52.6	54.9	63.0
	25	35.8	30.3	51.9	56.4	56.3	66.3
	30	39.6	35.2	53.8	60.5	57.7	69.7
	35	43.3	40.7	55.7	64.8	59.0	73.0
	40	47.1	47.1	57.5	69.2	60.4	76.7
69	-30	-5.1	4.2	32.0	25.0	42.1	37.6
	-25	-1.3	5.2	33.8	26.9	43.4	39.5
	-20	2.4	6.3	35.7	29.1	44.8	41.7
	-15	6.2	7.7	37.6	31.4	46.2	44.0
	-10	9.9	9.2	39.5	33.9	47.5	46.2
	-5	13.6	11.1	41.3	36.4	48.9	48.7
	0	17.4	13.2	43.2	39.2	50.2	51.2
	5	21.1	15.6	45.1	42.2	51.6	53.9
	10	24.9	18.5	46.9	45.2	53.0	56.8
	15	28.6	21.5	48.6	48.0	54.2	59.5

	15	28.6	21.7	48.8	48.6	54.3	59.5
		Single Pane		Double Pane		Triple Pane	
Temp. Room °F	20	32.3 Glass	25.3	50.7 Glass	52.1	55.7 Glass	62.7
	25	36.1	29.6	52.5	55.7	57.0	65.7
	30	39.8 /	34.3	54.4 /	59.8	58.4 /	69.1
	35	43.6	39.8	56.3	64.0	59.8	72.6
	40	47.3	45.9	58.2	68.6	61.1	76.0
70	-30	-4.8	4.1	32.6	24.8	42.8	37.3
	-25	-1.1	5.0	34.5	26.8	44.2	39.4
	-20	2.7	6.2	36.3	28.8	45.5	41.4
	-15	6.4	7.5	38.2	31.1	46.9	43.7
	-10	10.2	9.1	40.1	33.6	48.2	45.9
	-5	13.9	10.8	41.9	36.0	49.6	48.3
	0	17.6	12.9	43.8	38.8	51.0	51.0
	5	21.4	15.3	45.7	41.7	52.3	53.5
	10	25.1	18.0	47.6	44.8	53.7	56.3
	15	28.9	21.2	49.4	48.0	55.0	59.0
	20	32.6	24.8	51.3	51.5	56.4	62.1
	25	36.3	28.8	53.2	55.3	57.8	65.3
	30	40.1	33.6	55.0	59.0	59.1	68.4
	35	43.8	38.8	56.9	63.2	60.5	71.9
	40	47.6	44.8	58.8	67.7	61.8	75.3
71	-30	-4.6	4.0	33.2	23.6	43.5	37.0
	-25	-0.8	5.0	35.1	26.5	44.9	39.1
	-20	2.9	6.0	37.0	28.7	46.2	41.1
	-15	6.7	7.4	38.8	30.8	47.6	43.3
	-10	10.4	8.8	40.7	33.2	49.0	45.7
	-5	14.1	10.6	42.6	35.8	50.3	48.0
	0	17.9	12.6	44.4	38.4	51.7	50.5
	5	21.6	14.9	46.3	41.3	53.0	53.0
	10	25.4	17.6	48.2	44.3	54.4	55.8
	15	29.1	20.7	50.1	47.6	55.8	58.7
	20	32.8	24.1	51.9	50.9	57.1	61.6
	25	36.6	28.2	53.8	54.6	58.5	64.7
	30	40.3	32.7	55.7	58.5	59.8	67.8
	35	44.1	37.9	57.5	62.5	61.2	71.3
	40	47.8	43.7	59.4	66.9	62.6	74.9

72	-30	-4.3	4.0	33.8	24.3	44.3	36.9			
	-25	-0.6	4.8	35.7	26.3	45.6	38.8			
	-20	3.2	5.9	37.6	28.4	47.0	41.0			
	-15	6.9	7.2	39.5	30.6	48.3	43.0			
	-10	10.7	8.7	41.3	32.9	49.7	45.3			
Temp. Room °F	Temp. Outside °F	Single Pane Glass		Double Pane Glass		Triple Pane Glass				
		T	/	% R.H.	T	/	% R.H.	T	/	% R.H.
		14.4		10.4	43.2	35.4	51.1	47.8		
		18.1		12.3	45.1	38.1	52.4	50.1		
		21.9		14.6	46.9	40.8	53.8	52.8		
		25.6		17.2	48.8	43.8	55.1	55.3		
29.4		20.5	50.7	47.1	56.5	58.2				
	20	33.1	23.6	52.6	50.5	57.9	61.2			
	25	36.8	27.5	54.4	54.0	59.2	64.2			
	30	40.6	32.0	56.3	57.8	60.6	67.4			
	35	44.3	36.9	58.2	61.9	61.9	70.6			
	40	48.1	42.7	60.0	66.0	63.3	74.2			
73	-30	-4.1	3.8	34.5	24.2	45.0	36.7			
	-25	-0.3	4.8	36.3	26.0	46.3	38.6			
	-20	3.4	5.8	38.2	28.1	47.7	40.7			
	-15	7.2	7.1	40.1	30.3	49.1	42.9			
	-10	10.9	8.5	42.0	32.7	50.4	45.0			
	-5	14.7	10.2	43.8	35.0	51.8	47.4			
	0	18.4	12.1	45.7	37.7	53.1	49.7			
	5	22.1	14.3	47.6	40.5	54.5	52.4			
	10	25.9	16.9	49.4	43.3	55.9	55.1			
	15	29.6	19.7	51.3	46.5	57.2	57.4			
	20	33.4	23.1	53.2	49.9	58.6	60.7			
	25	37.1	26.9	55.0	53.3	59.9	63.6			
	30	40.8	31.2	56.9	57.1	61.3	66.8			
	35	44.6	36.1	58.8	61.2	62.7	70.2			
	40	48.3	41.6	60.7	65.4	64.0	73.5			
74	-30	-3.8	3.8	35.1	24.0	45.7	36.4			
	-25	-0.1	4.7	37.0	25.9	47.1	38.4			
	-20	3.7	5.7	38.8	27.8	48.4	40.4			
	-15	7.4	6.9	40.7	30.0	49.8	42.5			
	-10	11.2	8.3	42.6	32.3	51.2	44.8			
	-5	14.9	9.9	44.5	34.8	52.5	47.0			
	0	18.6	11.8	46.3	37.3	53.9	49.5			

Temp. Room °F	Temp. Outside °F	Single Pane Glass	Double Pane Glass	Triple Pane Glass			
		T / % R.H.	T / % R.H.	T / % R.H.			
5	22.4	14.0	48.2	40.1			
10	26.1	16.4	50.1	43.0			
15	29.9	19.3	51.9	46.0			
20	33.6	22.6	53.8	49.3			
25	37.3	26.2	55.7	52.9			
30	41.1	30.5	57.5	56.4			
35	44.8	35.2	59.4	60.4			
40	48.6	40.7	61.3	64.6			
75	-30	-3.5	3.7	35.7	23.8	46.4	36.2
	-25	0.2	4.6	37.6	25.6	47.8	38.2
	-20	3.9	5.6	39.5	27.7	49.2	40.3
	-15	7.7	6.8	41.3	29.7	50.5	42.2
	-10	11.4	8.1	43.2	32.0	51.9	44.5
	-5	15.2	9.7	45.1	34.4	53.2	46.7
	0	18.9	11.6	46.9	36.9	54.6	49.1
	5	22.6	13.6	48.8	39.6	56.0	51.7
	10	26.4	16.1	50.7	42.6	57.3	54.2
	15	30.1	18.9	52.6	45.7	58.7	57.0
	20	33.9	22.1	54.4	48.8	60.0	59.7
	25	37.6	25.7	56.3	52.3	61.4	62.7
	30	41.3	29.7	58.2	56.0	62.8	65.9
	35	45.1	34.4	60.0	59.7	64.1	69.0
	40	48.8	39.6	61.9	63.8	65.5	72.4
76	-30	-3.3	3.6	36.4	23.6	47.2	36.1
	-25	0.4	4.5	38.2	25.4	48.5	37.9
	-20	4.2	5.5	40.1	27.4	49.9	39.9
	-15	7.9	6.6	42.0	29.5	51.2	41.9
	-10	11.7	8.0	43.8	31.7	52.6	44.2
	-5	15.4	9.5	45.7	34.1	54.0	46.5
	0	19.1	11.3	47.6	36.6	55.3	48.8
	5	22.9	13.4	49.4	39.2	56.7	51.3
	10	26.6	15.7	51.3	42.1	58.0	53.8
	15	30.4	18.5	53.2	45.1	59.4	56.5
	20	34.1	21.5	55.1	48.4	60.8	59.4
	25	37.8	25.0	56.9	51.7	62.1	62.2
	30	41.6	29.1	58.8	55.3	63.5	65.3

	35 40	45.3 49.1 Single Pane Glass	22.6 38.8	60.7 62.5 Double Pane Glass	59.2 63.1	64.9 66.2 Triple Pane Glass	68.3 71.7
Temp. Room °F	Temp. Outside °F	-3.0 0.7 4.4 8.2 11.9	/ 3.6 4.4 5.3 R.H.	37.0 38.8 40.7	/ 24.4 25.2 27.2 R.H.	47.9 49.3 50.6	/ 35.8 37.8 39.7 R.H.
	-5 0 5 10 15	15.7 19.4 23.1 26.9 30.6	9.3 11.1 13.0 15.4 18.0	46.3 48.2 50.1 51.9 53.8	33.7 36.3 38.9 41.6 44.6	54.7 56.1 57.4 58.8 60.1	46.1 48.6 50.9 53.5 56.0
	20 25 30 35 40	34.4 38.1 41.8 45.6 49.3	21.1 24.5 28.4 32.8 37.8	55.7 57.6 59.4 61.3 63.2	47.9 51.3 54.7 58.5 62.5	61.5 62.9 64.2 65.6 66.9	58.9 61.9 64.7 68.0 71.1
78	-30 -25 -20 -15 -10	-2.8 0.9 4.7 8.4 12.2	3.5 4.3 5.3 6.3 7.6	37.6 39.5 41.3 43.2 45.1	23.2 25.1 26.9 29.0 31.2	48.6 50.0 51.3 52.7 54.1	35.6 37.5 39.4 41.5 43.7
	-5 0 5 10 15	15.9 19.7 23.4 27.1 30.9	9.1 10.8 12.8 15.0 17.7	47.0 48.8 50.7 52.6 54.4	33.5 35.9 38.5 41.3 44.2	55.4 56.8 58.1 59.5 60.9	45.8 48.2 50.5 53.1 55.8
	20 25 30 35 40	34.6 38.4 42.1 45.8 49.6	20.6 24.0 27.8 32.0 37.0	56.3 58.2 60.0 61.9 63.8	47.3 50.7 54.0 57.8 61.8	62.2 63.6 64.9 66.3 67.7	58.4 61.3 64.2 67.4 70.7
79	-30 -25 -20 -15	-2.5 1.2 4.9 8.7	3.5 4.2 5.1 6.2	38.2 40.1 42.0 43.8	23.0 24.8 26.8 28.7	49.4 50.7 52.1 53.4	35.5 37.3 39.3 41.2

	-10	12.4 Single Pane	7.5	45.7 Double Pane	30.9	54.8 Triple Pane	43.4
Temp. Room °F	-5	16.2 Glass	8.9	47.6 Glass	33.2	56.2 Glass	45.6
	0	19.9	10.6	49.5	35.6	57.5	47.8
	5	23.6 /	12.5	51.3 /	38.1	58.9 /	50.3
	10	27.4	R4H.	53.2	R4H.	60.2	R4H.
	15	31.1	17.3	55.1	43.8	61.6	55.3
	20	34.9	20.2	56.9	46.8	63.0	58.1
	25	38.6	23.4	58.8	50.1	64.3	60.8
	30	42.3	27.1	60.7	53.6	65.7	63.9
	35	46.1	31.3	62.5	57.1	67.0	66.8
	40	49.8	36.0	64.4	61.0	68.4	70.1
80	-30	-2.3	3.4	38.9	22.9	50.1	35.3
	-25	1.5	4.2	40.7	24.6	51.4	37.0
	-20	5.2	5.0	42.6	26.5	52.8	39.0
	-15	8.9	6.1	44.5	28.5	54.2	41.0
	-10	12.7	7.3	46.3	30.6	55.5	43.0
	-5	16.4	8.7	48.2	32.8	56.9	45.3
	0	20.2	10.4	50.1	35.3	58.2	47.4
	5	23.9	12.2	51.9	37.7	59.6	49.9
	10	27.6	14.4	53.8	40.5	61.0	52.4
	15	31.4	16.9	55.7	43.4	62.3	54.9
	20	35.1	19.7	57.6	46.4	63.7	57.6
	25	38.9	22.9	59.4	49.5	65.0	60.3
	30	42.6	26.5	61.3	53.0	66.4	63.3
	35	46.3	30.6	63.2	56.6	67.8	66.4
	40	50.1	35.3	65.0	60.3	69.1	69.5

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Part 10: People/Occupancy Rules of Thumb

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10. Part 10: People/Occupancy Rules of Thumb

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10.1. 2015 IMC and ASHRAE Standard 62.1-2013

OCCUPANCY SCHEDULE

Max. Occupant Load

Occupancy Classification	People per 1,000 SF	SF/Person
Correctional Facilities		
Booking/waiting	50	20
Cell—with plumbing fixtures	25	40
Cell—without plumbing fixtures	25	40
Day room	30	33
Dining halls (see food and beverage service)		
Guard stations	15	67
Dry Cleaners, Laundries		
Coin-operated dry cleaner	20	50
Coin-operated laundries	20	50

Occupancy Classification	Max. Occupant Load People per 1,000 SF	SF/Person
Commercial dry cleaner	30	33
Commercial dry Storage, pick-up	10	100
Commercial dry Storage, pick-up	30	33
Education		
Art classroom	20	50
Auditoriums	150	6
Classrooms (ages 5 to 8)	25	40
Classrooms (ages 9 plus)	35	28
Computer lab	25	40
Corridors (see public spaces)	-	-
Daycare (through age 4)	25	40
Daycare sickroom	25	40
Lecture classroom	65	15
Lecture hall (fixed seats)	150	6
Locker/dressing rooms	-	-
Media center	25	40
Multiuse assembly	100	10
Music/theater/dance	35	28
Science laboratories	25	40
Smoking lounges	70	14
Sports locker rooms	-	-
University/college laboratories	25	40
Wood/metal shops	20	50
Food and Beverage Service		
Bars, cocktail lounges	100	10

	Max. Occupancy	Max. Occupant Load
Occupancy Classification	People per 1,000 SF	SF/Person
Cafeteria, fast food	100	10
Dining rooms	70	14
Kitchens (cooking)	20	-
Hospitals, Nursing and Convalescent Homes		
Autopsy rooms	-	-
Medical procedure rooms	20	50
Operating rooms	20	50
Patient rooms	10	100
Physical therapy	20	50
Recovery and ICU	10	100
Hotels, Motels, Resorts, and Dormitories		
Barracks sleeping areas	20	50
Bathrooms/toilet—private	-	-
Bedroom/living room	10	100
Laundry rooms, central	10	100
Laundry rooms, within dwelling units	10	100
Conference/meeting	-	-
Dormitory sleeping areas	-	-
Gambling casinos	-	-
Lobbies/prefunction	30	33
Multipurpose assembly	120	8
Miscellaneous Spaces		
Banks or bank lobbies	15	67
Freezer and refrigerated spaces (<50°F)	-	-

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
General manufacturing (excludes heavy industrial and processes using chemicals)	7	
Janitor closets, trash rooms, recycling	-	-
Kitchenettes	-	-
Shipping/receiving	2	500
Sorting, packing, light assembly	7	140
Transportation waiting	100	10
Offices		
Conference rooms	50	20
Main entry lobbies	10	100
Occupiable storage rooms for dry materials	2	500
Office spaces	5	200
Reception areas	30	33
Telephone/data entry	60	16
Private Dwellings, Single and Multiple		
Common corridors	-	-
Garages, common for multiple units	-	-
Garages, separate for each dwelling	-	-
Kitchens	-	-
Living areas	Based upon number of bedrooms. First bedroom, 2; each additional bedroom, 1	-
Toilet rooms and	-	-

bathrooms	Max. Occupant Load	
Public spaces		
Occupancy Classification	People per 1,000 SF	SF/Person
Breakrooms	25	40
Corridors	-	-
Courtrooms	70	14
Elevator car	-	-
Legislative chambers	50	20
Libraries	10	100
Lobbies	150	6
Museums (children's)	40	25
Museums/galleries	40	25
Occupiable storage rooms for liquids or gels	2	500
Places of religious worship	120	8
Shower room (per shower head)	-	-
Smoking lounges	70	14
Toilet rooms—public	-	-
Retail Stores, Sales Floors, and Showroom Floors		
Dressing rooms	-	-
Mall common areas	40	25
Sales (except as below)	15	66
Shipping and receiving	-	-
Smoking lounges	70	14
Storage rooms	-	-
Warehouses (see storage)	-	-
Specialty Shops		

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Automotive motor-fuel dispensing stations	-	-
Barbers	25	40
Beauty salons	25	40
Nail salons	25	40
Embalming rooms	-	-
Pet shops (animal areas)	10	100
Supermarkets	8	125
Sports and Amusement		
Bowling alleys (seating area)	40	25
Disco/dance floors	100	10
Game arcades	20	50
Gym, stadium (play area)	7	-
Health club/aerobics room	40	25
Health club/weight room	10	100
Ice arenas without combustion engines	-	-
Spectator areas	150	6
Swimming pools (pool and deck area)	-	-
Storage		
Repair garages, enclosed parking garages	-	-
Soiled laundry storage rooms	-	-
Storage rooms	-	-

Occupancy Classification	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Storage rooms, chemical		
Warehouses		
Theaters		
Auditoriums (see education)	-	-
Lobbies	150	6
Stages, studios	70	14
Ticket booths	60	16
Transportation		
Platforms	100	10
Transportation waiting	100	10
Workrooms		
Bank vaults/safe deposit	5	200
Computer (without printing)	4	250
Copy, printing rooms	4	250
Darkrooms	-	-
Meat processing	10	100
Pharmacy (prep. area)	10	100
Photo studios	10	100

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EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 10: People/Occupancy Rules of Thumb, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 11: Lighting Rules of Thumb

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11. Part 11: Lighting Rules of Thumb

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11.01. Code Lighting Power Level Requirements—Building Area Method

Building Area	Watts/Square Foot 2015 IECC and ASHRAE Std 90.1-2013
Auditorium	-
Automotive Facility	0.80
Bank/Financial Institution	-
Classroom/Lecture Hall	-
Convention Center	1.01
Corridor, Restroom, Support Area	-
Courthouse	1.01
Dining-Bar, Lounge Leisure	1.01
Dining-Cafeteria, Fast Food	0.90
Dining-Family	0.95
Dormitory	0.57
Exercise Center	0.84
Exhibition Hall	-

	Watts/Square Foot
Grocery Store	-
Fire Station	0.67
Building Area	2015 IECC and ASHRAE Std 90.1-2013
Gymnasium	0.94
Healthcare Clinic	0.90
Hospital	1.05
Hotel/Motel	0.87
Industrial Work, <20' Ceiling Height	-
Industrial Work, ≥20' Ceiling Height	-
Kitchen	-
Library	1.19
Lobby-Hotel	-
Lobby-Other	-
Mall, Arcade, or Atrium	-
Multifamily	0.51
Manufacturing Facility	1.17
Museum	1.02
Office	0.82
Parking Garage	0.21
Penitentiary	0.81
Police Station	0.87
Post Office	0.87
Religious Building	1.00
Restaurant	-
Retail	1.26
School/University	0.87
Sports Arena	0.91
Storage, Industrial and Commercial	-
Theater-Motion Picture	0.76

Theater-Performance	1.39	Watts/Square Foot
Town Hall	0.89	2015 IECC and ASHRAE Std 90.1-2013
Building Area		
Transportation	0.70	
Warehouse	0.66	
Workshop	1.19	
Other	-	

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11.02. Code Lighting Power Level Requirements—Space-by-Space Method

Watts/Square Foot

**2015 IECC and
ASHRAE Std 90.1-
2013**

Common Space Type

Atrium		
	That is 40 feet or less in height	0.03/ft. total height
	That is greater than 40 feet in height	0.04 + 0.02/ft. total height
Audience Seating Area		
	In a Gymnasium	0.65
	In an Auditorium	0.63
	In a Convention Center	0.82
	In a Penitentiary	0.28
	In Religious Buildings	1.53
	In a Sports Arena	0.43
	In a Performing Arts Theater	2.43
	In a Motion Picture Theater	1.14
Notes:	All Other Audience Seating	0.43

Areas		Watts/Square Foot
Automotive-Service Repair		0.67
Common Space Type		1.15
Classroom/Lecture/Training		2015 IECC and ASHRAE Std 90.1- 2013
	In a Penitentiary	1.34
	All Other Classroom/Lecture/Training	1.24
Computer Rooms		1.71
Conference/Meeting/Multipurpose		1.23
Confinement Cells		- ^a , 0.81 ^b
Convention Center-Exhibit Space		1.45
Copy/Print Rooms		0.72
Corridor		
	In a Facility for the Visually Impaired	0.92
	In a Hospital	0.79 ^a , 0.99 ^b
	In a Manufacturing Facility	0.41
	All Other Corridors	0.66
Courtroom		1.72
Dining Areas		
	In a Penitentiary	0.96
	In a Facility for the Visually Impaired	1.90 ^a , 2.65 ^b
	In a Bar/Lounge/Leisure Dining	1.07
	In a Cafeteria or Fast Food Dining	0.65
	In Family Dining	0.89
	All Other Dining Areas	0.65
Nursery-Living Quarters		0.38

Common Space Type		Watts/Square Foot
Dormitory-Living Quarters		0.50
Dressing Rooms for Performing Arts Theater		0.61
Electrical/Mechanical Rooms		0.05 ^a , 0.42 ^b
Emergency Vehicle Garage		0.56
Facility for the Visually Impaired		
	In a Chapel	2.21
	In a Recreation Room/Common Living Room	2.41
Fire Station-Sleeping Quarters		0.22
Food Preparation		1.21
Guest Rooms		0.47 ^a , 0.91 ^b
Gymnasium/Fitness Centers		
	In an Exercise Area	0.72
	In a Playing Area	1.20
Healthcare Facility		
	In an Exam/Treatment Room	1.66
	In an Imaging Room	1.51
	In a Medical Supply Room	0.74
	In a Nursery	0.88
	In a Nurse's Station	0.71
	In an Operating Room	2.48
	In a Patient Room	0.62
	In a Physical Therapy Room	0.91
	In a Recovery Room	1.15
Laboratory		
	In or as a classroom	1.43
	All Other Laboratories	1.81
Laundry/Washing Area		0.60

Library		Watts/Square Foot
	In Reading Area	1.06
Common Space Type		2015 IECC and ASHRAE Std 90.1- 2013
Loading Dock, Interior		0.47
Lobby		
	In a Facility for the Visually Impaired	1.80
	For an Elevator	0.64
	In a Hotel	1.06
	In a Motion Picture Theater	0.59
	In a Performing Arts Theater	2.00
	All Other Lobbies	0.90
Locker Room		0.75
Lounge/Breakroom		
	In a Healthcare Facility	0.92
	All Other Lounges/Breakrooms	0.73
Manufacturing Facility		
	In a Detailed Manufacturing Area	1.29
	In an Equipment Room	0.74
	In an Extra High Bay Area (>50 feet Floor-to-Ceiling Height)	1.05
	In a High Bay Area (25–50 feet Floor-to-Ceiling Height)	1.23
	In a Low Bay Area (<25 feet Floor-to-Ceiling Height)	1.19
Museum		
	In a General Exhibition Area	1.05
Notes:	In a Restoration Area	1.02

Office		Watts/Square Foot
Common Space Type	Enclosed	1.11 ^a
	Open Plan	0.98
Parking Area, Interior		0.19
Pharmacy Area		1.68
Post Office-Sorting Area		0.94
Religious Buildings		
	In a Fellowship Hall	0.64
	In a Worship/Pulpit/Choir Area	1.53
	Fellowship Hall	0.9
Restrooms		
	In a Facility for the Visually Impaired	1.21
	All Other Restrooms	0.98
Retail Facilities		
	In a Sales Area	1.59 ^a , 1.44 ^b
	In a Dressing/Fitting Room	0.71
	In a Mall Concourse	1.10
Seating Area, General		0.54
Sports Arena		
	For a Class I Facility	3.68
	For a Class II Facility	2.40
	For a Class III Facility	1.80
	For a Class IV Facility	1.20
Stairwell		0.69
Storage Room		0.63 ^a
	< 50 ft ²	1.24 ^b
Notes:	All Other Storage Rooms	0.63 ^b

2015 IECC and
ASHRAE Std 90.1-
2013

Transportation Facility		Watts/Square Foot
Common Space Type	In a Baggage/Carousel Area	0.53
	In an Airport Concourse	0.36
	At a Terminal Ticket Counter	0.80
Warehouse		
	For Medium to Bulky, Palletized Items	0.58
	For Smaller, Hand-Carried Items	0.95
Workshop		1.59
Notes:		
a. 2015 IECC.		
b. ASHRAE Standard 90.1-2013.		

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Part 12: Appliance/Equipment Rules of Thumb

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12.01. Offices and Commercial Spaces

- A. Total Appliance/Equipment Heat Gain 0.5-8.0 watt/sq.ft.**
- B. Computer equipment loads for office spaces range between 0.5 watt/sq.ft. and 3.5 watts/sq.ft. (2.0 watts/sq.ft. is recommended). If actual computer equipment loads are available, they should be used in lieu of the values listed here.**
- C. Depending on the facility, the appliance/equipment diversity factors can range from 25 to 75 percent (recommend diversities of 50 percent are recommended).**

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12.02. Computer Rooms, Data Centers, and Internet Host Sites

- A. 2.0-500.0 watts/sq.ft. (Recommend 300 watts/sq.ft. Minimum)**

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12.03. Telecommunication Rooms

- A. 50.0-120.0 watts/sq.ft.**

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12.04. Electrical Equipment Heat Gain

- A. Transformers**

1. 150 KVA and smaller	50 watts/KVA
2. 151-500 KVA	30 watts/KVA
3. 501-1000 KVA	25 watts/KVA
4. 1001-2500 KVA	20 watts/KVA
5. Larger than 2500 KVA	15 watts/KVA

B. Switchgear

1. Low voltage breaker 0-40 amps	10 watts
2. Low voltage breaker 50-100 amps	20 watts
3. Low voltage breaker 225 amps	60 watts
4. Low voltage breaker 400 amps	100 watts
5. Low voltage breaker 600 amps	130 watts
6. Low voltage breaker 800 amps	170 watts
7. Low voltage breaker 1,600 amps	460 watts
8. Low voltage breaker 2,000 amps	600 watts
9. Low voltage breaker 3,000 amps	1,100 watts
10. Low voltage breaker 4,000 amps	1,500 watts
11. Medium voltage breaker/switch 600 amps	1,000 watts
12. Medium voltage breaker/switch 1,200 amps	1,500 watts
13. Medium voltage breaker/switch 2,000 amps	2,000 watts
14. Medium voltage breaker/switch 3,000 amps	2,500 watts

C. Panelboards

1. 2 watts per circuit.

D. Motor Control Centers

1. 500 watts per section—each section is approximately 20" wide × 20" deep × 84" high

E. Starters

1. Low voltage starters size 00	50 watts
2. Low voltage starters size 0	50 watts
3. Low voltage starters size 1	50 watts
4. Low voltage starters size 2	100 watts
5. Low voltage starters size 3	130 watts
6. Low voltage starters size 4	200 watts
7. Low voltage starters size 5	300 watts
8. Low voltage starters size 6	650 watts
9. Medium voltage starters size 200 amps	400 watts
10. Medium voltage starters size 400 amps	1,300 watts
11. Medium voltage starters size 700 amps	1,700 watts

F. Variable Frequency Drives

1. 2-6% of the KVA rating: 3% is most common

G. Miscellaneous Equipment

1. Bus duct	0.015 watts/ft./amp
2. Capacitors	2 watts/KVAR

Notes:

1. Actual electrical equipment heat gain values will vary from one manufacturer to another—use actual values when available.

2. In the past, electrical equipment rooms only required ventilation to keep equipment from overheating. Most electrical rooms were designed for 95°F to 104°F, although electrical equipment used today may require a maximum design temperature of 90°F because of electronic components and controls. Consult your electrical engineer for equipment temperature tolerances. If space temperatures below 90°F are required by the equipment, the air conditioning (tempering) of space will be required.
3. If outside air is used to ventilate the electrical room, the electrical room design temperature will be 10°F to 15°F above outside summer design temperatures.
4. If conditioned air from an adjacent space is used to ventilate the electrical room, the electrical room temperature can be 10°F to 20°F above the adjacent spaces.
5. Elevator machine rooms require 90°F space temperature (maximum) due to electronic components of elevator equipment. Therefore, elevator machine rooms must be air conditioned (tempered).

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12.05. Motor Heat Gain

A. Motors Only

1. Motors 0–2 hp	190 watts/hp
2. Motors 3–20 hp	110 watts/hp
3. Motors 25–200 hp	75 watts/hp
4. Motors 250 hp and Larger	60 watts/hp

Motors and driven equipment are shown in the following table:

**The Location of Motor and Driven Equipment with
Respect to a Conditioned Space or Airstream**

Motor Horsepower	Motor In, Driven Equipment In Btu/h	Motor Out, Driven Equipment In Btu/h	Motor In, Driven Equipment Out Btu/h
1/20	360	130	240
1/12	580	200	380
1/8	900	320	590
1/6	1,160	400	760
1/4	1,180	640	540
1/3	1,500	840	660
1/2	2,120	1,270	850
3/4	2,650	1,900	740
1	3,390	2,550	850
1- $\frac{1}{2}$	4,960	3,820	1,140
2	6,440	5,090	1,350
3	9,430	7,640	1,790
5	15,500	12,700	2,790
7- $\frac{1}{2}$	22,700	19,100	3,640
10	29,900	24,500	4,490
15	44,400	38,200	6,210
20	58,500	50,900	7,610
25	72,300	63,600	8,680
30	85,700	76,300	9,440
40	114,000	102,000	12,600
50	143,000	127,000	15,700
60	172,000	153,000	18,900
75	212,000	191,000	21,200
100	283,000	255,000	28,300
125	353,000	318,000	35,300
150	420,000	382,000	37,800
200	569,000	509,000	50,300
250	699,000	636,000	62,900

12.06. Miscellaneous Guidelines

- A. **Actual equipment layouts and information should be used for calculating equipment loads.**
- B. **Movie projectors, slide projectors, overhead projectors, and similar types of equipment can generally be ignored because lights are off when being used and the lighting load will normally be larger than this equipment heat gain.**
- C. **Items such as coffee pots, microwave ovens, refrigerators, food warmers, etc., should be considered when calculating equipment loads.**
- D. **Kitchen, laboratory, hospital, computer room, and process equipment should be obtained from the owner, architect, engineer, or consultant due to the extreme variability of equipment loads.**

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Part 13: Cooling Load Factors

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13.01. Diversity Factors

A. *Diversity factors* are an engineer's judgment applied to various people, lighting, equipment, and total loads to consider actual usage. Actual diversities may vary depending on building type and occupancy. Diversities listed here are for office buildings and similar facilities.

B. Room/Space Peak Loads

1. People	1.0 × Calculated Load.
2. Lights	1.0 × Calculated Load.
3. Equipment	1.0 × Calculated Load. ^[a]

^[a]Calculated Load may have a diversity factor that has been calculated using individual pieces of equipment, equipment as a group, or incorporating no equipment at all.

C. Floor/Zone Block Loads

1. People	$0.90 \times \text{Sum of Peak Room/Space People Loads.}$
2. Lights	$0.95 \times \text{Sum of Peak Room/Space Lighting Loads.}$
3. Equipment	$0.90 \times \text{Sum of Peak Room/Space Equipment Loads.}$
4. Floor/Zone Total Loads	$0.90 \times \text{Sum of Peak Room/Space Total Loads.}$

D. Building Block Loads

1. People	$0.75 \times \text{Sum of Peak Room/Space People Loads.}$
2. Lighting	$0.95 \times \text{Sum of Peak Room/Space Lighting Loads.}$
3. Equipment	$0.75 \times \text{Sum of Peak Room/Space Equipment Loads.}$
4. Building Total Load	$0.85 \times \text{Sum of Peak Room/Space Total Loads.}$

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13.02. Safety Factors

A. Room/Space Peak Loads	$1.1 \times \text{Calc. Load.}$
B. Floor/Zone Loads (Sum of Peak)	$1.0 \times \text{Calc. Load.}$
C. Floor/Zone Loads (Block)	$1.1 \times \text{Calc. Load.}$
D. Building Loads (Sum of Peak)	$1.0 \times \text{Calc. Load.}$
E. Building Loads (Block)	$1.1 \times \text{Calc. Load.}$

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13.03. Cooling Load Factors

A. Lighting Load Factors

1. Existing lighting fixtures

a. Fluorescent lights	$1.25 \times \text{Bulb Watts.}$
b. Incandescent lights	$1.00 \times \text{Bulb Watts.}$
c. HID lighting	$1.25 \times \text{Bulb Watts.}$

2. New lighting fixtures

a. Fluorescent lights	$0.85\text{--}1.15 \times \text{Bulb Watts.}$
b. Incandescent lights	$1.00 \times \text{Bulb Watts.}$
c. HID lighting	$0.85\text{--}1.15 \times \text{Bulb Watts.}$
d. Electronic ballasts have provided better energy performance. Electronic ballast factors are very dependent on the manufacturer, type of lighting fixture, and type of lamp. Consult electrical engineer for exact lighting watts required for fixtures.	

B. Return Air Plenum (RAP) Factors

1. Heat of lights to space with RAP	$0.76 \times \text{Lighting Load.}$
2. Heat of lights to RAP	$0.24 \times \text{Lighting Load.}$
3. Heat of roof to space with RAP	$0.30 \times \text{Roof Load.}$
4. Heat of roof to RAP	$0.70 \times \text{Roof Load.}$

D. Ducted Exhaust or Return Air (DERA) Factors

1. Heat of lights to space with DERA	$1.00 \times \text{Lighting Load.}$
2. Heat of roof to space with DERA	$1.00 \times \text{Roof Load.}$

C. Other Cooling Load Factors (CLFs) are in accordance with ASHRAE recommendations.

1. CLF × Other Loads.

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Part 14: Heating Load Factors

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14. Part 14: Heating Load Factors

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14.01. Safety Factors

A. Room/Space Peak Loads	1.1 × Calc. Load
B. Floor/Zone Loads (Sum of Peak)	1.0 × Calc. Load
C. Floor/Zone Loads (Block)	1.1 × Calc. Load
D. Building Loads (Sum of Peak)	1.0 × Calc. Load
E. Building Loads (Block)	1.1 × Calc. Load
F. Generally: Sum of Peak Loads	1.1 × Block Loads

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14.02. Heating Load Credits

- A. Solar. Credit for solar gains should not be taken unless the building is specifically designed for solar heating. Solar gain is not a factor at night when design temperatures generally reach their lowest point.**
- B. People. Credit for people should not be taken. People gain is not a factor at night when design temperatures generally reach their lowest point because buildings are generally unoccupied at night.**
- C. Lighting. Credit for lighting should not be taken. Lighting is an inefficient means to heat a building and lights are generally off at night when design temperatures generally reach their lowest point.**

- D. **Equipment.** Credit for equipment should not be taken unless a reliable source of heat is generated 24 hours a day (e.g., computer facility, industrial process). Only a portion of this load should be considered (50 percent) and the building heating system should be able to keep the building from freezing if these equipment loads are shut down for extended periods of time. Consider what would happen if the system or process shut down for extended periods of time.

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14.03. Heating System Selection Guidelines

- A. **If heat loss exceeds 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.**
- B. **If heat loss is between 250 and 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, and blanketing the exposed wall and window areas.**
- C. **If heat loss is less than 250 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away from, the exposed wall and window areas.**

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Part 15: Design Conditions and Energy Conservation

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15.01. Design Conditions

A. Outside Design Conditions

1. Outdoor design conditions should be taken from either the *ASHRAE Handbook of Fundamentals*, local weather data, or some other recognized source.
2. ASHRAE summer design conditions are based on the following:
 - a. Total yearly hours: 8,760 hours.
 - b. Annual extreme values represent maximum summer design conditions.
 - c. 0.4 percent design values represent summer design conditions that, on average, are exceeded fewer than 35 hours annually above stated conditions.
 - d. 1.0 percent design values represent summer design conditions that, on average, are exceeded fewer than 88 hours annually above stated conditions.
 - e. 2.0 percent design values represent summer design conditions that, on average, are exceeded fewer than 175 hours annually above stated conditions.
 - f. 5.0 percent design values represent summer design conditions that, on average, are exceeded fewer than 438 hours annually above stated conditions.

3. ASHRAE winter design conditions are based on the following:
 - a. Total yearly hours: 8,760 hours.
 - b. Annual extreme values represent maximum winter design conditions.
 - c. 99.6 percent design values represent winter design conditions that, on average, are exceeded fewer than 35 hours annually below stated conditions.
 - d. 99.0 percent design values represent winter design conditions that, on average, are exceeded fewer than 88 hours annually below stated conditions.
4. Outside design condition example: Ambient weather conditions are based on Pittsburgh (Allegheny County Airport), Pennsylvania weather data from the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (ASHRAE) *Handbook of Fundamentals, 2005 Edition* (see [Fig. 15.1](#)).

Design conditions for PITTSBURGH, PA, USA

Station Information																
Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period								
1a	1b	1c	1d	1e	1f	1g	1h	1i								
PITTSBURGH	725200	40.50N	80.22W	1224	14.058	-5.00	NAE	7201								
Annual Heating and Humidification Design Conditions																
Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.5% DB			
	99.6%	99%	99.5%		99%		99%		0.4%		1%		MCWS		PCWD	
	2	3a	3b	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	6a	6b	
1	1.8	7.5	-7.1	3.9	4.3	-2.3	5.1	9.7	28.5	25.6	25.9	24.6	9.6	260		
Annual Cooling, Dehumidification, and Enthalpy Design Conditions																
Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
		0.4%		1%		2%		0.4%		1%		2%		MCWS		PCWD
		7	8	9a	9b	9c	9d	9e	9f	10a	10b	10c	10d	10e	10f	11a
7	18.9	89.1	72.5	86.2	70.9	83.8	69.3	74.9	85.0	73.3	82.5	71.9	80.3	10.3	240	
Dehumidification DP/MCDB and HR																
0.4%		1%		2%		0.4%		1%		2%		Enthalpy/MCDB		MCWS		PCWD
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	17a	17b
12a	12b	12c	12d	12e	12f	12g	12h	12i	13a	13b	13c	13d	13e	13f		
71.8	123.0	80.1	70.3	116.9	78.2	69.0	111.6	76.8	31.5	85.1	30.0	82.7	28.7	80.5		
Extreme Annual Design Conditions																
Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB								
1%	2.5%	5%		Mean	Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years			
14a	14b	14c	15	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	
23.5	19.8	17.9	81.3	92.6	-4.6	3.5	7.9	95.1	-10.3	97.2	-14.9	99.1	-19.3	101.7	-25.1	
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures																
%	Jan		Feb		Mar		Apr		May		Jun					
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB				
	16a	16b	16c	16d	16e	16f	16g	16h	16i	16j	16k	16l				
0.4%	61.9	55.8	64.5	53.3	76.4	58.8	82.1	61.8	85.9	68.3	90.5	72.2				
1%	58.0	52.8	61.6	52.4	73.0	56.7	79.9	61.4	84.2	66.8	88.2	71.1				
2%	55.1	50.4	58.1	49.1	70.0	55.6	77.1	60.3	82.4	65.6	86.4	70.4				
%	Jul		Aug		Sep		Oct		Nov		Dec					
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB				
	18m	18n	18o	18p	18q	18r	18s	18t	18u	18v	18w	18x				
0.4%	93.4	74.1	92.4	73.6	87.2	70.4	77.9	64.0	71.5	59.5	63.9	56.4				
1%	91.4	73.5	90.2	73.4	85.1	70.1	76.1	62.8	69.1	58.2	61.2	54.5				
2%	89.5	73.1	88.0	72.3	83.0	68.8	74.1	61.4	66.6	56.5	58.7	53.2				
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures																
%	Jan		Feb		Mar		Apr		May		Jun					
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB				
	19a	19b	19c	19d	19e	19f	19g	19h	19i	19j	19k	19l				
0.4%	56.4	60.8	56.0	62.5	61.2	72.0	65.2	76.3	71.9	81.5	75.3	86.1				
1%	54.0	57.4	53.4	58.8	59.4	68.2	63.7	75.1	70.6	80.0	74.2	84.6				
2%	50.9	55.1	51.1	55.9	57.3	66.3	62.2	73.5	68.9	78.4	73.2	83.1				
%	Jul		Aug		Sep		Oct		Nov		Dec					
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB				
	19m	19n	19o	19p	19q	19r	19s	19t	19u	19v	19w	19x				
0.4%	77.3	88.5	77.0	87.8	74.0	82.9	66.9	73.6	61.8	67.7	58.4	62.1				
1%	76.2	86.9	75.6	85.9	72.9	81.0	65.4	72.2	60.3	66.1	56.7	60.3				
2%	75.2	85.4	74.5	83.9	71.5	78.9	64.0	70.6	59.0	64.7	54.2	57.6				
Monthly Mean Daily Temperature Range																
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					
20a	20b	20c	20d	20e	20f	20g	20h	20i	20j	20k	20l					
14.1	15.6	18.2	20.3	20.3	19.9	18.9	18.7	19.0	18.8	15.4	13.5					

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Figure 15.1.

- a. Abbreviations:
1. db = dry bulb temperature.
 2. wb = wet bulb temperature.

3. dp = dewpoint temperature.
- b. Pittsburgh, PA summer design conditions:
 1. Average annual extreme value: 92.6°F db/81.3°F wb.
 2. Annual extreme value (20 years): 99.1°F db/81.3°F wb.
 3. 0.4% values: 89.1°F db/74.9°F wb.
 4. 1.0% values: 86.2°F db/73.3°F wb.
 5. 2.0% values: 83.8°F db/71.9°F wb.
 - c. Pittsburgh, PA winter design conditions:
 1. Average annual extreme value: -4.6°F db.
 2. Annual extreme value (20 years): -19.3°F db.
 3. 99.6% values: 1.8°F db/-7.1°F dp.
 4. 99.0% values: 7.5°F db/-2.3°F dp.
5. Recommended outside design conditions values:
 - a. General facilities and spaces—office buildings, schools, commercial and industrial facilities, other noncritical temperature and humidity control facilities:
 1. Summer: 1.0% values.
 2. Winter: 99.0% values.
 - b. Semicritical facilities and spaces—hospitals, medical facilities, laboratories, other semicritical temperature and humidity control facilities:
 1. Summer: 0.4% values.
 2. Winter: 99.6% values.
 - c. Critical facilities and spaces—laboratories, computer facilities, high-tech industrial, other critical temperature and humidity control facilities:
 1. Summer: 0.4% values.
 2. Winter: 99.6% values.
 3. Annual extreme values may even be appropriate here.
 - d. Mechanical equipment rooms, electrical equipment rooms, and similar

spaces:

1. Summer: 2.0% values.

2. Winter: 99.0% values.

B. Indoor Design Conditions

INDOOR DESIGN CONDITIONS

Facility Type/Spaces (1)	Cooling		Heat
	Temperature °F Dry Bulb	Humidity %RH	Temperature °F Dry Bulb
Office Buildings, Commercial Facilities			
Offices	75	50	70
Conference Rooms, Meeting Rooms, Classrooms, Training Rooms	75	50	70
Reception Areas, Lobbies, Corridors	75	50	70
Network Computer Rooms	72 ± 2	-	72 ± 2
Telecommunication Areas/Data Entry	75	50	70
General Spaces			
Mechanical/Electrical/Equip. Rooms	85-90	-	60
Elevator Machine Rooms	85-90	-	65
Telecommunication Rooms	72 ± 2	-	72 ± 2
Toilet Rooms, Locker Rooms, Shower Rooms	78	50	70
Janitor Closets, Housekeeping	85	-	60
Lobbies, Corridors, Elevator Lobbies, Atriums	75	50	70
Vestibules, Entrances, Stairs	-	-	60
Stairs on Perimeter of Building or w/Glass	80	-	60
Notes	78	50	70

Facility Type/ Spaces (1)	Cooling		Heating
	Temperature °F Dry Bulb	Humidity %RH	Temperature °F Dry Bulb
Garages—Open			
Garages—Enclosed			
Educational Facilities			
Auditoriums, Gymnasiums, Multipurpose Rooms	75	50	70
Classrooms, Lecture Halls	75	50	70
Laboratories—High School (4)	75	50	70
Laboratories—College or University (4)	75 ± 2	45 ± 5	72 ± 2
Libraries	75	50	70
Music Rooms, Art Rooms	75	50	70
Training Shops	75	50	70
Food and Beverage Service			
Restaurants, Dining Rooms, Bars, Lounges, Cocktail Lounges	75	50	70
Cafeteria, Fast Food	75	50	70
Kitchens, Dishwashing	80	-	68
Hotels, Motels, Resorts, and Dormitories			
Conference Rooms, Meeting Rooms, Ballrooms	75	50	70
Bedrooms, Bathrooms	75	50	70
Dormitory Sleeping Areas	75	50	70
Living Rooms, Dining Rooms	75	50	70
Gambling Casinos, Gaming Rooms	75	50	70
Correctional Facilities			
Prison Cells	75	50	70
Dining Halls, Day Rooms	75	50	70
Guard Stations	75	50	70

1. Multiple Storage and Specialty Storage

Retail Stores and Specialty Shops			
Facility Type/Spaces (1)	Cooling		Heating
	75°F Dry Bulb Temperature	50% Humidity	70°F Dry Bulb Temperature
Department Stores, Supermarkets, Showroom Floors, Clothiers, Furniture	75	50	70
Dressing Rooms	75	50	70
Shipping and Receiving	-	-	60
Storage Rooms	78	50	70
Warehouses (7)	78	50	70
Barber Shop, Beauty Shop, Nail Salons	75	50	70
Hardware, Drug Stores, Fabric Stores, Specialty Stores	75	50	70
Pet Stores	75	50	70
Automobile Showrooms	75	50	70
Theaters			
Auditoriums, Concert Halls, Performing Arts Centers—Seating Area (5)	75	50	70
Stages, Performing Arts Studios—Performance Areas (5)	72 ± 2	40 ± 5	72 ± 2
3D Theaters (6)	72	50	70
Lobbies, Ticket Booths, On-Call Windows	75	50	70
Sports and Entertainment			
Ballrooms, Disco, Dance Establishments	75	50	70
Bowling Alleys, Game Rooms, Arcades	75	50	70
Firing Ranges	75	50	70
Notes: Casinos, Playing Floors	75	50	65

Swimming Pools, Natatoriums	75	50	70
Facility Type/Spaces (1)	Temperature	Humidity	Temperature
	°F Dry Bulb	%RH	°F Dry Bulb
Transportation			
Bus Stations, Airports	75	50	70
Waiting Areas	75	50	70
Storage Facilities			
Repair Garages (8)	-	-	65
Warehouses (7)	78	50	70
Workrooms			
Bank Vaults	75	50	70
Darkrooms	75	50	70
Duplicating, Printing	75	50	70
Pharmacy	75	50	70
Photo Studios	75	50	70
Private Dwelling—Single and Multiple			
Living Rooms, Dining Rooms, Bedrooms, Kitchens	75	50	70
Toilet Rooms, Bathrooms	78	50	70
Garages	-	-	50 (9)
Laboratories, Computer Facilities, High-Tech Industrial, Special Facilities (4)			
Laboratories—Research	72 ± 2	45 ± 5	72 ± 2
Computer Rooms, Data Centers, Internet Host Sites, Server Rooms, Demarc Rooms	70 ± 2	45 ± 5	70 ± 2
High Tech	68 ± 2	45 ± 5	68 ± 2
High Tech (low humidity)	68 ± 2	35 ± 5	68 ± 2
Animal Research Rooms	68–84 ± 2	40–70 ± 5	68–84 ± 2
Notes: Museums, Galleries, Rare Document Libraries, Archives	72 ± 2	40 ± 5	72 ± 2

Surgical and Critical Care (2)	Cooling		Heating
Facility Type/Spaces (1)	Temperature 75 °F Dry Bulb	Humidity max 60 %RH	Temperature 68 °F Dry Bulb
Operating/surgical cystoscopic rooms	75	max 60	68
Delivery room (Caesarean)	75	max 60	68
Substerile service area	-	-	-
Recovery room	75	max 60	70
Critical and intensive care	75	max 60	70
Intermediate care	75	max 60	70
Wound intensive care (burn unit)	75	max 60	70
Newborn intensive care	78	max 60	72
Treatment room	75	max 60	70
Trauma room (crisis or shock)	75	max 60	70
Medical/anesthesia gas storage	-	-	-
Laser eye room	75	max 60	70
ER waiting rooms	75	max 65	70
Triage	75	max 60	70
ER decontamination	75	-	-
Radiology waiting rooms	75	max 60	70
Procedure room (Class A surgery)	75	max 60	70
Emergency department exam/treatment room	75	max 60	70
Inpatient Nursing			
Patient room	75	max 60	70
Nourishment area or room	-	-	-
Toilet room	-	-	-
Newborn nursery suite	78	max 60	72
Protective environment room	75	max 60	70

Airborne Infectious Isolation (All) room	75 Cooling	max 60 Humidity	70 Heat
Facility Type/Spaces (1) Combination All/Protective Environment (PE) room	75 F Dry Bulb	max 60 %RH	70 F Dry Bulb
All anteroom	-	-	-
PE anteroom	-	-	-
Combination All/PE anteroom	-	-	-
Labor/delivery/recovery/postpartum (LDRP)	75	max 60	70
Labor/delivery/recovery (LDR)	75	max 60	70
Patient Corridor	-	-	-
Nursing Facility			
Resident room	75	-	70
Resident gathering/activity/dining	75	-	70
Resident unit corridor	-	-	-
Physical therapy	75	-	70
Occupational therapy	75	-	70
Bathing room	75	-	70
Radiology			
X-ray (diagnostic and treatment)	78	max 60	72
X-ray (surgery/critical care and catheterization)	75	max 60	70
Darkroom	-	-	-
Diagnostic and Treatment			
Bronchoscopy, sputum collection, and pentamidine administration	73	-	68
Laboratory, general	75	-	70
Laboratory, bacteriology	75	-	70
Laboratory, biochemistry	75	-	70

Facility Type/Spaces (1)	75	Cooling	70	Heating
	°F Dry Bulb	Temperature	Humidity	Temperature
	75	-	%RH	70
Laboratory, cytology	75	-	-	70
Laboratory, glass washing	75	-	-	70
Laboratory, histology	75	-	-	70
Laboratory, microbiology	75	-	-	70
Laboratory, nuclear medicine	75	-	-	70
Laboratory, pathology	75	-	-	70
Laboratory, serology	75	-	-	70
Laboratory, sterilizing	75	-	-	70
Laboratory, media transfer	75	-	-	70
Nonrefrigerated body-holding room	75	-	-	70
Autopsy room	75	-	-	68
Pharmacy	-	-	-	-
Examination room	75	max 60	-	70
Medication room	75	max 60	-	70
Gastrointestinal endoscopy procedure room	73	max 60	-	68
Endoscope cleaning	-	-	-	-
Treatment room	75	max 60	-	70
Hydrotherapy	80	-	-	72
Physical therapy	80	max 65	-	72
Dialysis treatment area	78	-	-	72
Dialyzer reprocessing room	-	-	-	-
Nuclear medicine hot lab	75	-	-	70
Nuclear medicine treatment room	75	-	-	70
Sterilizing				
Sterilizer equipment room	-	-	-	-
Central Medical and Surgical Supply				
Soiled or decontamination room	78	-	-	72

Facility Type/Spaces (1)	Temperature	Humidity	Temperature
	°F Dry Bulb	%RH	°F Dry Bulb
Clean workroom	78	max 60	72
Sterile storage	78	60	72
Service			
Food preparation center	78	-	72
Warewashing	-	-	-
Dietary storage	78	-	72
Laundry, general	-	-	-
Soiled linen sorting and storage	-	-	-
Clean linen storage	78	-	72
Linen and trash chute room	-	-	-
Bedpan room	-	-	-
Bathroom	78	-	72
Janitor's closet	-	-	-
Support Space			
Soiled workroom or soiled holding	-	-	-
Clean workroom or clean holding	-	-	-
Hazardous material storage	-	-	-

Notes:

- Indoor design conditions are recommendations that may be used when the facility used have no specific criteria. When codes, processes, or codes require different design conditions than those listed here, they should be used for design purposes.**
- ASHRAE Standard 170-2013 *Ventilation of Health Care Facilities* (incorporated into Part 4 of the 2014 Facility Guidelines Institute *Guidelines for Design and Construction of Hospitals and Outpatient Facilities*) provides ranges for design conditions for spaces. The systems shall be capable of maintaining the rooms within the temperature and relative humidity ranges listed in the table during normal operation. Some specialty procedures may require special temperature and relative humidity levels. The hospital staff should be consulted to determine special requirements.**

3. Surgeons or procedures may require room temperatures and relative humidity that exceed the minimum indicated ranges.
4. With laboratories, computer facilities, high tech industrial, special museums, and other spaces requiring critical temperature and relative humidity control, the owners and their staff should be consulted to verify the specific requirements. Requirements provided here are for general guidance.
5. Some performances will require strict temperature and relative humidity during the performance. Careful consideration must be given to the type of performances and their requirements when designing these facilities.
6. 3D type theaters (IMAX and OMNIMAX) should be maintained at temperature or below 72°F because the incidents of motion sickness increase considerably above these temperatures.
7. Warehouse temperature and relative humidity requirements can vary considerably depending on the materials being stored.
8. Repair garages are generally not air conditioned. If air conditioning is provided, cooling design temperature recommendation would be 80 to 85°F.
9. Heating parking garages is not recommended because minimum-code ventilation rates require heating of the makeup air for the heating to be effective.

15.02. General Energy Conservation Requirements

- A. **The major energy codes referenced by the 2015 International Building Code (2015 IBC) and the 2015 International Mechanical Code (2015 IMC) are:**
1. 2015 International Energy Conservation Code (2015 IECC is based on and references ASHRAE Standard 90.1-2013).
 2. ASHRAE Standard 90.1-2013.
- B. **ASHRAE Standard 90.1-2013 requires glazing systems to be certified in accordance with National Fenestration Rating Council (NFRC) Standards 100, 200, 300, and 400 and tested by a laboratory accredited by a nationally recognized accreditation organization for**

the following:

1. Air leakage.
2. U-values.
3. Emissivity coatings.
4. Solar Heat Gain Coefficients (SHGCs).
5. Shading Coefficients (SCs).
6. Visible Light Transmittance (VT).
7. Condensation Resistance Ratings (CRs).

C. National Fenestration Rating Council Product Certification Program (NFRC 700-2015)

1. Paragraph 4 reads " ... products may be authorized for certification only if they have been rated in accordance with NFRC-approved procedures, computer programs, and test methods."
2. Paragraph 4.3.2 reads "Product Evaluation. A Licensee shall obtain from an NFRC-accredited laboratory NFRC required ratings for each product to be authorized for certification."
3. Paragraph 4.3.2.1 reads "Valid Computational Procedure."
 - a. Paragraph 4.3.2.1.A reads "This procedure is used for obtaining U-factor ratings. The licensee shall obtain a simulation report from an NFRC-accredited simulation laboratory for each product line to be authorized for certification."
 - b. Paragraph 4.3.2.1.B reads "The licensee shall then obtain a physical test report from an NFRC-accredited test laboratory. The test report shall contain the test results of the baseline product (the representative product of the product line) chosen by the licensee in order to validate the simulations conducted for the product line."
4. Paragraph 4.3.2.2 reads "Computational Procedure. This procedure is used for obtaining SHGC, VT, and Condensation Resistance ratings. Under this procedure, the licensee shall obtain a simulation report from an NFRC-accredited simulation laboratory for each product line to be authorized for certification. The Testing Alternative procedure for these ratings is to be used only if the product cannot be simulated."

D. As can be seen in paragraphs 15.02.B and C, shown earlier, glazing systems must be certified and the certification must involve a physical product test. I include this information to emphasize this building envelope requirement, because many design professionals are unaware of the magnitude of these requirements and the potential construction cost impacts. Recommended specification text is indicated in the following.

1. A representative sample of each glazing product to be installed on the project shall be tested in a certified, independent, testing laboratory in accordance with NFRC testing procedures.
2. Glazing products shall include, but are not limited to, curtain wall assemblies, field-assembled units, factory-assembled units, spandrel glazing units, operable units, fixed units, glazing with and without frit, clear units, tinted/colored units, low e-units, low iron units, metal-/aluminum-framed units, wood-framed units, sealed units, and all other glazing units.
3. U-values and solar heat gain coefficients (SHGCs) shall be determined by an NFRC test method at a certified, independent testing laboratory and shall be expressed as Btu/(h ft.² °F) for each glazing product. Test glazing products with a 15-mph wind (6.7 m/s), 0°F (-18°C) cold side temperature, and 70°F (21°C) warm side temperature. The NFRC testing procedure shall include both the thermal computer model and the physical product test.
4. Maximum U-values must be specified and include the effects of the framing system.
 - a. For example: Maximum U-values including the frame shall be 0.46 Btu/(h ft.² °F).
 - b. Include the maximum U-values obtained from ASHRAE Std 90.1 or the IECC, or values used in the COMcheck program or the Energy Model that shows compliance.
5. The maximum SHGC must be specified.
 - a. For example: the maximum SHGC shall be 0.39.
 - b. The maximum SHGC values obtained from ASHRAE Std 90.1 or the IECC, or values used in the COMcheck program or the Energy Model that shows compliance.

E. Prescriptive Code Approach

1. The prescriptive approach is an explicitly defined design approach based on

design, construction, and maintenance requirements for all building systems.

2. The prescriptive approach is less flexible.
3. The prescriptive approach requires less design effort.
4. The following is an illustration of the ASHRAE Standard 90.1 prescriptive approach.

THE ASHRAE STANDARD 90.1 PRESCRIPTIVE APPROACH

Architectural Building Envelope		Mechanical HVAC		Plumbing Water Heating	Electrical Lighting
Mandatory Requirements		Mandatory Requirements		Mandatory Requirements	Mandatory Requirements
Prescriptive Method	Building Envelope Trade-off Method	Simple Method	Prescriptive Method	Prescriptive Method	Space-by-Space Method

F. Performance Code Approach

1. The performance approach is a design approach based on performance goals, objectives, and criteria.
2. The performance approach is more flexible.
3. The performance approach requires a much greater design effort.
4. The following is an illustration of ASHRAE Standard 90.1 performance approach.

ASHRAE STANDARD 90.1 PERFORMANCE APPROACH

**Architectural
Building
Envelope**

**Mechanical
HVAC**

**Plumbing
Water
Heating**

**Electrical
Lighting**

**Ele
Power**

**Mandatory
Requirements**

**Mandatory
Requirements**

**Mandatory
Requirements**

**Mandatory
Requirements**

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Energy Cost Budget Method "The Energy Model"

- G. **As can be seen in the previous illustrations, all disciplines (architectural, mechanical, plumbing, and electrical) must be actively involved in the energy conservation aspects of building design and construction. Even the contractors must be cognizant of how their construction activities and policies affect the end product with respect to energy conservation. This book will concentrate on the HVAC aspects of energy conservation. However, some of the lighting energy conservation requirements are contained in Part 11.**
- H. **It's always surprising when a design colleague or someone else involved in the design process raises the question(s): "Who is going to enforce these energy conservation requirements (implying who understands these requirements well enough to enforce them)? or Who are the "Energy Police" who will enforce these requirements? The answer should roughly be: "It is the design professional's responsibility to enforce these requirements, especially if they have RA (registered architect) or PE (professional engineer) after their names." Your professional license as an architect or engineer requires you to uphold the laws and codes of the jurisdictions in which you are licensed, in addition to protecting the public health and safety. Therefore, it is ultimately the design professionals' responsibility.**
- I. **Energy Performance Computer Programs are quite useful in determining compliance. The Department of Energy (DOE) has a free residential compliance program (REScheck) and a free commercial compliance program (COMcheck) that can be downloaded from their web site. It is easy to use, and many municipalities accept the output from these programs as certification of compliance. These programs also provide checklists that assist in the design of the building or**

structure. These programs utilize the prescriptive requirements to determine compliance and generally cannot be used to determine the compliance for the performance approach.

- J. Summaries of the energy codes outlining/highlighting the more frequently uses requirements are indicated in the following. For detailed design requirements, consult the official code text.**

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15.03. 2015 IECC

A. Scope and Intent

1. Minimum prescriptive and performance requirements for building energy conservation.
2. Applicable buildings: residential and commercial.
3. Systems covered—provide effective use of energy in buildings:
 - a. Architectural—Building envelope.
 - b. Mechanical—HVAC and plumbing.
 - c. Electrical—Power and lighting.
4. The code is not intended to limit flexibility or negate the safety, health, or environmental requirements of building design and construction.

B. Design Conditions

1. The United States is categorized into eight climate zones with Climate Zone 1 at the tip of Florida and Climate Zone 8 in Alaska.
2. Outdoor design conditions—2013 ASHRAE Handbook of Fundamentals.
3. Indoor design conditions.
 - a. Heating: 72°F maximum.
 - b. Cooling: 75°F minimum.

C. Residential Energy Efficiency —Mandatory Requirements

1. Duct insulation
 - a. Supply and return ducts in attics 3 inches in diameter and greater: Insulation with R-value = 8.0.

- b. Supply and return ducts in attics less than 3 inches in diameter: Insulation with R-value = 6.0.
- c. Supply and return ducts in other portions of the building 3 inches in diameter and greater: Insulation with R-value = 6.0.
- d. Supply and return ducts in other portions of the building less than 3 inches in diameter: Insulation with R-value = 4.2.
- e. Exception: ducts completely inside the building envelope do not require insulation.

2. Pipe insulation

- a. Pipe fluid above 105°F: Insulation with R-value = 3.0.
- b. Pipe fluid below 55°F: Insulation with R-value = 3.0.
- c. Domestic hot water: Insulation with R-value = 3.0.

D. Commercial Energy Efficiency Requirements

1. The 2015 IECC references ASHRAE Standard 90.1—Energy Standard for Buildings Except Low Rise Residential Buildings, but also provides its own prescriptive and performance requirements.
2. Mandatory requirements:
 - a. Heating and cooling load calculations shall be performed in accordance with *ASHRAE Standard 183* and equipment size based on these calculations.
 - b. Heating and cooling loads shall be adjusted to account for energy recovery systems.
 - c. Minimum HVAC equipment performance requirements are defined in the code. These requirements are not included here. Chiller performance requirements can be found in Part 28.
 - d. Thermostatic controls shall be provided for all HVAC systems. Humidity controls shall be provided for HVAC systems where humidification or dehumidification, or both are provided.
 - e. A 5°F deadband is required between heating and cooling setpoints.
 - f. Off-hour setback controls are required.

- g. Damper controls: Outdoor air and exhaust air systems (gravity vents and louvers) shall be provided with motorized shutoff dampers when the system is not in use.
 - 1. Exception: Gravity dampers are permitted in buildings that are two stories and less in height.
 - 2. Exception: Gravity dampers are permitted in buildings of any height located in Climate Zones 1, 2, or 3.
 - 3. Exception: Gravity dampers are permitted in systems with airflows of 300 CFM and less.
- h. Energy recovery systems shall be provided when the following conditions are met:
 - 1. HVAC systems where the supply airflow rate of a fan system exceeds the values listed in 2015 IECC, Tables C403.2.7(1) and C403.2.7(2) based on climate zone and percentage of outdoor airflow rate at design conditions.
 - 2. The energy recovery system shall recover at least 50 percent of the energy difference between the enthalpy difference of the outside air and the room air (50-percent minimum efficiency).
 - a. Exceptions:
 - 1. Where energy recovery systems are prohibited by the *International Mechanical Code*.
 - 2. Laboratory fume hood systems that include at least one of the following:
 - a. VAV exhaust hoods with supply air and exhaust airflow reduction to 50 percent or less of the system design airflow.
 - b. Direct makeup air delivered to the laboratory fumes hoods equal to at least 75 percent of the exhaust flow rate, heated no warmer than 2°F below the room design temperature, cooled to no cooler than 3°F above the room design temperature, no humidification added, and no simultaneous heating and cooling used for dehumidification control.
 - 3. Heating only systems with design space temperatures less than 60°F.

4. Where 60 percent of the outdoor heating energy is provided by site recovered energy or site solar energy.
 5. Heating energy recovery in Climate Zones 1 and 2.
 6. Cooling energy recovery in Climate Zones 3C, 4C, 5B, 5C, 6B, 7, and 8.
 7. Systems requiring dehumidification that employ energy recovery in series with the cooling coil.
 8. Where the largest exhaust source is less than 75 percent of the design outdoor airflow.
 9. Systems expected to operate less than 20 hours per week at the outdoor air percentage covered by Table C403.2.7(1).
 10. Hazardous exhaust systems: See Part 17.
 11. Commercial kitchen hoods.
3. Energy recovery control or bypass must be provided to permit the operation of airside economizers.
 - i. Ductwork:
 1. Construction and materials: See Part 17.
 2. Insulation: See Part 35.
 - j. Piping:
 1. Construction and materials: See Part 18 through Part 22.
 2. Insulation: See Part 35.
 - k. HVAC system balancing is required for both the air systems and the hydronic systems.
 - l. Operation and maintenance manuals are required to be turned over to the owner.
3. Economizers—prescriptive approach:
 - a. See 2015 IECC, Sec. C403.3 for detailed requirements.

- b. Economizer systems shall be integrated with the mechanical cooling system and be capable of providing partial cooling even where additional mechanical cooling is required to provide the remainder of the cooling load.
 - c. HVAC system design and economizer controls shall be such that economizer operation does not increase building heating energy during normal operation.
 - d. Air economizers:
 - 1. Air economizer systems shall be capable of modulating outdoor air and return air dampers to provide up to 100 percent of the design supply air quantity as outdoor air for cooling.
 - 2. Economizer dampers shall be capable of being sequenced with the mechanical cooling equipment and shall not be controlled by only mixed-air temperature.
 - 3. Air economizers shall be capable of automatically reducing outdoor air intake to the design minimum outdoor air quantity when outdoor air intake will no longer reduce cooling energy usage.
 - 4. Systems shall be capable of relieving excess outdoor air during air economizer operation to prevent overpressurizing the building. The relief air outlet shall be located to avoid recirculation into the building.
 - e. Water-side economizers:
 - 1. Water-side economizers shall be capable of providing 100 percent of the cooling load at outside air temperatures of 50°F db/45°F wb and below.
4. Hydronic and multiple-zone HVAC systems controls and equipment—prescriptive approach:
- a. See 2015 IECC, Sec. C403.4 for detailed requirements.
 - b. Fan control:
 - 1. Each cooling system shall be designed to vary the indoor fan airflow as a function of load.
 - 2. Static pressure sensors used to control VAV fans shall be located such that the controller setpoint is not greater than 1.2 inches w.c.

3. For systems with direct digital control of individual zones reporting to the central control panel, the static pressure setpoint shall be reset based on the zone requiring the most pressure. In such case, the setpoint is reset lower until one zone damper is nearly wide open.

c. Hydronic systems controls:

1. Three-pipe hydronic systems are prohibited.
2. Two-pipe changeover hydronic systems shall be provided with a deadband of at least 15°F, operation of one mode for at least four hours before changing to the other mode, and automatic controls that allow heating and cooling supply temperatures at the changeover point to be no more than 30°F apart.
3. Hydronic heat pump systems shall be designed with a 20°F deadband between the removal of heat and the addition of heat to the loop. A bypass around the closed circuit evaporative cooler or the cooling tower is required for climate zones 3 and 4 to prevent heat loss, except for minimum flow to prevent freezing. For climate zones 3 and 4 where a separate heat exchanger is used to isolate the cooling tower from the heat pump loop, heat loss shall be controlled by shutting down the circulation pump on the cooling tower loop. For climate zones 5 through 8, where a closed circuit evaporative cooler or cooling tower is used, a separate heat exchanger shall be used to isolate the cooling tower from the heat pump loop, and heat loss shall be controlled by shutting down the circulation pump on the cooling tower loop. All water-source heat pumps shall be provided with two-position control valves on all heat pump systems with total pump energy exceeding 10 horsepower to stop flow when the heat pump has cycled off (variable flow water distribution system).
4. Hydronic heating and cooling systems 500,000 Btu/h capacity or greater shall have automatic supply-water temperature reset controls using coil valve position, zone-return water temperature, building-return water temperature, or outside air temperature as an indicator of building heating or cooling demand. The temperature shall be capable of being reset by not less than 25 percent of the design supply-to-return water temperature difference.

5. Hydronic heating and cooling systems 500,000 Btu/h capacity or greater with a combined motor capacity of 10 horsepower or greater with three or more control valves shall reduce system pump flow by at least 50 percent of the design flow rate utilizing adjustable speed drives on pumps or multiple-staged pumps where at least 1/2 of the total pump horsepower can be turned off or where control valves are designed to modulate closed as a function of load. Pump flow shall be controlled to maintain one control valve nearly wide open or to satisfy the minimum differential pressure.
 6. Boiler systems with a design input greater than 1,000,000 Btu/h and less than or equal to 5,000,000 Btu/h shall have a minimum turndown ratio of 3 to 1; greater than 5,000,000 Btu/h and less than or equal to 10,000,000 Btu/h shall have a minimum turndown ratio of 4 to 1; and greater than 10,000,000 Btu/h shall have a minimum turndown ratio of 5 to 1.
 7. Chilled water and boiler plants having more than one chiller and/or boiler shall have the capability to reduce flow automatically through the chiller/boiler plant when a chiller/boiler is shut down.
- d. Heat rejection equipment fans 7.5 horsepower and greater shall have automatic controls in order to reduce fan speed to 2/3 of full speed or less.
- e. Complex mechanical systems serving multiple zones:
1. Supply air systems serving multiple zones shall be variable air volume systems that, during periods of occupancy, are designed and capable of being controlled to reduce primary air supply to each zone to 30 percent of maximum supply air, 300 CFM or less, minimum ventilation requirements, higher rate if approved by the code official, or the airflow rate required to maintain pressure relationships or minimum air change rates before reheating, recooling, or mixing takes place.
 2. Fractional horsepower fan motors that are greater than or equal to 1/12 horsepower and less than 1 horsepower shall be electronically commutated motors or shall have a minimum motor efficiency of 70 percent.
 3. Multiple-zone HVAC systems shall include controls that automatically reset the supply air temperature not less than 25 percent of the difference between the design supply air temperature and the design

room temperature in response to representative building loads or to outdoor air temperature.

4. Multiple-zone HVAC systems with direct digital control of individual zone boxes reporting to a central control panel shall have automatic controls configured to reduce outdoor air intake flow below design rates in response to changes in system ventilation efficiency as defined by the *International Mechanical Code*.
- f. Condenser water heat recovery is required for the heating or reheating of service hot water, provided the facility operates 24 hours per day and the total water-cooled system exceeds 6,000,000 Btu/h capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/h.
- g. Cooling systems shall not use hot gas bypass or other evaporator pressure control systems unless the system is designed with multiple steps of unloading or continuous capacity modulation. The capacity of the hot gas bypass shall be limited to 50 percent of total capacity for systems with a rated capacity greater than or equal to 240,000 Btu/h, and 25 percent of total capacity for systems with a rated capacity less than 240,000 Btu/h.

E. Performance Approach

1. When using a performance-based energy compliance approach for either a residential or commercial facility, the energy model will have to be performed at least twice: once for the standard reference design using the standard energy performance values defined in the code and once using the proposed design performance values as defined on the construction documents.
2. Energy analysis shall be performed over a full calendar year (8,760 hours) using climatic data, energy rates, building envelope data, occupancy schedules, and simulated loads as applicable to the location.
3. The heating and cooling system zoning, orientation, and other building features for the standard building shall be the same as the proposed building except:
 - a. The window area of the standard design shall be the same as the proposed design, or 35 percent of the above-grade wall area, whichever is less.
 - b. The skylight area of the standard design shall be the same as the

proposed design, or 3 percent of the gross roof area, whichever is less.

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15.04. ASHRAE Standard 90.1-2013

A. Purpose: To provide minimum requirements for the energy-efficient design of buildings except low-rise residential buildings.

B. Scope

1. Application:

- a. New buildings and their systems.
- b. New portions of buildings and their systems.
- c. New systems and equipment in existing buildings.
- d. New equipment or building systems specifically identified as part of industrial or manufacturing processes.

2. Building elements and systems:

- a. Building envelope.
- b. HVAC systems.
- c. Service water heating systems.
- d. Electrical power distribution and metering systems.
- e. Electric motors, belts, and drives.
- f. Lighting.

3. The code is not intended to limit flexibility or to negate safety, health, or environmental requirements of building design and construction.

C. Mandatory Provisions

1. Mechanical equipment shall meet minimum equipment efficiencies. These requirements were not included here. Chiller performance requirements can be found in Part 28.
2. Heating and cooling load calculations shall be performed in accordance with ASHRAE Standard 183-2007 (RA2014) and equipment size based on these calculations.

3. The supply of heating and cooling energy shall be individually controlled by a thermostat responding to temperatures within the zone.
4. A 5°F deadband is required between heating and cooling setpoints. Where heating and cooling systems serving a zone are controlled by separate thermostats, provisions in the control system shall prevent the simultaneous heating and cooling of the zone.
5. HVAC systems shall be provided with off-hour controls:
 - a. Exceptions:
 1. HVAC systems intended to operate continuously.
 2. HVAC systems with design heating and cooling capacities less than 15,000 Btu/h and with accessible on/off controls.
 - b. Automatic shutdown shall be equipped with at least one of the following:
 1. Time schedules for seven different day types:
 - a. Capable of retaining control programs for a minimum of 10 hours during a power outage.
 - b. Accessible manual override for system operation up to two hours.
 2. Occupant sensor.
 3. Manually operated timer with 2-hour operation limitation.
 4. Interlock with security system—security system activation shuts down the HVAC system.
 - c. Setback controls:
 1. Heating systems: Provide controls with a setback temperature of at least 10°F lower than the occupied heating setpoint (or 4°F lower than the occupied heating setpoint for radiant heating systems).
 2. Cooling systems: Provide controls with a setup temperature of at least 5°F higher than the occupied cooling setpoint.
 - d. Optimum start controls (system with setback controls and DDC).
 - e. Zone isolation controls for HVAC systems serving zones that are intended to operate or be occupied nonsimultaneously.
6. Ventilation control:

- a. Stair and elevator shaft vents shall be equipped with motorized dampers that are closed during normal building operation and are opened as required by fire and smoke detection systems.
- b. Damper controls: Outdoor air and exhaust air systems (gravity vents and louvers) shall be provided with motorized shutoff dampers when the system is not in use or during preoccupancy building warm-up, cool-down, and setback.
 - 1. Exception: Gravity dampers are permitted for exhaust and relief in buildings three stories and less in height and in buildings of any height in Climate Zones 1, 2, and 3.
 - 2. Exception: Gravity dampers are permitted in systems with an airflow of 300 CFM or less.
 - 3. Exception: Ventilation systems serving unconditioned spaces.
- c. Recommendation: Provide all dampers with a maximum damper leakage rate of 4.0 CFM per square foot of damper area at 1.0 inches water column differential.
- d. Ventilation fan controls: Fans greater than 3/4 horsepower shall have automatic shutdown controls that shut off fans when not required.
- e. Demand control ventilation is required for HVAC systems serving spaces larger than 500 square feet with an occupant density exceeding 25 people per 1,000 square feet (some exceptions apply; see ASHRAE Standard 90.1-2013, Sec. 6.4.3.8). The HVAC systems must also have one or more of the following:
 - 1. Air-side economizer.
 - 2. Automatic modulating control of the outdoor air damper.
 - 3. Design outdoor airflow greater than 3,000 CFM.
- f. Ductwork:
 - 1. Construction and materials: See Part 17.
 - 2. Insulation: See Part 35.
- g. Piping:
 - 1. Construction and materials: See Part 18 through Part 22.
 - 2. Insulation: See Part 35.

h. Construction requirements:

1. Record drawings shall be required.
2. Operation and maintenance manuals shall be required.
3. Air distribution and hydronic systems shall be balanced.
4. HVAC control systems shall be commissioned for projects larger than 50,000 square feet.

D. Simplified Prescriptive Approach

1. Building meeting the following:
 - a. Two stories or less.
 - b. 25,000 square feet or less.
2. HVAC system serves a single zone.
3. HVAC system varies indoor fan airflow.
4. HVAC provided by packaged or split system equipment.
5. Airside economizer shall be provided.
6. System changeover shall be by a manual changeover or by a dual setpoint thermostat.
7. The system does not permit simultaneous heating and cooling.

E. Prescriptive Approach

1. Economizers—either an airside or a waterside economizer is required as indicated in the following tables.

Climate Zones	Comfort Cooling Capacity Requiring Economizer
1A, 1B	No economizer required
2A, 2B, 3A, 4A, 5A, 6A, 3B, 3C, 4B, 4C, 5B, 5C, 6B, 7, 8	$\geq 54,000$ Btu/h

Climate Zones	Computer Room Cooling Capacity Requiring Economizer
----------------------	--

1A, 1B, 2A, 3A, 4A	No economizer required
2A, 5A, 6A, 7, 8	$\geq 135,000$ Btu/h
3B, 3C, 4B, 4C, 5B, 5C, 6B	$\geq 65,000$ Btu/h

a. Exceptions:

1. Systems smaller than those indicated in the tables under the design conditions listed.
2. In hospitals and ambulatory surgery centers where 75 percent or more of the HVAC system serve spaces that require humidification levels above a 35°F dewpoint temperature.
3. Where 25 percent or more of the HVAC system serves spaces that require humidification levels above a 35°F dewpoint temperature.
4. Systems that utilize condenser heat recovery.
5. Residential HVAC systems where the capacity is less than five times the requirements listed in the preceding table.
6. Systems that serve spaces whose sensible cooling load at design conditions, excluding transmission and infiltration loads, is less than or equal to transmission and infiltration losses at an outdoor temperature of 60°F.
7. Systems expected to operate less than 20 hours per week.
8. Where the use of outdoor air for cooling will affect supermarket open refrigerated casework systems.
9. Other exceptions apply; see ASHRAE Standard 90.1-2013, Sec. 6.5.1.

2. Airside economizers:

- a. Design capacity: 100 percent of the supply air quantity.
- b. Controls: Must be sequenced with mechanical cooling systems and shall not be controlled by only mixed air temperature.

- c. Minimum position: System shall reduce outside airflow to the minimum position when the outside air will no longer reduce cooling energy usage.
 - d. Relief: HVAC systems must provide a means to relieve excess outside air.
 - e. Sensors must meet certain accuracies (see ASHRAE Standard 90.1-2013, Sec. 6.5.1.1.6).
3. Waterside economizers:
- a. Design capacity: 100 percent of the expected system cooling load at outside air temperatures of 50°F db/45°F wb and below.
 - b. Maximum water pressure drop: 15 feet of water.
4. Economizer control:
- a. Economizers shall provide partial cooling even when additional mechanical cooling is required to meet the load.
 - b. Economizers shall not increase the building heating energy use during normal operation.
 - c. Economizer control methods.

Climate Zones	Allowed Control Types	Prohibited Control Types
1B, 2B, 3B, 3C, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8	Fixed dry bulb Differential dry bulb Fixed enthalpy Differential enthalpy	
1A, 2A, 3A, 4A	Fixed dry bulb Fixed enthalpy Differential enthalpy	Differential dry bulb

5. Thermostatic zone controls shall reduce the following:
- a. Reheating.
 - b. Recooling.
 - c. Mixing.
 - d. Simultaneous heating and cooling.

- e. Exceptions: When the quantity of air to be reheated, recooled, or mixed is no greater than the following:
 - 1. The prescribed code ventilation requirements.
 - 2. Zones where special pressure relationships are required to prevent cross-contamination.
 - 3. Code required minimum air change rates—hospitals are an example.
 - 4. Where 75 percent or more of the energy required for reheating is provided by an energy recovery system.
 - 5. Laboratory exhaust systems.
 - 6. Other exceptions apply; see ASHRAE Standard 90.1-2013, Sec. 6.5.2.1.
- 6. Humidistatic zone controls shall reduce the following:
 - a. Reheating.
 - b. Recooling.
 - c. Mixing.
 - d. Simultaneous heating and cooling.
 - e. Exceptions:
 - 1. Systems that reduce supply air quantities to 50 percent or lower.
 - 2. Individual cooling systems with capacity less than or equal to 80,000 Btu/h and reduces cooling capacity to 50 percent before reheating.
 - 3. Individual cooling systems with capacity of 40,000 Btu/h or less.
 - 4. HVAC systems serving process needs and requirements.
 - 5. Where 75 percent or more of the energy required for reheating is provided by an energy recovery system.
- 7. Hydronic systems controls
 - a. Three-pipe hydronic systems are prohibited.
 - b. Two-pipe changeover hydronic systems shall be provided with a deadband of at least 15°F, operation of one mode for at least four hours before changing to the other mode, and automatic control that allows

heating and cooling supply temperatures at the changeover point to be no more than 30°F apart.

- c. Hydronic heat pump systems shall be design with a 20°F deadband between the removal of heat and the addition of heat to the loop. Bypass around the closed circuit evaporative cooler or the cooling tower is required for Climate Zones 3 through 8 with heating degree days in excess of 1800 to prevent heat loss, except for minimum flow to prevent freezing.
- d. Hydronic systems having 10 horsepower or more of total pump system power:
 - 1. Provide control valves to modulate or step closed as a function of load to reduce water flow to 50 percent or less of the design flow rate.
 - 2. Chilled water pumps serving variable-flow systems having motors exceeding 5 horsepower shall have controls and/or devices (such as variable-speed control) that will result in pump motor demand of not more than 30 percent of their design wattage at 50 percent of the design water flow.
 - a. Exception: Where minimum flow required is less than the minimum flow required by the equipment manufacturer for proper equipment operation and where the total pump system power is 75 horsepower or less.
 - b. Exception: Systems with no more than three control valves.
- e. Hydronic heating and cooling systems 300,000 Btu/h capacity or greater shall have automatic supply-water temperature reset controls using zone-return water temperature, building-return water temperature, or outside air temperature as an indicator of building heating or cooling demand.
- f. Heat rejection equipment: Heat rejection equipment fans 7.5 horsepower and greater shall have automatic controls to be able to reduce fan speed to 2/3 of full speed or less and as a function of leaving water temperature or condensing temperature/pressure of the heat rejection device.
- g. Condenser water heat recovery is required for heating or reheating of service hot water provided the facility operates 24 hours per day and the total water cooled system exceeds the 6,000,000 Btu/h capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/h.

8. Fan system power and efficiency.
 - a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.1.
9. Fan control.
 - a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.2.
10. Multiple-zone VAV system ventilation optimization control.
 - a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.3.
11. Supply air temperature reset controls.
 - a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.4.
12. Fractional horsepower fan motors.
 - a. See ASHRAE Standard 90.1-2013, Sec. 6.5.3.5.
13. Energy recovery systems are required for individual fan systems with a design supply fan capacity that exceeds the values listed in ASHRAE Standard 90.1-2013, Tables 6.5.6.1-1 and 6.5.6.1-2 based on climate zone and percentage of outdoor airflow rate at design conditions. The energy recovery system will have a minimum energy recovery effectiveness of 50 percent (50 percent of the difference between the outside air enthalpy and the return air enthalpy at design conditions).
 - a. Exceptions:
 1. Laboratory exhaust systems as defined in the following.
 2. Commercial kitchen hoods.
 3. Hazardous exhaust systems: See Part 17.
 4. Heating only systems with design space temperatures less than 60°F.
 5. Where 60 percent of the outdoor heating energy is provided by site recovered energy or site solar energy.
 6. Heating energy recovery in Climate Zones 1 and 2.
 7. Cooling energy recovery in Climate Zones 3C, 4C, 5B, 5C, 6B, 7, and 8.
 8. Where the largest exhaust source is less than 75 percent of the design outdoor airflow.
 9. Systems requiring dehumidification that employ energy recovery in series with the cooling coil.

10. Systems expected to operate less than 20 hours per week at the outdoor air percentage covered by Table 6.5.6.1-1.

14. Commercial kitchen hood exhaust systems.

a. See ASHRAE Standard 90.1-2013, Sec. 6.5.7.1.

15. Buildings with laboratory exhaust systems having a total exhaust airflow rate greater than 5,000 CFM shall have at least one of the following features:

a. VAV laboratory exhaust and room supply system capable of reducing exhaust and makeup airflow rates and/or incorporate a heat recovery system to precondition makeup air from laboratory exhaust that shall meet the following:

$$A + B \times (E/M) \geq 50\%$$

where

A = percentage that the exhaust and makeup airflow rates can be reduced from design conditions

B = percentage sensible recovery effectiveness

E = exhaust airflow rate through the heat recovery device at design conditions

M = makeup airflow rate of the system at design conditions

b. VAV exhaust hoods with supply air and exhaust airflow reduction to 50 percent or less of the system design airflow.

c. Direct makeup air delivered to the laboratory fumes hoods equal to at least 75 percent of the exhaust flow rate, heated no warmer than 2°F below the room design temperature, cooled to no cooler than 3°F above the room design temperature, no humidification added, and no simultaneous heating and cooling used for dehumidification control.

d. Heat recovery systems to precondition makeup air without using any exceptions.

16. Hot gas bypass:

a. Hot gas bypass shall not be used unless the system has multiple steps of capacity control or continuous modulation capacity control.

b. Hot gas bypass shall be limited as follows:

1. System capacity \leq 240,000 Btu/h: 15% of total system capacity.

2. System capacity > 240,000 Btu/h: 10% of total system capacity.

F. Performance Approach—Energy Cost Budget Method (Compliance Only)

1. Mandatory energy conservation requirements must still be met using the performance approach.
2. The energy cost budget for the proposed building must be less than or equal to the energy cost budget for the budget building design for compliance.
3. When using a performance-based energy compliance approach for a commercial facility, the energy model will have to be performed at least twice: once for the budget building design using the budget energy performance values defined in the code, and once using the proposed building design values as defined on the construction documents.
4. See ASHRAE Standard 90.1-2013, Sec. 11 for complete requirements of the energy cost budget method.

G. Performance Rating Method—Normative Appendix G

1. This performance rating method is intended for use in rating the energy efficiency of building designs that exceed the minimum requirements of this code.
2. Mandatory energy conservation requirements must still be met using the performance rating method.
3. The improved performance of the proposed building design is calculated in accordance with provisions of this appendix using the following formula:
Percentage improvement = $100 \times (\text{Baseline building performance} - \text{Proposed building performance}) / \text{Baseline building performance}$
4. See ASHRAE Standard 90.1-2013, Normative Appendix G for complete requirements of the performance rating method.

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15.05. ASHRAE Standard 90.2-2007

A. Purpose: To provide minimum requirements for the energy-efficient design of residential buildings.

B. Duct Insulation

1. All portions of the air distribution system used for heating or cooling shall be insulated with R-8 insulation.
2. Ducts are not required to be insulated:
 - a. When supply and return ductwork are within the conditioned space.
 - b. If it is exhaust ductwork.

C. Pipe Insulation

1. Piping shall be insulated as follows:

Fluid Design Operating Temperature	Conductivity Btu in./h ft.2 °F	Nominal Pipe or Tube Diameter				
		<1"	1" to 1- 1/4"	1- 1/2" to 3- 1/2"	4" to 6"	≥8"
Heating Systems—Hot Water and Steam Condensate						
201-250°F	0.27-0.30	1.5	1.5	2.0	2.0	2.0
141-200°F	0.25-0.29	1.0	1.0	1.0	1.5	1.5
105-140°F	0.22-0.28	0.5	0.5	1.0	1.0	1.0
Heating Systems—Steam						
212-250°F 0-15 Psig	0.27-0.30	1.5	1.5	2.0	2.0	2.0
Cooling Systems—Chilled Water, Glycol, Brine, and Refrigerant						
40-55°F	0.22-0.28	0.5	0.5	1.0	1.0	1.0
< 40°F	0.22-0.28	0.5	1.0	1.0	1.0	1.5

D. Ventilation: See Part 8 or ASHRAE Standard 62.2.

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Part 16: HVAC System Selection Criteria

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16. Part 16: HVAC System Selection Criteria

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16.01. HVAC System Selection Criteria

A. Building Type

1. Institutional: hospital, prisons, nursing homes, education.
2. Commercial: offices, stores.
3. Residential: hotel, motel, apartments.
4. Industrial: manufacturing.
5. Research and development: laboratories.

B. Owner Type

1. Government.
2. Developer.
3. Business.
4. Private.

C. Performance Requirements

1. Supporting a process: computer facility, telephone facility.
2. Promoting a germ-free environment.
3. Increasing sales and rental income.
4. System efficiency.

5. Increasing property salability.
6. Standby and reserve capacity.
7. Reliability, life expectancy: frequency of maintenance and failure.
8. How will equipment failures affect the building? Owner operations?

D. Capacity Requirements

1. Cooling loads: magnitude and characteristics.
2. Heating loads: magnitude and characteristics.
3. Ventilation.
4. Zoning requirements:
 - a. Occupancy.
 - b. Solar exposure.
 - c. Special requirements.
 - d. Space temperature and humidity tolerances.

E. Spatial Requirements

1. Architectural constraints:
 - a. Aesthetics.
 - b. Structural support.
 - c. Architectural style and function.
2. Space available to house equipment and location.
3. Space available for distribution of ducts and pipes.
4. Acceptability of components protruding into occupied space, physically and visually.
5. Furniture placement.
6. Flexibility.
7. Maintenance accessibility.
8. Roof.

9. Available space constraints.
10. Are mechanical rooms/shafts required?

F. Comfort Considerations

1. Control options.
2. Noise and vibration control.
3. Heating, ventilating, and air conditioning.
4. Filtration.
5. Air quality control.

G. First Cost

1. System cost. Return on investment.
2. Cost to add zones.
3. Ability to increase capacity.
4. Contribution to life safety needs.
5. Air quality control.
6. Future cost to replace and/or repair.

H. Operating Costs

1. Energy costs.
2. Energy type:
 - a. Electricity. Voltage available, rate schedule.
 - b. Gas.
 - c. Oil.
 - d. District steam.
 - e. District chilled water.
 - f. Other sources.
3. Energy types available at project site.
4. Equipment selection.

I. **Maintenance Cost**

1. Cost to repair.
2. Capabilities of owner's maintenance personnel.
3. Cost of system failure on productivity.
4. Economizer cycle:
 - a. Airside economizer.
 - b. Waterside economizer.
5. Heat recovery.
6. Future cost to replace.
7. Ease and quickness of servicing.
8. Ease and quickness of adding zones.
9. Extent and frequency of maintenance.

J. **Codes**

1. Codes govern HVAC and other building systems design.
2. Most building codes are adopted and enforced at the local level.
3. Most of the states have adopted the International Series of Codes.
4. Codes are not enforceable unless adopted by municipality, borough, county, state, etc.
5. Codes regulate:
 - a. Design and construction.
 - b. Allowable construction types.
 - c. Building height.
 - d. Egress requirements.
 - e. Structural components.
 - f. Light and ventilation requirements.
 - g. Material specifications.

6. Code approaches:
 - a. Prescriptive. Dictate specific materials and methods (ASTM A53, Steel Pipe, Welded).
 - b. Performance. Dictate desired results (HVAC system to provide and maintain a design temperature of 70°F winter and 75°F/50 percent RH summer).
7. Codes developed because of:
 - a. Loss of life.
 - b. Loss of property.
 - c. Pioneered by insurance industry.
8. 2015 International Code Council Series of Codes (ICC):
 - a. 2015 International Building Code.
 - b. 2015 International Mechanical Code.
 - c. 2015 International Energy Conservation Code.
 - d. 2015 International Plumbing Code.
 - e. 2015 International Fire Code.
 - f. 2015 International Fuel Gas Code.
 - g. 2015 International Residential Code.
 - h. 2015 International Existing Building Code.
 - i. 2015 International Performance Code for Buildings and Facilities.
 - j. 2015 International Private Sewage Disposal Code.
 - k. 2015 International Property Maintenance Code.
 - l. 2015 International Zoning Code.
 - m. 2015 International Wildland-Urban Interface Code.

16.02. Heating System Selection Guidelines

- A. **If heat loss exceeds 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.**
- B. **If heat loss is between 250 and 450 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, and blanketing the exposed wall and window areas.**
- C. **If heat loss is less than 250 Btu/h per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away from, the exposed wall and window areas.**

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 16: HVAC System Selection Criteria, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 17: Air Distribution Systems

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17. Part 17: Air Distribution Systems

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17.01. Ductwork Systems

A. Ductwork Sizing Criteria Table

DUCTWORK SIZING CRITERIA

System Type	Maximum Friction Rate in. W.G./100 ft.	Minimum Velocity ft./min.	Maximum Velocity ft./min.	Comments/Reasons
General Air Handling Systems				
Low Pressure Ducts	0.10 (0.15)	-	1,500-1,800	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs; applicable for supply, return, exhaust, and outside air systems
Medium Pressure Ducts	0.20 (0.25)	-	2,000-2,500	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs; applicable for supply systems only
Notes 1. Friction rates in parenthesis should only be used when space constraints dictate. 2. Maximum aspect ratio 4:1; unless space constraints dictate greater aspect ratios.				

System Type	Maximum Friction Rate in. W.G./100 ft.	Minimum Velocity ft./min.	Maximum Velocity ft./min.	Comments/Reasons
High Pressure Ducts	0.40 (0.45)	-	2,500-3,500	When CFM > 5,000 velocity governs; when CFM < 5,000 friction rate governs; applicable for supply systems only
Transfer Air Ducts	0.03-0.05	-	1,000	When CFM > 3,200 velocity governs; when CFM < 3,200 friction rate governs
Outside Air Shafts	0.05-0.10	-	1,000	When CFM > 1,200 velocity governs; when CFM < 1,200 friction rate governs
Gravity Relief Air Shafts	0.03-0.05	-	1,000	When CFM > 3,200 velocity governs; when CFM < 3,200 friction rate governs
General Exhaust and Special Exhaust Systems				
General Exhaust Ducts	0.10 (0.15)	-	1,500-1,800	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs
Toilet Exhaust Ducts	0.10 (0.15)	-	1,500-1,800	When CFM > 6,000 velocity governs; when CFM < 6,000 friction rate governs
Kitchen Hood Exhaust Ducts	-	1,500	2,200	2015 IMC: 500 FPM min.; NFPA 96-2014: 500 FPM min.
Dishwasher Exhaust Ducts	0.10 (0.15)	1,500	2,200	
Notes:	0.50 (0.60)	1,000	3,000	Mains and risers

System Type	Maximum Friction Rate in. W.G./100 ft.	Minimum Velocity ft./min.	Maximum Velocity ft./min.	Comments/Reasons
Ammonia, and Solvent Mains				1,500–3,000 FPM; Branches and lateral 1,000–2,000 FPM
Acid, Ammonia, and Solvent Stacks		3,000	4,000	
Silane Ducts	-	250	-	Velocity across the neck of the cylinder or cabinet window or access port
Louvers				
Intake	-	-	500	Maximum velocity through free area; assuming 50% free area—max. velocity 250 FPM through gross louver area
Exhaust or Relief	-	-	700	Maximum velocity through free area; assuming 50% free area—max. velocity 350 FPM through gross louver area
<p>Notes:</p> <ol style="list-style-type: none"> Friction rates in parenthesis should only be used when space constraints dictate. Maximum aspect ratio 4:1; unless space constraints dictate greater aspect ratios. When diffusers, registers, and grilles are mounted to supply, return, and exhaust ducts, duct velocities should not exceed 1,500 FPM or noise will result. 				

B. Ductwork System Sizing

1. Low pressure: 0.10 (0.15) in. W.G./100 ft.; 1,500–1,800 FPM maximum.
2. Medium pressure: 0.20 (0.25) in. W.G./100 ft.; 2,000–2,500 FPM maximum.
3. High pressure: 0.40 (0.45) in. W.G./100 ft.; 2,500–3,500 FPM maximum.
4. Transfer ducts: 0.03–0.05 in. W.G./100 ft.; 1,000 FPM maximum.
5. Transfer grilles: 0.03–0.05 in. W.G. pressure drop.
6. Outside air shafts: 0.05–0.10 in. W.G./100 ft.; 1,000 FPM maximum.
7. Gravity relief air shafts: 0.03–0.05 in. W.G./100 ft.; 1,000 FPM Maximum.
8. Decrease or increase duct size whenever the duct changes by 4" or more in one or two dimensions. Do *NOT* use fractions of an inch for duct sizes.
9. Try to change only one duct dimension at a time because it is easier to fabricate fittings and therefore generally less expensive—that is, 36 × 12 to 30 × 12 in lieu of 36 × 12 to 32 × 10.
10. Duct taps should be 2" smaller than the main duct to properly construct and seal the duct. The duct size should be 2" wider than diffusers, registers, and grilles.
11. All 90-degree square elbows should be provided with double radius turning vanes. Elbows in dishwasher, kitchen, and laundry exhausts should be of unvaned smooth radius construction with a radius equal to 1-½ times the width of the duct.
12. Provide flexible connections at the point of connection to equipment in all ductwork systems (supply, return, and exhaust) connected to air handling units, fans, and other equipment.
13. Provide access doors to access all fire dampers, smoke dampers, smoke detectors, volume dampers, motor-operated dampers, humidifiers, coils (steam, hot water, chilled water, electric), and other items located in ductwork that requires service and/or inspection.
14. All rectangular duct taps should be made with shoe (45 degree) fittings. Do *NOT* use splitter dampers or extractors.
15. NFPA 90A-2015:

- a. Service openings shall be located at approximately 20-foot intervals in horizontal ducts and at the base of each vertical riser to facilitate cleaning unless the ductwork can be accessed through removable diffusers, registers, and grilles.
 1. Exception: Service openings are not required where all of the following can be met:
 - a. The occupancy has no process that produces combustible material such as dust, lint, or greasy vapors (banks, offices, churches, hotels, and health care facilities, except kitchens, laundries, and manufacturing portions of such facilities).
 - b. The air inlets are at least 7 feet above the floor and are protected by metal screens (registers, grilles) that prevent paper, refuse, or other combustible solids from entering the system.
 - c. The minimum return duct design velocity is 1,000 FPM.
 - b. Air outlets and inlets shall be located at least 3" above the floor unless provisions have been made to prevent dirt and dust from entering the system. Where outlets are located less than 7 feet above the floor, outlet openings shall be protected by a grille or screen with a maximum ½" opening size (register or grille).
16. Maximum ductwork hanger spacing:
- a. SMACNA minimum requirements:
 1. Horizontal: 8 to 10 feet maximum.
 2. Vertical: One- or two-story intervals—12 to 24 feet.
 - b. Recommended:
 1. Horizontal ducts less than 4 square feet: 8 feet maximum.
 2. Horizontal ducts 4 to 10 square feet: 6 feet maximum.
 3. Horizontal ducts greater than 10 square feet: 4 feet maximum.
 4. Vertical round ducts: 12 feet maximum.
 5. Vertical rectangular ducts: 10 feet maximum.

DUCTWORK SUPPORT

Ductwork Type	Maximum Hanger Spacing Feet
Horizontal Ducts Less than 4 Square Feet	8
Horizontal Ducts 4 to 10 Square Feet	6
Horizontal Ducts Greater than 10 Square Feet	4
Vertical Round Ducts	12
Vertical Rectangular Ducts	10

C. Friction Loss Estimate

1. $1.5 \times \text{System Length (ft./100)} \times \text{Friction Rate (in. W.G./100 ft.)}$.

D. Ductwork Sizes

1. 4" × 4" smallest rectangular size.
2. 8" × 4" smallest recommended size.
3. Rectangular ducts: Use even duct sizes—that is, 24 × 12, 10 × 6, 72 × 36, 48 × 12.
4. 4:1 maximum recommended aspect ratio.
5. 3" smallest round size, odd and even sizes available.
6. Round ducts available in 0.5-inch increments for duct sizes through 5.5-inch diameter, 1-inch increments for duct sizes 6 inches through 20 inches, and 2-inch increments for duct sizes 22 inches and greater.

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17.02. Duct Construction

A. Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) Duct Construction Manuals:

1. *SMACNA—HVAC Duct Construction Standards—Metal and Flexible*, Third Edition, referred to herein as SMACNA-HVAC.
2. *SMACNA—Fibrous Glass Duct Construction Standards*, Seventh Edition, referred to herein as SMACNA-FG.

3. *SMACNA—Rectangular Industrial Duct Construction Standard, Second Edition*, referred to herein as SMACNA-IDC.
4. *SMACNA—Round Industrial Duct Construction Standard, Second Edition*, referred to herein as SMACNA-RIDC.
5. *SMACNA—Thermoplastic Duct (PVC) Construction Manual, Second Edition*, referred to herein as SMACNA-PVC.

B. SMACNA-HVAC Pressure Ratings

1. $\pm\frac{1}{2}$; ± 1 ; ± 2 ; ± 3 ; ± 4 ; ± 6 ; ± 10 .

C. SMACNA-IDC and SMACNA-RIDC Pressure Ratings

1. +12" to + 100" by multiples of 2".
2. -4" to -100" by multiples of -2".

D. SMACNA Ductwork Testing

1. -4" W.G. and lower: 1.5 × Pressure Rating.
2. -3" to +3" W.G.: Generally not tested.
3. +4" W.G. and higher: 1.5 × Pressure Rating.

E. ASHRAE Standard 90.1-2013: A minimum of 25 percent of duct systems designed to operate at static pressures exceeding 3" WC and all ductwork located outdoors shall be leak tested according to industry-accepted procedures.

F. Recommended Testing

1. All supply duct systems operating at static pressures 3" and higher must be leak tested from air the handling unit to the vertical riser and from the vertical riser to 5 feet beyond shaft penetration on each and every floor (ductwork hidden in shaft construction).
2. All return duct systems operating at static pressures 3" and higher must be leak tested from the air handling unit to the vertical riser and from the vertical riser to 5 feet beyond shaft penetration on each and every floor (the ductwork is hidden in the shaft construction).
3. Leak test a representative sample of duct systems designed to operate at static pressures exceeding 3" WC on each floor to complete the minimum 25-percent leak testing required by ASHRAE Standard 90.1 and other energy conservation codes.

G. **SMACNA-HVAC Ductwork Seal Classes**

1. Seal Class A: 2–5 percent total system leakage (seal all transverse joints, longitudinal seams, and duct penetrations).
2. Seal Class B: 3–10 percent total system leakage (seal all transverse joints and longitudinal seams).
3. Seal Class C: 5–20 percent total system leakage (seal all transverse joints).
4. Unsealed: 10–40 percent total system leakage.
5. SMACNA recommended seal classes.

SMACNA DUCTWORK SEAL CLASSES

Seal Class	Applicable Static Pressure Construction Class
A	4" WC and higher
B	3" WC
C	2" WC
C	½" WC and higher for all ductwork upstream of VAV terminal units

H. **ASHRAE Standard 90.1-2013 Ductwork Seal Class**

1. ASHRAE Standard 90.1-2013 requires ductwork and all plenums with a pressure rating to be constructed to Seal Class A (seal all transverse joints, longitudinal seams, and duct penetrations).

I. **Recommended Ductwork Seal Classes**

1. Seal Class A: Seal all transverse joints, longitudinal seams, and duct penetrations.
2. Seal Class B: Seal all transverse joints and longitudinal seams.
3. Seal Class C: Seal all transverse joints.

RECOMMENDED DUCTWORK SEAL CLASSES

SMACNA Pressure Class (in. WC)

	$\pm\frac{1}{2}$	± 1	± 2	± 3	± 4	± 6	± 10
Supply Ductwork							
Outdoors	A	A	A	A	A	A	A
Unconditioned Space	B	B	B	A	A	A	A
Conditioned Space	B	B	B	A	A	A	A
Return Ductwork							
Outdoors	A	A	A	A	A	A	A
Unconditioned Space	B	B	B	B	A	A	A
Conditioned Space	B	B	B	B	A	A	A
SMACNA Pressure Class (in. WC)							
	$\pm\frac{1}{2}$	± 1	± 2	± 3	± 4	± 6	± 10
Exhaust Ductwork							
Outdoors	B	B	B	B	A	A	A
Unconditioned Space	B	B	B	B	A	A	A
Conditioned Space	B	B	B	B	A	A	A

J. Ductwork Materials

1. Galvanized Steel: HVAC Applications; Most Common; Galvanized steel sheets meeting *ASTM A90, A525, and A527, Lock Forming Quality.*

Minimum Coating Weight oz./sq.ft.

Single Spot Test

ASTM Galvanized Coating Designations	Triple Spot Test Average Total Both Sides	One Side	Total Both Sides
G210	2.10	0.72	1.80
G185	1.85	0.64	1.60
G165	1.65	0.56	1.40
G140	1.40	0.48	1.20
G115	1.15	0.40	1.00
G90	0.90	0.32	0.80
G60	0.60	0.20	0.50
G40	0.40	0.12	0.30
G30	0.30	0.10	0.25

2. Carbon steel: Breechings, flues, and stacks; carbon steel meeting *ASTM A569* for stacks and breechings 24" and larger; galvanized sheet steel meeting *ASTM A527* with *ANSI/ASTM A525 G90* zinc coating for stacks and breechings less than 24".
3. Aluminum: Moisture laden air streams; aluminum base alloy sheets meeting *ASTM B209*, Lock Forming Quality.
4. Stainless steel: Kitchen hood and fume hood exhaust; stacks and breechings (prefabricated); Type 304, 304L, 316, or 316L stainless steel sheets meeting *ASTM A167*:
 - a. 304 and 316: Non-welded applications.
 - b. 304L and 316L: Welded applications.
 - c. Kitchen exhaust finish:
 1. Concealed: None.
 2. Exposed: No. 2B, No. 4, or match equipment (No. 4 preferred).

- d. Lab fume exhaust finish:
 - 1. Concealed: No. 2B.
 - 2. Exposed: No. 2B.
- 5. Fiberglass: HVAC applications; 1"-thick glass duct board meeting U.L. 181.
- 6. Fiberglass reinforced: Chemical exhaust; plastic (FRP).
- 7. Polyvinyl chloride (PVC): Chemical exhaust, underground ducts; PVC conforming to *NFPA 91*, *ASTM D1784*, *D1785*, *D1927*, and *D2241*.
- 8. Concrete: Underground ducts, air shafts; reinforced concrete pipe meeting *ASTM C76*, *Class IV*.
- 9. Gypsum: Air shafts (generally provided by architects).
 - a. 2015 IMC:
 - 1. Temperature shall not exceed 125°F.
 - 2. Gypsum board surface temperature must be maintained above the dewpoint.
 - 3. Gypsum board ducts shall not be used for supply air.
 - b. NFPA 90A-2015: Gypsum board ducts shall be permitted to be used for negative pressure exhaust and return ducts where the temperature of the conveyed air does not exceed 125°F.
- 10. Copper: ornamental.
- 11. Polyvinyl Steel and Stainless Steel (PVS and PVSS): Chemical exhaust; common type: Halar-coated stainless steel, Teflon-coated stainless steel.
- 12. Sheet metal gauges (applies to preceding item numbers 1, 3, 4, and 10):
 - a. 16, 18, 20, 22, 24, 26 SMACNA or welded construction.
 - b. 10, 11, 12, 13, 14 welded construction only.

K. Flexible Duct

- 1. 5-8 ft. maximum recommended length.
- 2. Insulated, uninsulated.
- 3. NFPA 90A-2015: 14 feet maximum.

L. Ductwork Sheet Metal Gauges and Weights

SMACNA HVAC DUCTWORK SHEET METAL GAUGES

SMACNA Pressure Class

Maximum Duct Dimension	$\pm\frac{1}{2}$		± 1		± 2		± 3		± 4		± 6		± 1
	A	B	A	B	A	B	A	B	A	B	A	B	A
	4"-8"	26	-	26	-	26	-	24	26	24	26	24	26
9"-10"	26	-	26	-	26	-	24	26	22	26	24	24	20
11"-12"	26	-	26	-	26	-	24	26	22	26	20	24	18
13"-14"	26	-	26	-	24	26	22	24	20	24	20	22	18
15"-16"	26	-	26	-	24	26	22	24	20	24	18	22	16
17"-18"	26	-	24	26	22	26	20	24	18	24	18	22	16
19"-20"	24	26	24	26	20	26	18	24	18	24	16	22	-
21"-22"	22	26	22	26	18	26	18	24	18	24	16	22	-
23"-24"	22	26	22	26	18	26	18	24	18	22	16	22	-
25"-26"	20	26	20	26	18	26	18	24	16	22	-	20	-
27"-28"	18	26	18	26	18	24	18	22	16	22	-	20	-
29"-30"	18	26	18	26	18	24	18	22	16	22	-	18	-
31"-36"	181	26	18	24	16	24	16	20	-	20	-	18	-
37"-42"	6	26	16	24	-	22	-	20	-	18	-	16	-
43"-48"	16	26	16	22	-	22	-	18	-	18	-	16	-
49"-54"	-	26	-	22	-	20	-	18	-	18	-	16	-
55"-60"	-	24	-	22	-	20	-	18	-	16	-	16	-
61"-72"	-	22	-	18	-	18	-	16	-	16	-	16	-
73"-84"	-	22	-	18	-	16	-	16	-	16	-	16	-
85"-96"	-	20	-	18	-	16	-	16	-	16	-	16	-
97"-108"	-	18	-	16	-	16	-	16	-	16	-	16	-
109"-120"	-	16	-	16	-	16	-	16	-	16	-	16	-

Notes:

1. The table is based on the following:

- a. Column A: Duct gauge requirement with no reinforcement.**
- b. Column B: Duct gauge with reinforcement as indicated below.**

- c. $\pm\frac{1}{2}$ " Pressure Class: 5 feet reinforcing spacing for 19"-120".
SMACNA Pressure Class
- d. ± 1 " Pressure Class: 5 feet reinforcing spacing for 17"-108" and 4 feet spacing for 109"-120".
Maximum
- e. ± 2 " Pressure Class: 5 feet reinforcing spacing for 15"-84", 4 feet spacing for 85"-108", and 3 feet spacing for 109"-120".
Dimension
- f. ± 3 " Pressure Class: 5 feet reinforcing spacing for 4"-84", 4 feet spacing for 85"-96", and 3 feet spacing for 97"-120".
- g. ± 4 " Pressure Class: 5 feet reinforcing spacing for 4"-60", 4 feet spacing for 61"-72", and 3 feet spacing for 73"-120".
- h. ± 6 " Pressure Class: 5 feet reinforcing spacing for 4"-48", 4 feet spacing for 49"-60", and 3 feet spacing for 61"-120".
- i. ± 10 " Pressure Class: 5 feet reinforcing spacing for 4"-42", 4 feet spacing for 43"-54", 3 feet spacing for 55"-72", and 2 feet spacing for 73"-120".
2. Lighter sheet metal gauges may be used with additional reinforcing, and heavier gauges may be used with less reinforcing (see the SMACNA manuals).
3. Commercial installations recommend a 24-gauge minimum.

SHEET METAL GAUGES AND WEIGHTS

Material Weight lbs./sq.ft.

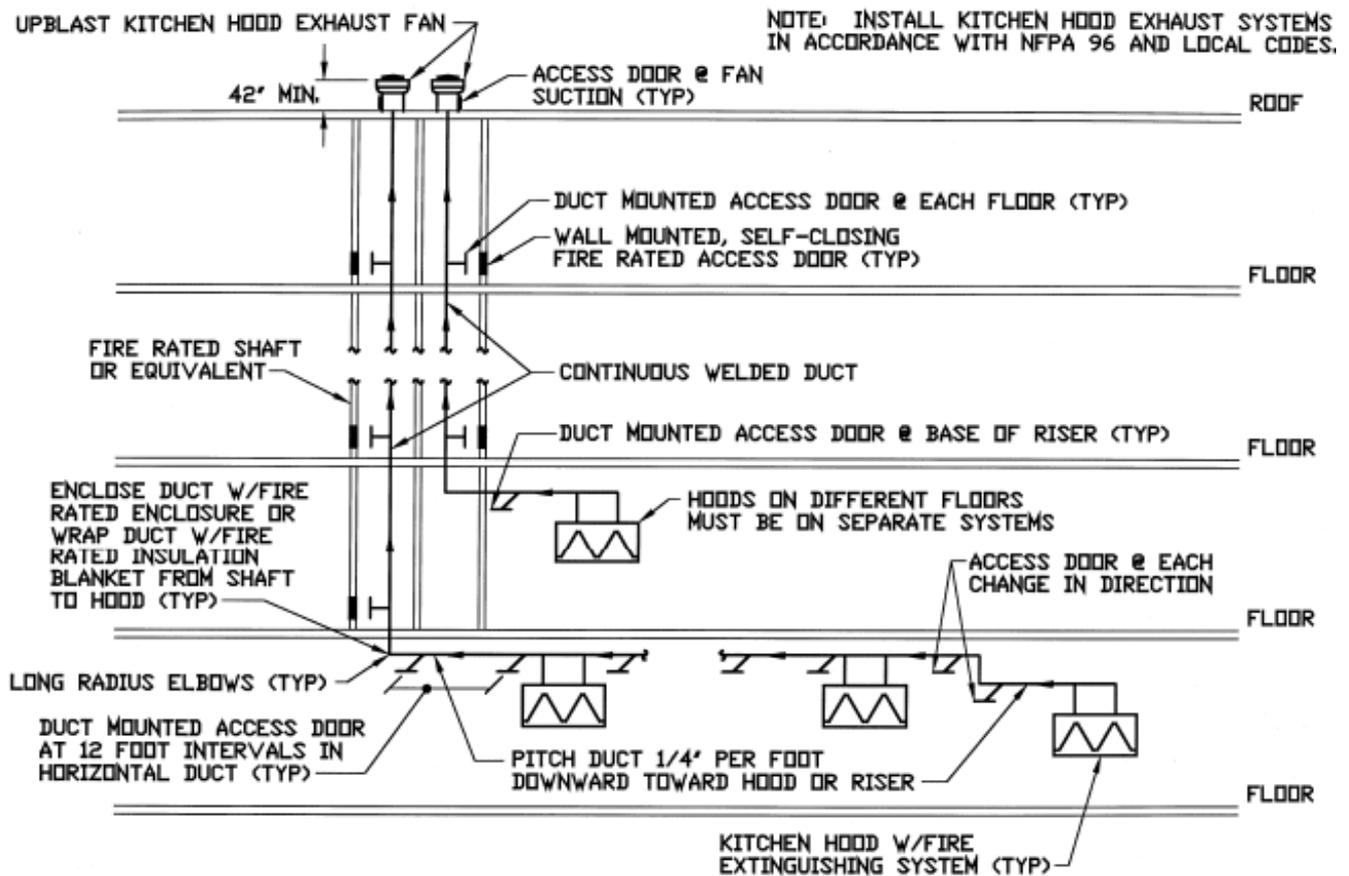
Sheet Metal Gauge	Galvanized Steel	300 Series Stainless Steel	Aluminum
26	0.906	0.748	0.224
24	1.156	0.987	0.282
22	1.406	1.231	0.352
20	1.656	1.491	0.451
18	2.156	2.016	0.563
16	2.656	2.499	0.718
14	3.281	3.154	0.901
12	4.531	4.427	1.141
10	5.781	5.670	1.436

SHEET METAL GAUGES

Sheet Metal Gauge	Thickness Inches	Remarks	Sheet Metal Gauge	Thickness Inches	Remarks
0	0.3125	Welded Ductwork Only	19	0.0437	SMACNA Ductwork Construction
1	0.2810		20	0.0375	
2	0.2650		21	0.0343	
3	0.2500		22	0.0312	
4	0.2340		23	0.0280	
5	0.2187		24	0.0250	
6	0.2030		25	0.0218	
7	0.1875		26	0.0187	
8	0.1720		27	0.0170	Gauges Not Permitted for Ductwork Construction
9	0.1560		28	0.0156	
10	0.1400		29	0.0140	
11	0.1250		30	0.0125	
12	0.1090		31	0.0109	
13	0.0937		32	0.0100	
14	0.0780		33	0.0093	
15	0.0700		34	0.0085	
16	0.0625	SMACNA Ductwork Construction	35	0.0078	
17	0.0560		36	0.0070	
18	0.0500				

17.03. Kitchen Exhaust Ducts and Hoods

A. For examples of kitchen hood exhaust systems, see **Figs. 17.1** through **17.3**.



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Figure 17.1. KITCHEN HOOD EXHAUST SYSTEM-UPBLAST FAN.

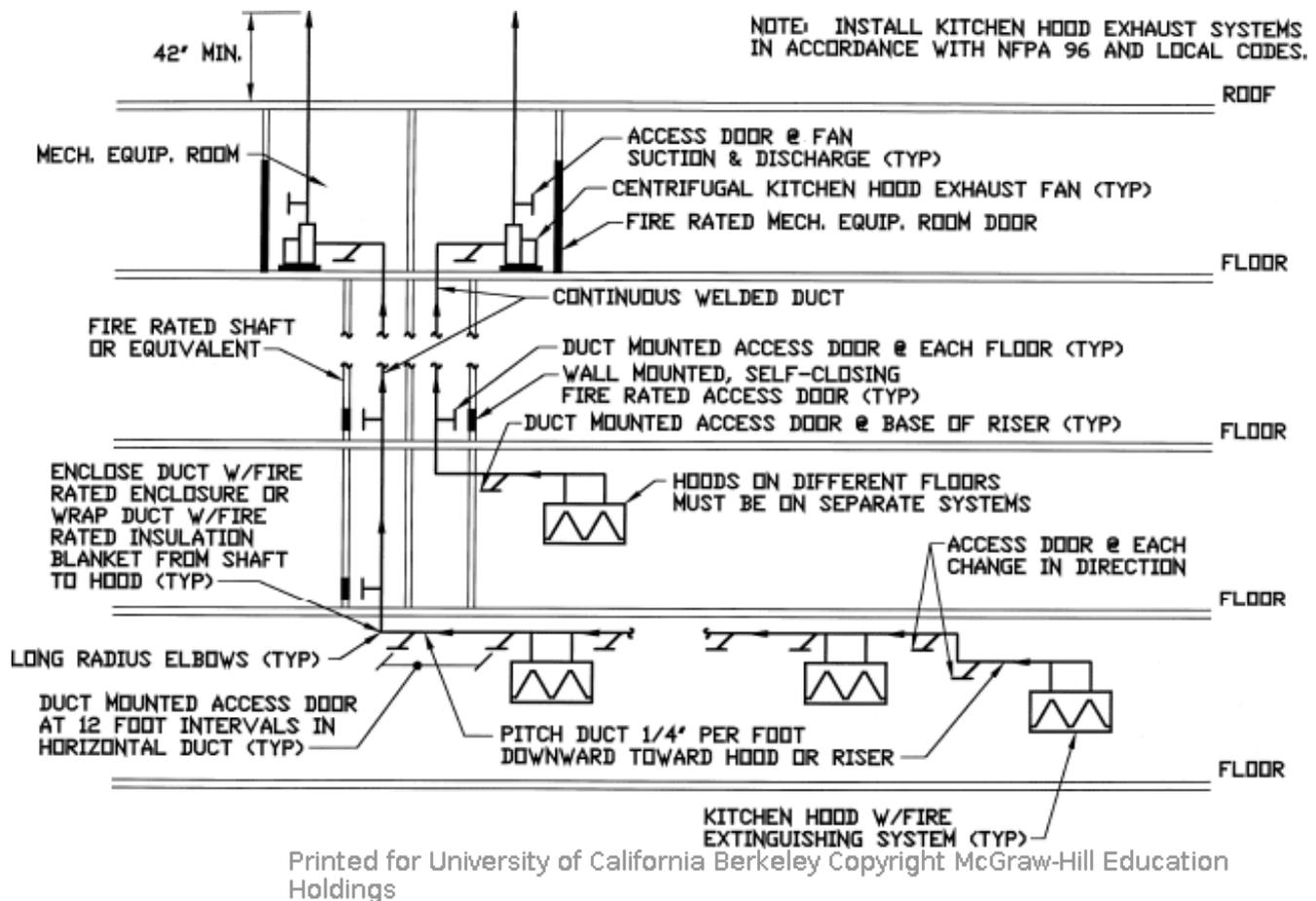


Figure 17.2. KITCHEN HOOD EXHAUST SYSTEM-UTILITY SET FAN.

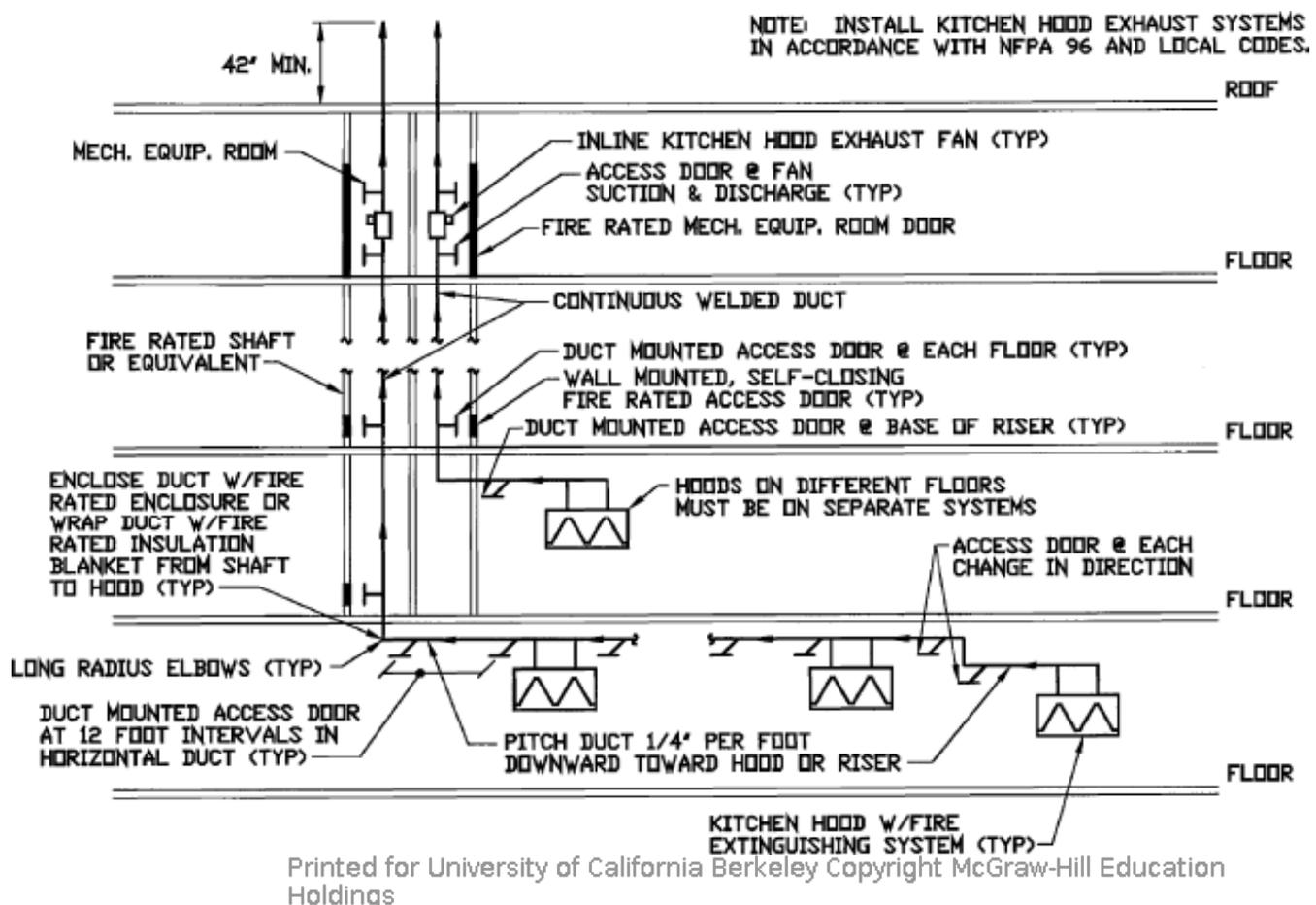


Figure 17.3. KITCHEN HOOD EXHAUST SYSTEM-INLINE FAN.

1. Exhaust/makeup air:
 - a. Exhaust systems: 500 ft./min. minimum duct velocity.
 - b. Type I hood exhaust systems shall be independent of all other exhaust systems. Combining Type I systems permitted if all of the following are met:
 1. Hoods are located on the same floor.
 2. Hoods located in the same room or adjoining rooms.
 3. Interconnecting ducts do not penetrate fire rated assemblies.
 4. Solid fuel appliances must have separate exhaust system.
 - c. Type II hood exhaust systems shall be independent of all other exhaust systems. Combining Type II hoods is permitted following the same rules as listed for Type I hoods.
 - d. Hoods serving solid fuel cooking appliances must have separate exhaust systems from all the other hoods.
 - e. Makeup air systems: ΔT shall not be greater than 10°F, unless it is part of the AC system or will not cause a decrease in comfort conditions.
 - f. Supply air shall be approximately equal to the exhaust air.
 - g. The exhaust shall terminate a minimum of 40" above the roof.
2. Duct sheet metal construction:
 - a. 16 ga. steel.
 - b. 18 ga. 304 stainless steel.
 - c. Type I hood exhaust ducts shall be all welded or brazed construction.
 - d. Type I hood horizontal duct slope:
 1. Horizontal ducts 75 feet or less in length: 1/4" per foot.
 2. Horizontal ducts greater than 75 feet in length: 1" per foot.
 - e. Type I hood exhaust ducts shall be enclosed in a fire rated enclosure from the penetration of the ceiling, wall, or floor to the point of the outlet terminal. The rating of the enclosure shall not be less than that of the assembly penetrated and not less than 1 hour.
 1. Horizontal (in kitchen): Fire rated duct wrap recommended.

2. Horizontal (shaft offsets): Shaft enclosure recommended.
 3. Vertical: Shaft enclosure recommended.
3. Cleanouts:
- a. Base of riser.
 - b. Horizontal:
 1. Every 20 feet.
 2. Not more than 10 feet from changes in direction that are greater than 45 degrees.
4. Hoods:
- a. Type I hoods: Serve appliances that produce grease or smoke—such as griddles, fryers, broilers, ovens, ranges, and wok ranges.
 1. Type I hood exhaust system shall operate automatically through an interlock with the cooking appliances, by means of heat sensors, or by other approved methods.
 - b. Type II hoods: Serve appliances that produce heat or steam but do not produce grease or smoke—such as steamers, kettles, pasta cookers, and dishwashers.
 - c. Domestic appliances used for commercial purposes shall be provided with Type I or Type II hoods as applicable.
 - d. Hood construction:
 1. Type I hoods:
 - Steel: 18 gauge
 - Stainless steel: 20 gauge
 2. Type II hoods:
 - Steel 22 gauge
 - Stainless steel: 24 gauge
 - e. Hood exhaust:

Minimum CFM per Lineal Foot of Hood

Type of Cooking Appliances

Type of Hood	Extra- Heavy Duty	Heavy Duty	Medium Duty	Light Duty

	Minimum CFM per Lineal Foot of Hood			
	550	400	300	200
	Type of Cooking Appliances			
Type of Hood	Extra-Heavy Duty	Heavy Duty	Medium Duty	Light Duty
Wall-Mounted Canopy				
Single Island Canopy	700	600	500	400
Double Island Canopy (per side)	550	400	300	250
Backshelf/Pass-Over	Not permitted	400	300	250
Eyebrow	Not permitted	Not permitted	250	250

Notes:

- 1. Airflows indicated in the table are net quantity of exhaust air and shall be calculated by subtracting any airflow supplied directly to a hood cavity from the total exhaust flow rate of the hood.**
- 2. Where more than one type of appliance is located under a single hood, the highest exhaust rate shall be used.**
- 3. Extra-heavy duty cooking appliances: Cooking appliances using solid fuel as the primary source of heat for cooking, such as wood, charcoal, briquettes, and mesquite. Type I hoods serving barbeque pits, barbeque cooking appliances, solid fuel burning stoves and ovens, hickory grilles, charbroilers, and charcoal grilles. Hoods serving these systems must have separate exhaust systems from all the other hoods.**
- 4. Heavy duty cooking appliances: Type I hoods serving electric under-fired broilers, electric chain (conveyor) broilers, gas open-burner ranges (with or without oven), electric and gas wok ranges, and electric and gas over-fired (upright) broilers and salamanders.**
- 5. Medium duty cooking appliances: Type I hoods serving electric discrete element ranges (with or without oven), electric and gas hot-top ranges, electric and gas griddles, electric and gas double-sided griddles, electric and gas fryers (open deep fat fryers, donut fryers, kettle fryers, and pressure fryers), electric and gas pasta cookers, electric and gas conveyor pizza ovens, electric and gas**

tilting skillets (braising pans), and electric and gas rotisseries.

Minimum CFM per Lineal Foot of Hood

6. Light duty cooking appliances: Type I hoods serving electric and gas ovens (standard, bake, roasting, revolving, retherm, convection, combination convection/steamer, conveyor, deck or deck style pizza, and pastry), electric and gas steam-jacketed kettles, electric and gas compartment steamers (both pressure and atmospheric), and electric and gas cheesemelters.

C. NFPA 96-2014

1. Exhaust/makeup air:

- a. Exhaust systems: 500 ft./min. minimum duct velocity.
- b. Supply air shall be adequate to prevent negative pressures from exceeding 0.02" WC.
- c. Exhaust shall terminate a minimum of 40" above the roof.
- d. Exhaust ducts shall not pass through fire walls.
- e. All ducts shall lead directly to the exterior of the building to reduce the risk of fire hazard.
- f. Exhaust ducts shall be independent of all other exhaust systems.
- g. Hoods serving solid fuel cooking appliances must have separate exhaust systems from all the other hoods.

2. Duct sheet metal construction:

- a. Carbon steel: 16 gauge
- b. Stainless steel: 18 gauge
- c. Exhaust ducts shall be all welded construction.
- d. Horizontal duct slope:
 1. All ducts shall be installed without forming drips or traps that might collect residues.
 2. All duct runs up to 75 feet in length shall be installed with a minimum of 2 percent slope. Duct runs greater than 75 feet in length shall be installed with a minimum of 8 percent slope.

- e. Exhaust ducts shall be enclosed in a fire rated enclosure from the penetration of the ceiling, wall, or floor to the point of the outlet terminal.
 - 1. Horizontal (in kitchen): Fire rated duct wrap recommended.
 - 2. Horizontal (shaft offsets): Shaft enclosure recommended.
 - 3. Vertical: Shaft enclosure recommended.
 - 4. 1 hour rating minimum for buildings less than four stories.
 - 5. 2 hour rating minimum for buildings four stories or more.
 - f. Exhaust duct enclosures shall be vented to the exterior of the building through weather-protected openings.
 - g. Each exhaust duct system shall constitute an individual system serving only exhaust hoods in one fire zone on one floor.
 - h. Common duct (manifold) systems: Master kitchen exhaust ducts that serve multiple tenants shall include provisions to bleed air from outdoors or from adjacent spaces into the master exhaust duct to maintain the necessary minimum air velocity in the master exhaust duct.
 - 1. The bleed air duct shall have a fire damper at least 12" from the master exhaust duct connection.
 - 2. The bleed air duct shall have a volume balancing damper upstream of the fire damper.
 - 3. The bleed air duct cannot be used for exhaust of grease-laden vapors and shall be labeled as such.
 - 4. The bleed air duct shall have the same construction requirements as the exhaust duct.
 - i. Dampers shall not be installed in exhaust ducts or exhaust duct systems.
3. Cleanouts:
- a. Horizontal: Every 12 feet.
 - b. Vertical: Every floor.
4. Hoods:
- a. Steel: 18 gauge.
 - b. Stainless steel: 20 gauge.

5. Hood exhaust: Exhaust air volumes for hoods shall be of sufficient level to provide for capture and removal of grease-laden cooking vapors.
6. Fire damper: A fire damper with a 286°F fusible link is required at each supply air connection to the hood.
 - a. Exception: If the supply air connection discharges air out the face of the hood rather than the bottom or into the hood and is isolated from the exhaust hood by continuously welded construction, it does not require a fire damper.

D. ASHRAE Standard 154-2011

1. Exhaust/makeup air:
 - a. Exhaust systems: 500 ft./min. minimum duct velocity.
 - b. The commercial kitchen ventilation system shall provide pressure differentials to control odor migration and to control dust, dirt, and insects.
 1. Kitchen—negative (maximum 0.02 in. w.c.) with respect to dining and other adjacent areas.
 2. Negative with respect to outdoors when the food-service facility shares a wall with an adjacent non-food-service facility, such as a retail center.
 - c. Exhaust discharge shall be designed to prevent re-entrainment into air intakes.
 - d. The minimum horizontal distance between intakes and discharge shall be 10 feet.
2. Hoods:
 - a. Type I hoods: A hood designed to capture heat, smoke and/or grease-laden vapor produced by a cooking process, incorporating listed grease-removal devices and fire suppression equipment. Equipment requiring Type I hoods—ranges, fryers, griddles, broilers, and ovens that produce smoke or grease-laden vapors.
 - b. Type II hoods: A hood designed to capture heat, odors, products of combustion, and/or moisture where smoke or grease laden vapor is not present. A Type II hood may or may not have filters or baffles and does not have a fire-suppression system. Equipment requiring Type II hoods—

dishwashers, microwave ovens, toasters, steam tables, popcorn poppers, hot dog cookers, coffee makers, rice cookers, egg cookers, and holding/warming ovens.

c. Mounting heights and overhang requirements:

Type of Hood	Mounting Height	End Overhang	Front Overhang	Rear Overhang
Wall-Mounted Canopy	78"	6"	12"	N/A
Single Island Canopy	78"	12"	12"	12"
Double Island Canopy	78"	12"	12"	N/A
Eyebrow	78"	N/A	12"	N/A
Backshelf/Pass-over	24"	6"	10"	N/A

Note:

1. Mounting heights are minimum dimensions and are listed with respect to the finished floor except the backshelf/pass-over hoods, which are the maximum dimensions above the cooking surface.

d. Hood exhaust:

**Type II Minimum Net Exhaust Flow Rate
CFM/Lineal Foot of Hood Length**

Type of Hood	Light Duty	Medium Duty
Wall-Mounted Canopy	200	300
Single Island Canopy	400	500
Double Island Canopy	250	250
Eyebrow	250	250
Backshelf/Pass-over	200	300

e. Appliance duty level:

1. Light duty: A cooking process requiring an exhaust airflow rate of less than 200 CFM/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Gas and electric ovens (standard, bake, roasting, revolving, rethermalizer, convection, combination convection/steamer, conveyor, deck or deck style pizza and pastry ovens, electric and gas steam-jacketed kettles, electric and gas compartment steamers, electric and gas cheesemelters, and electric and gas rethermalizers).
2. Medium duty: A cooking process requiring an exhaust airflow rate of 200 to 300 CFM/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Electric discrete element ranges, electric and gas hot-top ranges, electric and gas griddles, electric and gas double-sided griddles, electric and gas fryers (open deep fat fryers, donut fryers, kettle fryers, and pressure fryers), electric and gas pasta cookers, electric and gas conveyor (pizza) ovens, electric and gas tilting skillets/braising pans, and electric and gas rotisseries.
3. Heavy duty: A cooking process requiring an exhaust airflow rate of 300 to 400 CFM/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Electric and gas underfired broilers, electric and gas chain (conveyor) broilers, gas open-burner ranges (with or without oven), electric and gas wok ranges, electric and gas overfired (upright) broilers, and salamanders.
4. Extra-heavy duty: A cooking process requiring an exhaust airflow rate of greater than 400 CFM/ft. for capture, containment, and removal of the cooking effluent and products of combustion. Appliances using solid fuel such as wood, charcoal, briquettes, and mesquite.

E. Figures 17.4 and 17.5 are photographs of an upblast kitchen hood exhaust fan and makeup air unit in their installed conditions.



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Figure 17.4. PHOTOGRAPH OF AN UPBLAST KITCHEN HOOD EXHAUST FAN.



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Figure 17.5. PHOTOGRAPH OF A KITCHEN HOOD MAKEUP AIR UNIT.

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17.04. Louvers

A. Louvers: Use stationary louvers only. Do not use operable louvers because they become rusty or become covered with snow and ice and may not operate:

1. Intake (outdoor air): 500 ft./min. maximum velocity through free area.
2. Exhaust or relief: 700 ft./min. maximum velocity through free area.
3. Free area range:
 - a. Metal: 40–70 percent of gross area. Recommend using 50 percent free area.
 - b. Wood: 20–25 percent of gross area.
4. Pressure loss: 0.01–0.10" W.G.

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17.05. Volume Dampers (Manual or Balancing Dampers)/ Motor Operated Dampers (Control Dampers)

A. Damper Characteristics

1. Opposed blade: Balancing, mixing, modulating, and 2-position control applications.
2. Parallel blade: Two-position applications (open/closed).
3. Pressure Loss: 0.15" W.G. @ 2000 FPM (full open)
4. Size dampers at a flow rate of approximately 1,200–1,500 CFM/sq.ft. (1,200–1,500 FPM) rather than on duct size.
5. Linkage type:
 - a. Concealed—inside duct. When specifying concealed linkage, be careful of duct air temperatures and actuator ratings (e.g., generator radiator exhaust can reach temperatures in excess of some actuator ratings).
 - b. Exposed—outside duct.
6. Dampers may be specified with integral insulation.

B. Damper Leakage Classes (AMCA Certified)

1. Class I dampers:
 - 4.0 CFM/sq.ft. @ 1" W.G. differential.
 - 8.0 CFM/sq.ft. @ 4" W.G. differential.
 - 11.0 CFM/sq.ft. @ 8" W.G. differential.
 - 14.0 CFM/sq.ft. @ 12" W.G. differential.
2. Class II dampers:
 - 10.0 CFM/sq.ft. @ 1" W.G. differential.
 - 20.0 CFM/sq.ft. @ 4" W.G. differential.
 - 28.0 CFM/sq.ft. @ 8" W.G. differential.
 - 35.0 CFM/sq.ft. @ 12" W.G. differential.
3. Class III dampers:
 - 40.0 CFM/sq.ft. @ 1" W.G. differential.
 - 80.0 CFM/sq.ft. @ 4" W.G. differential.
 - 112.0 CFM/sq.ft. @ 8" W.G. differential.
 - 140.0 CFM/sq.ft. @ 12" W.G. differential.

C. Damper Types

1. Standard V-groove blade—approximately 2,000 FPM maximum velocity.

2. Airfoil blade—approximately 4,000 FPM maximum velocity.

D. Recommended

1. Two-position ducted applications: AMCA certified Ultra-low Leakage Class with a maximum 8.0 CFM/sq.ft. leakage rate at a 4" WC pressure differential, airfoil-parallel blade, motor-operated damper.
2. All other ducted applications: AMCA certified Ultra-low Leakage Class with a maximum 8.0 CFM/sq.ft. leakage rate at 4" WC pressure differential, airfoil-opposed blade, motor operated damper.
3. Non-ducted applications: AMCA certified Ultra-low Leakage Class with a maximum 8.0 CFM/sq.ft. leakage rate at 4" WC pressure differential, insulated-airfoil-opposed blade, motor-operated damper.

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17.06. Fire Dampers, Smoke Dampers, and Combination Fire/Smoke Dampers

A. Fire, Smoke, and Combination Damper Classifications

1. Damper type:
 - a. Expanding curtain type (fire damper only):
 1. Type A: Frame and damper storage are located in the airstream.
 2. Type B: Damper storage is totally recessed out of the airstream.
 3. Type C: Frame and damper storage are totally recessed out of the airstream.
 4. Recommend using Type C in ducted and ducted transfer applications and Type A in transfer grille applications (to fit within the grille dimension, must oversize the grille to account for the frame and blades).
 - b. Opposed blade type:
 1. V-groove blades: Maximum velocity of 2,000 FPM.
 2. Airfoil blades: Maximum velocity of 4,000 FPM.
 3. Blades and frame are located in the airstream. Must account for the pressure drop of the damper and frame in static pressure calculations.
 4. Leakage class:

- a. Leakage Class I:
 - 4.0 CFM/sq.ft. @ 1" WC pressure differential.
 - 8.0 CFM/sq.ft. @ 4" WC pressure differential.
 - 11.0 CFM/sq.ft. @ 8" WC pressure differential.
 - 14.0 CFM/sq.ft. @ 12" WC pressure differential.

- b. Leakage Class II:
 - 10.0 CFM/sq.ft. @ 1" WC pressure differential.
 - 20.0 CFM/sq.ft. @ 4" WC pressure differential.
 - 28.0 CFM/sq.ft. @ 8" WC pressure differential.
 - 35.0 CFM/sq.ft. @ 12" WC pressure differential.

- c. Leakage Class III: (Not Permitted by IMC Code)
 - 40.0 CFM/sq.ft. @ 1" WC pressure differential.
 - 80.0 CFM/sq.ft. @ 4" WC pressure differential.
 - 112.0 CFM/sq.ft. @ 8" WC pressure differential.
 - 140.0 CFM/sq.ft. @ 12" WC pressure differential.

- d. Leakage Class IV: (Not Permitted by IMC Code)
 - 60.0 CFM/sq.ft. @ 1" WC pressure differential.
 - 120.0 CFM/sq.ft. @ 4" WC pressure differential.
 - 168.0 CFM/sq.ft. @ 8" WC pressure differential.
 - 210.0 CFM/sq.ft. @ 12" WC pressure differential.

2. Fire rating:

- a. 1-½ hour.

- b. 3 hour.

3. Closure rating:

- a. *U.L. 555* and *UL 555S* require fire, smoke, and fire/smoke dampers to bear an affixed label stating whether the damper is static or dynamic rated.

- b. Dynamic Rating: Dynamic rated dampers must be U.L. tested and show airflow and maximum static pressure against which the damper will operate (fully close). Dampers are tested to 4" static pressure for "no duct" applications and 8" static pressure for "in duct" applications.

- c. Static Rating: Static rated dampers have not been U.L. tested against airflow and may not close under medium-to-high airflow conditions that may be encountered in HVAC systems that do not shut down in the event of fire.

- d. Recommend using dynamically rated fire/smoke dampers in all applications.
4. Temperature rating of fusible links:
- a. Standard: 165°F.
 - b. Optional expanding curtain type (see code requirements): 212°F, 285°F.
 - c. Optional blade type (see code requirements): 212°F, 250°F, 285°F, 350°F, 450°F.
 - d. Smoke control requirements:
 - 1. Primary: 285°F (can be overridden by the fire department).
 - 2. Secondary: 350°F (cannot be overridden by fire department).

B. Fire/Smoke Damper Recommendations

- 1. Fire dampers (HVAC applications):
 - a. Curtain type: Type C, 1-½ or 3 hours to match wall construction, Expanding Curtain Type Fire Damper with 165°F fusible link for all applications (including transfer duct applications) except transfer grille applications shall be Type A.
 - b. Blade type: 3,000 FPM minimum velocity, Airfoil Blade, Leakage Class I at 4" WC pressure differential, 1-½ or 3 hours to match wall construction, Dynamic Fire Damper at 8" WC closure rating with 165°F fusible link.
- 2. Smoke Dampers and Combination Fire/Smoke Dampers (HVAC Applications):
 - a. Blade type: 3,000 FPM minimum velocity, Airfoil Blade, Leakage Class I at 4" WC pressure differential, 1-½ or 3 hours to match wall construction, Dynamic Fire Damper at 8" WC closure rating with 250°F primary fusible link and 350°F secondary fusible link.
- 3. Fire dampers, smoke dampers, and combination fire/smoke dampers (smoke control applications):
 - a. Blade type: 3,000 FPM minimum velocity, Airfoil Blade, Leakage Class I at 4" WC pressure differential, 1-½ or 3 hours to match wall construction, Dynamic Fire Damper at 8" WC closure rating with 285°F primary fusible link and 350°F secondary fusible link.
- 4. Fire dampers, smoke dampers, and fire/smoke dampers: Blowout panels should be considered for ductwork systems under the following circumstances:

- a. Whenever, the potential exists for fire, smoke, and/or fire/smoke dampers to close suddenly and cause system pressures to exceed construction pressures of the ductwork especially in systems utilizing dynamic rated dampers.
- b. Whenever human operation of fire, smoke, and/or fire/smoke dampers is required by code, by local authorities, or for smoke evacuation systems, in the event that the fire department personnel or owner's operating personnel inadvertently close all the dampers, and system pressures exceed construction pressures of the ductwork.

C. 2015 IMC

1. Installation shall comply with the IMC and manufacturer's installation instructions and listing.
2. Testing procedures:
 - a. Fire dampers: UL 555.
 - b. Smoke dampers: UL 555S.
 - c. Combination fire/smoke dampers: UL 555 and UL 555S.
 - d. Ceiling dampers: UL 555C.
 - e. Actuators: UL 555 and UL 555S.
3. Fire protection rating:
 - a. Less than 3-hour rated assemblies: 1-½ hours
 - b. Three hours and above rated assemblies: 3 hours
4. Fire damper actuating devices:
 - a. HVAC systems: 50°F above the normal operating temperature within the duct system, but not less than 160°F.
 - b. Smoke control systems: 350°F maximum.
5. Smoke damper actuating devices:
 - a. Elevated temperature rating: 250°F minimum, 350°F maximum.
 - b. Duct mounted smoke damper: Provide duct mounted smoke detector located within 5 feet with no inlet/outlets between damper and detector.
 - c. Unducted smoke damper: Provide space-mounted smoke detector located

within 5 feet horizontally of wall opening with damper.

- d. Smoke dampers may be controlled by the smoke detection system where a smoke detection system is installed in all areas served by the duct in which the damper will be located.
 - e. Smoke damper leakage rating shall be Class I or II.
6. Combination fire/smoke damper actuating devices:
- a. Smoke control system: 50°F above smoke control design temperature, but not less than 160°F or more than 350°F.
 - b. Smoke detectors as indicated under smoke damper actuating devices.
7. Access: Fire, smoke, and fire/smoke dampers shall be provided with an approved means of access. Access doors shall be labeled with 0.5"-high letters minimum reading: "FIRE DAMPER," "SMOKE DAMPER," or "FIRE/SMOKE DAMPER," respectively.
8. Fire dampers are required at duct and transfer openings at the following locations:
- a. Fire walls.
 - b. Fire barriers:
 - 1. Exception: Dampers are not required in penetrations of walls with a required 1-hour fire-resistance rating or less by a ducted HVAC system that is of sheet steel not less than 26 gauge and is continuous from the air-handling equipment to the air outlet or inlet terminals in areas of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.
 - 2. Exception: Dampers are not required in ducts used as an approved smoke control system *where the damper would interfere with the operation of the smoke control system.*
- a. Fire partitions:
 - 1. Exception: Dampers are not required in penetrations of tenant separation and corridor walls in buildings of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.
 - 2. Exception: Dampers are not required in duct systems constructed of code-approved materials that meet all of the following:
 - a. Duct size 100 sq. in. or less.

- b. Duct constructed of a minimum of 24 gauge steel.
 - c. Duct cannot have openings that communicate the corridor with adjoining rooms or spaces.
 - d. Duct is installed above a ceiling.
 - e. Duct shall not terminate at a fire rated wall with a register.
 - f. A minimum 12" long × 16 gauge sleeve shall be centered at each duct opening.
3. Exception: Dampers are not required in penetrations of walls with a required 1-hour fire-resistance rating or less by a ducted HVAC system that is of sheet steel not less than 26 gauge and is continuous from the air-handling equipment to the air outlet or inlet terminals in areas of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.
9. Smoke dampers are required at duct and transfer openings at the following locations:
- a. Smoke barriers and corridors with smoke and draft controls.
 - 1. Exception: Dampers are not required at corridor penetrations where the building is equipped throughout with an approved smoke control system.
 - 2. Exception: Ducts penetrating smoke barriers where the duct serves a single smoke compartment and are constructed of steel.
 - 3. Exception: Dampers are not required in ducts that do not serve the corridor and are constructed of minimum 26 gauge steel.
10. Fire and smoke dampers or combination fire/smoke dampers are required at duct and transfer openings at the following locations:
- a. Shaft enclosures:
 - 1. Exception: Fire dampers are not required in exhaust systems equipped with steel exhaust air subducts extending at least 22" vertically in an exhaust shaft and where there is continuous airflow upward to the outside.
 - 2. Exception: Fire dampers are not required in penetrations tested in accordance with ASTM E 119 or UL 263 as part of the fire-resistance-rated assembly.

3. Exception: Smoke dampers are not required in bathroom, toilet, kitchen, and clothes dryer exhaust openings equipped with 26 gauge minimum steel exhaust air subducts extending at least 22" vertically in an exhaust shaft and where there is continuous airflow upward to the outside in Groups B and R occupancies equipped throughout with an automatic sprinkler system.
 4. Exception: Fire dampers and smoke dampers are not required in ducts used as an approved smoke control system where the damper would interfere with the operation of the smoke control system.
 5. Exception: Fire dampers and smoke dampers are not required in parking garage exhaust ducts that are separated from other building shafts by not less than 2-hour fire-resistance-rated assemblies.
 6. Exception: Fire dampers and smoke dampers are not required in kitchen and clothes dryer exhaust systems.
- b. Horizontal Assemblies (floor, floor/ceiling, roof ceiling): Horizontal assemblies shall be protected by shaft enclosures.
1. Exception: Fire dampers may be permitted to be installed at each floor provided the duct does not connect more than two floors in occupancies other than I-2 (Hospital) Occupancies and I-3 (Prison) Occupancies.
- c. Fire/smoke dampers may be an individual fire damper and smoke damper in series or a combination fire/smoke damper.

D. NFPA 90A-2015

1. Installation shall comply with the manufacturer's installation instructions and UL listing.
2. Testing procedures:
 - a. Fire dampers: UL 555.
 - b. Smoke dampers: UL 555S.
 - c. Combination fire/smoke dampers: UL 555 and UL 555S.
 - d. Ceiling dampers: UL 555C.
 - e. Actuators: UL 555 and UL 555S.
3. Fire protection rating:

- a. Less than 3-hour-rated assemblies: 1-½ hours
 - b. Three-hour and above rated assemblies: 3 hours
4. Fire damper actuating devices:
- a. HVAC systems: 50°F above ambient temperature, but not less than 160°F.
 - b. Smoke control systems: 50°F above smoke control design temperature, but not more than 350°F.
5. Smoke damper actuating devices:
- a. Duct Mounted Smoke Damper: Provide duct mounted smoke detector located within 5 feet with no inlet/outlets between damper and detector.
 - b. Unducted Smoke Damper: Provide space mounted smoke detector located within 5 feet of wall opening with damper.
 - c. Smoke dampers may be controlled by area smoke detectors at smoke doors, corridors, or where total coverage smoke detection system is employed.
6. Combination fire/smoke damper actuating devices:
- a. Smoke Control System: 50°F above smoke control design temperature, but not more than 350°F.
 - b. Smoke detectors as indicated under smoke damper actuating devices.
7. Access: A service opening shall be provided adjacent to each fire damper, smoke damper, fire/smoke damper, and smoke detector. Service openings shall be identified with letters 0.5" high minimum to indicate the type and location of the fire protection device.
8. Fire dampers shall be installed at the following penetration locations:
- a. Fire-rated walls and partitions with a 2-hour rating or more.
 - b. Air transfer openings in partitions that are required to have a fire resistance rating and in which other openings are required to be protected.
 - c. Fire-rated floors: Where air ducts extend through only one floor and serve only two adjacent floors, the ducts may be enclosed or provided with a fire damper at each floor penetration.
 - d. Shafts:
 1. Less than four stories: One-hour rating.

2. Four stories or more: Two-hour rating.
3. Shafts that constitute air ducts or that enclose air ducts used for movement of environmental air shall not enclose the following:
 - a. Kitchen hood exhaust ducts.
 - b. Ducts used to remove flammable vapors.
 - c. Ducts used for moving, conveying, or transporting stock, vapor, or dust.
 - d. Ducts used for the removal of nonflammable corrosive fumes and vapors.
 - e. Refuse or linen chutes.
 - f. Piping containing hazardous materials or combustible piping.
 - g. Combustible storage.
4. Exception: A fire damper is not required where the following occur:
 - a. Branch ducts connected to enclosed exhaust risers enclosed in shafts.
 - b. The airflow moves upward.
 - c. Steel subducts at least 22" in length are carried up inside the riser from each inlet.
 - d. The riser is appropriately sized to accommodate the flow restriction created by the subduct.
9. Smoke dampers shall be installed at the following penetration locations:
 - a. Smoke Barriers: Damper shall be installed within 2 feet of the smoke barrier and prior to any air inlet or outlet.
 1. Exception: Smoke dampers shall not be required on air systems other than where necessary for the proper function of that system where the system is designed specifically to accomplish the following:
 - a. Function as an engineered smoke control system.
 - b. Provide air to other areas of the building during a fire emergency.
 - c. Provide pressure differentials during a fire emergency.
 2. Exception: Smoke dampers shall not be required where ducts serve a single smoke compartment and no other smoke compartment.

- b. Smoke dampers shall be installed in air handling systems with a capacity greater than 15,000 CFM to isolate air handling equipment (supply and return).
 1. Exception: Air handling units located on the floor they serve and serving only that floor do not require smoke dampers.
 2. Exception: Air handling units located on the roof and serving only the floor immediately below the roof do not require smoke dampers.
10. Fire/smoke dampers shall be installed at the following penetration locations:
 - a. Fire-rate and smoke-rated walls and partitions.
11. Maintenance: At least every 4 years the following shall be performed:
 - a. Fusible links shall be removed.
 - b. All dampers shall be operated to verify that they close fully.
 - c. The latch, if provided, shall be checked.
 - d. Moving parts shall be lubricated as necessary.

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17.07. HVAC Smoke Detection Systems Control

A. 2015 IMC

1. HVAC systems shall be equipped with smoke detectors listed and labeled for installation in air distribution systems.
2. Smoke detectors shall be installed in accordance with NFPA 72 and manufacturer's installation instructions.
3. Smoke detectors are required at the following locations:
 - a. Return Air Systems: Smoke detectors are required in return air systems with design air capacity greater than 2,000 CFM (upstream of filters, exhaust connections, outdoor air connections, etc.).
 - b. Common Supply and Return Systems: Smoke detectors are required in the return air system where multiple air handling systems share common supply or return air ducts or plenums with a combined capacity greater than 2,000 CFM.
 - c. Return Air Risers: Smoke detectors are required in systems where the return air riser serves two or more floors and serves any portion of a return air

system having a design capacity greater than 15,000 CFM. Smoke detectors shall be installed at each floor where the return air duct connects to the riser.

- d. Fan Powered Boxes: Smoke detectors are required for fan-powered boxes with a capacity greater than 2,000 CFM.
 - e. Exception: Smoke detectors are not required where air distribution systems are incapable of spreading smoke beyond the enclosing walls, floors, and ceilings of the room or space in which smoke is generated.
 - f. Exception: Smoke detectors are not required where the building is equipped throughout with area smoke detectors connected to a fire alarm system.
4. Control/supervision:
- a. Upon detection of smoke, the air distribution system shall be shutdown. Air distribution systems that are part of a smoke control system shall switch to smoke control operation.
 - b. All smoke detectors shall be connected to the fire alarm system where a fire alarm system is required.

B. NFPA 90A-2015

- 1. Smoke detectors shall be installed in accordance with NFPA 72 and the manufacturer's installation instructions.
- 2. Smoke dampers installed to isolate the air handling system shall be arranged to close automatically when the system is not in operation.
- 3. Supply Air System: Smoke detectors are required in supply air systems with design air capacity greater than 2,000 CFM (downstream of filters, upstream of supply connections).
- 4. Return Air Risers: Smoke detectors are required in systems where the return air riser serves two or more floors and serves any portion of a return air system having a design capacity greater than 15,000 CFM. Smoke detectors shall be installed at each floor where the return air duct connects to the riser.
 - a. Exception: Return air smoke detectors are not required where the entire space served by the air distribution system is protected by an area smoke detection system.

5. Exception: Smoke detectors are not required for fan units whose sole function is to remove air from the inside of the building to the outside of the building.
6. Smoke detectors shall automatically stop their respective fans.
7. Where the system is functioning as an engineered smoke control system, the smoke detectors are not required to stop the air handling system.

C. Because the IMC and NFPA requirements are different, I recommend meeting both codes by providing smoke detectors in both the supply and return systems with a capacity greater than 2,000 CFM.

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17.08. Sound Attenuators

A. Types

1. Rectangular: 3-, 5-, 7-, and 10-foot lengths.
2. Round: Two or three times the diameter.

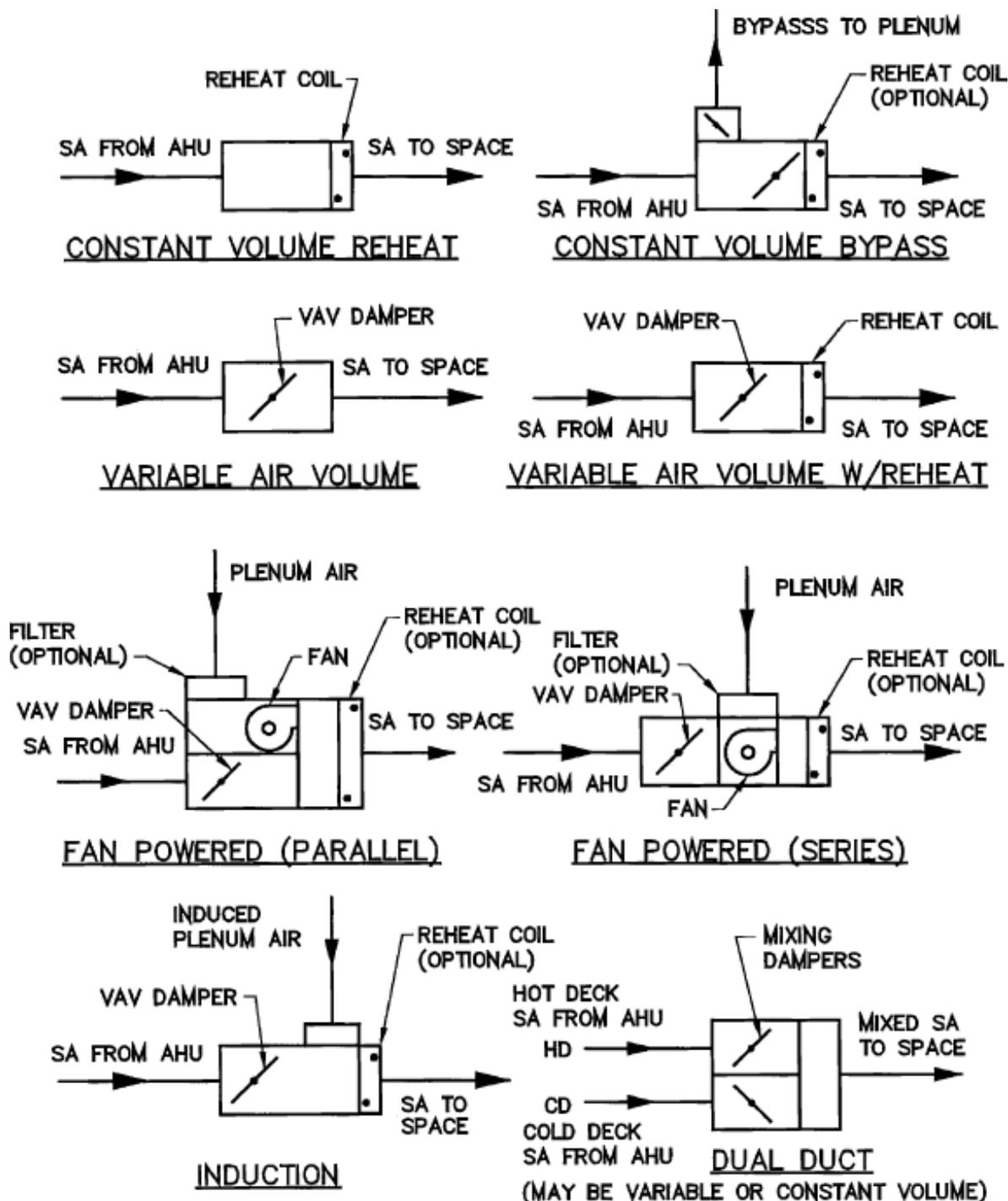
B. Locating

1. Centrifugal and axial fans:
 - a. Discharge: 1 duct diameter from discharge for every 1,000 FPM.
 - b. Intake: 0.75 duct diameters from intake for every 1,000 FPM.
2. Elbows: 3 duct diameters up and down stream.
3. Terminal Boxes: 1 duct diameter down stream.
4. Mechanical Equipment Rooms: Install in or close to mechanical equipment room wall opening.

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17.09. Terminal Units

A. For diagrammatic examples of air terminal units, see Fig. 17.6.



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Figure 17.6. AIR TERMINAL UNITS.

B. Variable Air Volume (VAV) Terminal Units

1. VAV w/o reheat:
 - a. Controls space temperature by varying the quantity of supply air.
 - b. Supply temperature is constant.
 - c. The energy savings is due to reduced supply air quantities and therefore reduced horsepower.
2. VAV w/reheat:

- a. Integrates heating at the VAV terminal unit to offset heating load, limit maximum humidity, provide reasonable air movement, and provide ventilation air.
3. Minimum CFM for VAV boxes:
 - a. Dictated by ASHRAE Standard 62.1.
 - b. Typical office building range: 30 percent to 50 percent of design flow.
 - c. When interior spaces are occupied or lights are on, the VAV terminal unit will maintain a minimum flow to offset the heat gain. Therefore, the only time a VAV terminal unit serving an interior space will be closed is when the space is unoccupied and the lights are off.

C. Fan-Powered Terminal Units

1. Parallel fan-powered terminal units:
 - a. Primary air is modulated in response to cooling demands and the fan is energized at a predetermined reduced primary airflow.
 - b. The fan is the first stage of heating by utilizing plenum air for return. The second stage of heating is the reheat coil.
 - c. Fan is located outside the primary airstream to allow intermittent fan operation.
2. Series fan-powered terminal units:
 - a. A constant volume fan mixes primary air with a varying amount of air from the ceiling plenum.
 - b. The fan is located within the primary airstream and runs continuously.
 - c. Series fan-powered boxes are generally used with low temperature supply air from the air handling unit.

D. Induction Terminal Units

1. Reduces cooling capacity by reducing primary air and inducing room or ceiling plenum air.
2. Incorporates reduced supply air quantity energy savings of the VAV system and air volume to space is constant to reduce the effect of stagnant air.

E. Constant Volume Reheat (CVR) Terminal Units

1. CVR terminal units provide zone/space control for areas of unequal loading, simultaneous cooling/heating, and close tolerance of temperature control.
2. Conditioned air is delivered to each terminal unit at a fixed temperature, and is then reheated to control space temperature.
3. Energy inefficient system.
4. Energy codes restrict the use of these systems.

F. Constant Volume Bypass Terminal Units

1. Variation of CVR system. Constant volume primary air system with VAV secondary system.
2. Supply air to space varied by dumping air to return air plenum.
3. Energy codes restrict the use of these systems.

G. Dual Duct Terminal Units

1. A constant volume of supply air is delivered to the space.
2. Space temperature is maintained by mixing varying amounts of hot and cold air.
3. Energy inefficient system.
4. Energy codes restrict the use of these systems.

H. VAV Dual Duct Terminal Units

1. A variable volume of supply air is delivered to space.
2. Space temperature is maintained by supplying either hot or cold air in varying amounts and limiting the amount of hot and cold air mixing.
3. More energy efficient than standard dual duct systems.
4. Energy codes restrict the use of these systems.

I. Single Zone Systems

1. Supply unit serves single temperature zone and varies supply air temperature to control space temperature.
2. Single zone systems are generally small capacity systems or serve large open

areas.

J. Multizone Systems

1. Supply unit serves two or more temperature zones and varies supply air temperature to each zone by mixing hot and cold air with zone dampers at the unit to control space temperature.
2. Each zone is served by a separate ductwork system.
3. Similar to dual duct systems, but where mixing occurs at the unit.
4. Limited number of zones, inflexible system, energy inefficient, and not a recommended system.
5. Multizone systems are essentially obsolete.

K. Terminal Unit Types

1. Pressure-independent terminal units: Terminal unit airflow is independent of pressure upstream of the box. Recommend using pressure-independent terminal units.
2. Pressure-dependent terminal units: Terminal unit airflow is dependent on pressure upstream of box.

L. Terminal Unit Installation

1. Locate all terminal units for unobstructed access to unit access panels, controls, and valving.
2. Minimum straight duct length upstream of terminal units:
 - a. Manufacturers generally recommend 1.5 duct diameters based on terminal unit inlet size.
 - b. 2.0 duct diameters are the recommended minimum.
 - c. 3.0 -5.0 duct diameters are preferred.
 - d. Best to use 3 feet of straight duct upstream of terminal units because you do not have to concern yourself with box size when producing ductwork layout (the maximum terminal unit inlet size is 16 inches with 2 duct diameters, which results in 32 inches, and most of the time you are not using 16-inch terminal units).

3. Duct runout to the terminal unit should never be smaller than the terminal unit's inlet size; it may be larger than the inlet size, though. Terminal unit inlet and discharge ductwork should be sized based on ductwork sizing criteria and not the terminal unit inlet and discharge connection sizes. The transition from the inlet and discharge connection sizes to the air terminal unit should be made at the terminal unit. A minimum of 3 feet of straight duct should be provided upstream of all terminal units.

M. Zoning

1. Partitioned offices:
 - a. One, two, three, or four offices/terminal unit.
 - b. Two or three offices/terminal unit most common.
 - c. One office/terminal unit; most desirable, also most expensive.
2. Open offices:
 - a. 400–1,200 sq.ft./terminal unit.
3. Perimeter and interior spaces should be zoned separately.
4. Group spaces/zones/rooms/areas of similar thermal occupancy:
 - a. For example, group offices with offices.
 - b. Don't put offices with conference rooms or other dissimilar rooms.
 - c. Don't put east offices with south offices, etc.
 - d. Corner offices or spaces should be treated separately.

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17.10. Process Exhaust Systems

- A. **Ductwork material must be selected to suit the material or chemical being exhausted—carbon steel, 304 or 316 stainless steel, Teflon- or Halar-coated stainless steel, fiberglass reinforced plastic (FRP), and polyvinyl chloride (PVC) are some examples. Sprinklers are generally required in FRP and PVC ductwork systems in all sizes larger than 8 inches in diameter.**
- B. **Process exhaust ductwork cannot penetrate fire walls, fire separation assemblies, or smoke walls.**

- C. Process exhaust systems should be provided with a blast gate or butterfly damper at each tap for a hood or equipment, at each lateral, and at each submain. At all fans, large laterals, and submains, a tight shutoff—style butterfly damper should be provided for balancing and positive shutoff in addition to the blast gate. Blast gates should be specified with a wiper gasket, of EPDM or other suitable material, to provide as tight a seal as possible for blast gates; otherwise, blast gates tend to experience high leakage rates. Wind loading on blast gates installed on the roof or outside the building must be considered, especially in large blast gates. Blast gate blades will act as a sail in the wind and cause considerable stress on the ductwork system.**
- D. Process exhaust ductwork should be sloped a minimum of 1/8 inch per foot with a drain provided at the low point. The drain should be piped to the appropriate waste system.**
- E. Process exhaust systems are required, in most cases, to undergo a treatment process—scrubbing, abatement, burning, or filtering.**
- F. Duct sizing must be based on capture velocities and entrainment velocities of the material or chemical being exhausted. For most chemical or fume exhaust systems, the mains, risers, submains, and large laterals should be sized for 2,000 to 3,000 feet per minute, and small laterals and branches should be sized for 1,500 to 2,500 feet per minute. Discharge stacks should be sized for 3,000 to 4,000 feet per minute discharge velocity and should terminate a minimum of 8 feet above the roof and a minimum of 10 feet from any openings or intakes. Properly locate discharge stacks and coordinate discharge height to prevent contamination of outside air intakes, cooling tower intakes, and combustion air intakes. Clearly indicate termination heights.**
- G. The connection to a fume hood or other piece of equipment will generally require between 1.0 and 3.0 inches WC negative pressure.**
- H. Branches and laterals should be connected above duct centerline. If branches and laterals are connected below the duct centerline, drains will be required at the low point. Hoods, tools, and equipment must be protected from the possibility of drainage contaminating or entering equipment when taps are connected below the centerline.**

- I. **Specify proper pressure class upstream and downstream of scrubbers and other abatement equipment.**
- J. **When ductwork is installed outside or in unconditioned spaces, verify if condensation will occur on the outside or the inside of this duct. Insulate the duct and/or heat trace if required.**
- K. **Process exhaust fans are required to be on emergency power by code.**
- L. **Process exhaust ductwork cannot penetrate fire-rated construction. Fire dampers are generally not desirable. If penetrating fire-rated construction cannot be avoided, process exhaust ductwork must be enclosed in a fire-rated enclosure until it exits the building, or sprinkler protection located inside the duct may be used if approved by authority having jurisdiction.**
- M. **Provide pressure ports at the end of all laterals, submains, and mains.**
- N. **Generally, drains are required in fan scroll, scrubber, and other abatement equipment.**
- O. **Provide flexible connections at fans and specify flexible connection material suitable for application.**
- P. **If adjustable or variable frequency drives are required or used, locate and coordinate them with the electrical engineer. Use direct drive fans with adjustable or variable frequency drives.**

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17.11. Hazardous Exhaust Systems

- A. **Hazardous exhaust systems as defined in the 2015 IMC.**
- B. **A hazardous exhaust system shall include exhaust systems containing:**
 - 1. Flammable vapors.
 - 2. Gases.
 - 3. Fumes.
 - 4. Mists.
 - 5. Dusts.

6. Paint residue.
7. Corrosive fumes.
8. Volatile or airborne materials posing a health hazard.

C. Hazardous Exhaust System Concerns:

1. Combustibility.
2. Flammability.
3. Toxicity.
4. Corrosiveness.
5. Explosiveness.
6. Microbial.
7. Pathogenic.

D. Hospital and research laboratory exhaust systems are designed to exhaust different substances. However, these substances may or may not be flammable, toxic, corrosive, or pathogenic. For the classification and identification of hazardous substances, see NFPA 704. NFPA 704 covers the concerns of combustibility, flammability, toxicity, corrosiveness, and explosiveness, but this standard does not address microbial, pathogenic, and other hospital or research exhaust hazards. Laboratory exhaust systems involve the use of chemicals and other hazardous materials for:

1. Testing.
2. Analysis.
3. Teaching.
4. Research.
5. Development.
6. Nonproduction purposes.
7. 2015 IMC: Laboratory exhaust systems do not have to be independent of other exhaust systems provided that all of the following conditions are met.

- a. All hazardous exhaust ductwork and other laboratory exhaust ductwork within both the occupied space and the shaft is under negative pressure while in operation.
- b. All hazardous exhaust ductwork manifolded together within the occupied space must originate in the same fire area.
- c. Hazardous exhaust ductwork originating in different fire areas and manifolded together in a common shaft shall be equipped with steel exhaust air subducts extending at least 22" vertically in exhaust shafts where there is continuous airflow upward to the outside.
- d. Each control branch has a flow regulating device.
- e. Perchloric acid hoods must have a separate exhaust system and cannot be manifolded together.
- f. Radioisotope hoods are properly filtered.
- g. Biological safety cabinets are properly filtered.
- h. A provision is made for continuous operation of the negative static pressure in the ductwork with standby fans.

E. Hazardous exhaust systems are required wherever hazardous materials are present to create any one of the following conditions. The criteria is based on the normal operating conditions and not the conditions that would exist in an accident or unusual condition.

1. Materials are present in concentrations at room temperature that exceed 25 percent of the lower flammability limit of the substance.
2. Materials are present at any concentration with a health hazard of 4.
 - a. Exception: Hazardous exhaust systems are required for laboratories where materials are present with a health hazard of 4 at concentrations exceeding 1 percent of the median lethal concentration for acute inhalation toxicity.
3. Materials are present with a health hazard of 1, 2, or 3 at concentrations exceeding 1 percent of the median lethal concentration for acute inhalation toxicity.

F. Hazardous exhaust systems must be independent of all other exhaust systems.

- G. Hazardous exhaust systems must be located in separate shafts from other HVAC duct systems and in separate shafts from other hazardous exhaust systems originating in different fire areas.**
- H. Hazardous exhaust systems must segregate compatible and incompatible material exhaust air streams.**
- I. Ductwork design methods:**
 - 1. Vapors, gases, and smoke: Constant velocity or equal friction methods.
 - 2. Dust, fibers, and particulate matter: Constant velocity method.
- J. Exhaust makeup air shall be delivered to the space with hazardous exhaust systems in quantities nearly equal to the exhaust air quantities. Normally, the makeup air is slightly less than the exhaust air quantity to help confine the contaminants.**
- K. Hazardous exhaust systems that penetrate a fire-rated floor/ceiling assembly or fire-rated wall assembly must be enclosed in a fire-resistance-rated shaft enclosure, meeting the fire rating of the highest rated assembly penetrated, from where the exhaust system penetrates the rated enclosure until it terminates outdoors.**
- L. In lieu of enclosing the hazardous exhaust duct that penetrates a fire-rated wall assembly in a fire-rated enclosure, the interior of the duct may be equipped with an approved automatic fire suppression system suitable for the materials being exhausted. Hazardous exhaust systems that penetrate a fire-rated floor/ceiling assembly must be enclosed in a fire-rated shaft, regardless of whether the system is protected by a fire suppression system or not.**
- M. Ducts shall not penetrate a fire wall.**
- N. Fire dampers and smoke dampers are not permitted in hazardous exhaust systems.**
- O. Hazardous exhaust systems shall be protected by an approved automatic fire suppression system. The automatic fire suppression system must be compatible with the materials being exhausted (water, dry chemical, carbon dioxide).**
 - 1. Except hazardous exhaust systems conveying nonflammable and noncombustible materials at all concentrations.

2. Except in metallic and noncombustible, nonmetallic exhaust ducts in semiconductor fabrication facilities.
3. Except in ducts where the cross-sectional duct diameter is less than 10 inches.
4. Except in laboratory hoods or laboratory exhaust systems.

P. Ductwork materials for hazardous exhaust systems:

1. G90 galvanized steel.
2. 304 or 316 stainless steel.
3. Fiberglass reinforced: Chemical exhaust; plastic (FRP).
4. Polyvinyl chloride (PVC): Chemical exhaust, underground ducts; PVC conforming to *NFPA 91*, *ASTM D1784*, *D1785*, *D1927*, and *D2241*.
5. Polyvinyl steel and stainless steel (PVS and PVSS): Chemical exhaust; common type: Halar-coated stainless steel, Teflon-coated stainless steel.
6. Nonmetal ducts must meet the ASTM E 84 flame spread index of 25 or less and a smoke developed index of 50 or less.
7. Ducts shall be constructed of materials that are compatible with the exhaust.
8. Minimum hazardous exhaust duct thickness:

Minimum Nominal Thickness

Diameter of Duct or Maximum Side Dimension	Nonabrasive Materials (Gauge)	Nonabrasive/Abrasive Materials (Gauge)	Abrasive Materials (Gauge)
0-8 inches	24	22	20
9-18 inches	22	20	18
19-30 inches	20	18	16
Over 30 inches	18	16	14

Q. Hazardous exhaust ducts shall be supported at intervals not

exceeding 10 feet. Supports shall be constructed of noncombustible materials.

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17.12. Galvanized Rectangular Ductwork Weights—Pound per Lineal Foot

GALVANIZED RECTANGULAR DUCT WEIGHT

Sheet Metal Gauge

Width + Depth Inches	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+)	16	Surface Area sq.ft./ln.ft.
38	-	9.15	11.13	13.11	17.07	21.03	6.34
39	-	9.39	11.42	13.46	17.52	21.58	6.50
40	-	9.63	11.72	13.80	17.97	22.13	6.67
41	-	9.87	12.01	14.15	18.42	22.69	6.83
42	-	10.12	12.30	14.49	18.87	23.24	7.00
43	-	10.36	12.60	14.84	19.31	23.79	7.17
44	-	10.60	12.89	15.18	19.76	24.35	7.34
45	-	10.84	13.18	15.53	20.21	24.90	7.50
46	-	11.08	13.47	15.87	20.66	25.45	7.67
47	-	11.32	13.77	16.22	21.11	26.00	7.83
48	-	11.56	14.06	16.56	21.56	26.56	8.00
49	-	11.80	14.35	16.91	22.01	27.11	8.17
50	-	12.04	14.65	17.25	22.46	27.67	8.34
51	-	12.28	14.94	17.60	22.91	28.22	8.50
52	-	12.52	15.23	17.94	23.36	28.77	8.67
53	-	12.76	15.52	18.29	23.81	29.32	8.83
54	-	13.01	15.82	18.63	24.26	29.88	9.00
55	-	13.25	16.11	18.98	24.70	30.43	9.17
56	-	13.49	16.40	19.32	25.15	30.99	9.34
57	-	13.73	16.70	19.67	25.60	31.54	9.50
Notes:	-	13.97	16.99	20.01	26.05	32.09	9.67
59	-	14.21	17.28	20.36	26.50	32.65	9.83
60	-	14.45	17.58	20.70	26.95	33.20	10.00

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated

61	-	-	17.87	21.05	27.40	33.75	10.17	
62	-	-	18.16	21.39	27.85	34.31	10.34	
Width			Sheet Metal Gauge					
63	-	-	18.45	21.74	28.30	34.86	10.50	
64	-	-	18.75	22.08	28.75	35.41	10.67	
Depth	26	24	22	20	18			
Inches	(12")	(24")	(48")	(60")	(60+)"			
65	-	-	19.04	22.43	29.20	35.97	10.84	
66	-	-	19.33	22.77	29.65	36.52	11.00	
67	-	-	19.63	23.12	30.09	37.07	11.17	
68	-	-	19.92	23.46	30.54	37.63	11.34	
69	-	-	20.21	23.81	30.99	38.18	11.50	
70	-	-	20.50	24.15	31.44	38.73	11.67	
71	-	-	20.80	24.50	31.89	39.29	11.83	
72	-	-	21.09	24.84	32.34	39.84	12.00	
73	-	-	21.38	25.19	32.79	40.39	12.17	
74	-	-	21.68	25.53	33.24	40.95	12.34	
75	-	-	21.97	25.88	33.69	41.50	12.50	
76	-	-	22.26	26.22	34.14	42.05	12.67	
77	-	-	22.55	26.57	34.59	42.61	12.83	
78	-	-	22.85	26.91	35.04	43.16	13.00	
79	-	-	23.14	27.26	35.48	43.71	13.17	
80	-	-	23.43	27.60	35.93	44.27	13.34	
81	-	-	23.73	27.95	36.38	44.82	13.50	
82	-	-	24.02	28.29	36.83	45.37	13.67	
83	-	-	24.31	28.64	37.28	45.93	13.83	
84	-	-	24.61	28.98	37.73	46.48	14.00	
85	-	-	24.90	29.33	39.18	47.03	14.17	
86	-	-	25.19	29.67	38.63	48.59	14.34	
87	-	-	25.48	30.02	39.08	48.14	14.50	
88	-	-	25.78	30.36	39.53	48.69	14.67	
89	-	-	26.07	30.71	39.98	49.25	14.83	
90	-	-	26.36	31.05	40.43	49.80	15.00	
91	-	-	26.66	31.40	40.87	50.35	15.17	
92	-	-	26.95	31.74	41.32	50.91	15.34	
Notes:	-	-	27.24	32.09	41.77	51.46	15.50	
94	-	-	27.53	32.43	42.22	52.01	15.67	
95	-	-	27.83	32.78	42.67	52.57	15.83	
96	-	-	28.12	33.12	43.12	53.12	16.00	
97	-	-	28.41	33.47	43.57	53.67	16.17	

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.

Sheet Metal Gauge

98	-	-	28.71	33.81	44.02	54.23	16.34
Width	-	-	29.00	34.16	44.47	54.78	16.50
100	- 26	- 24	29.29	34.50	44.92	55.33	16.67
Depth	- (12")	- (24")	29.58	34.85	45.37	55.89	16.83
Inches	-	-	29.88	35.19	45.82	56.44	17.00
103	-	-	30.17	35.54	46.26	56.99	17.17
104	-	-	30.46	35.88	46.71	57.55	17.34
105	-	-	30.76	36.23	47.16	58.10	17.50
106	-	-	31.05	36.57	47.61	58.65	17.67
107	-	-	31.34	36.92	48.06	59.21	17.83
108	-	-	31.64	37.26	48.51	59.76	18.00
109	-	-	31.93	37.61	48.96	60.31	18.17
110	-	-	32.22	37.95	49.41	60.87	18.34
111	-	-	32.51	38.30	49.86	61.42	18.50
112	-	-	32.81	38.64	50.31	61.97	18.67
113	-	-	33.10	38.99	50.76	62.53	18.83
114	-	-	33.39	39.33	51.21	63.08	19.00
115	-	-	33.69	39.68	51.65	63.63	19.17
116	-	-	33.98	40.02	52.10	64.19	19.34
117	-	-	34.27	40.37	52.55	64.74	19.50
118	-	-	34.56	40.71	53.00	65.29	19.67
119	-	-	34.86	41.06	53.45	65.85	19.83
120	-	-	35.15	41.40	53.90	66.40	20.00
121	-	-	35.44	41.75	54.35	66.95	20.17
122	-	-	35.74	42.09	54.80	67.51	20.34
123	-	-	36.03	42.44	55.25	68.06	20.50
124	-	-	36.32	42.78	55.70	68.61	20.67
125	-	-	36.61	43.13	56.15	69.17	20.83
126	-	-	36.91	43.47	56.60	69.72	21.00
127	-	-	37.20	43.82	57.04	70.27	21.17
128	-	-	37.49	44.16	57.49	70.83	21.34
129	-	-	37.79	44.51	57.94	71.38	21.50
130	-	-	38.08	44.85	58.39	71.93	21.67
131	-	-	38.37	45.20	58.84	72.49	21.83
132	-	-	38.67	45.54	59.29	73.04	22.00
Notes:	-	-	38.96	45.89	59.74	73.59	22.17

**Surface
Area
sq.ft./In.ft.**

			Sheet Metal Gauge					
			22	20	18	16		
Width	26	24	22	20	18	16	Surface Area	
Depth	(12")	(24")	(48")	(60")	(60")	(60")	sq.ft./In.ft.	
Inches								
134	-	-	39.25	46.25	60.19	74.15	22.34	
135	-	-	39.54	46.58	60.64	74.70	22.50	
136	-	-	39.84	46.92	61.09	75.25	22.67	
137	-	-	40.13	47.27	61.54	75.81	22.83	
138	-	-	40.42	47.61	61.99	76.36	23.00	
139	-	-	40.72	47.96	62.43	76.91	23.17	
140	-	-	41.01	48.30	62.88	77.46	23.34	
141	-	-	41.30	48.65	63.33	78.02	23.50	
142	-	-	41.59	48.99	63.78	78.57	23.67	
143	-	-	41.88	49.34	64.23	79.13	23.83	
144	-	-	42.18	49.68	64.68	79.68	24.00	
145	-	-	42.47	50.03	65.13	80.23	24.17	
146	-	-	42.77	50.37	65.58	80.79	24.34	
147	-	-	43.06	50.72	66.03	81.34	24.50	
148	-	-	43.35	51.06	66.48	81.89	24.67	
149	-	-	43.64	51.41	66.93	82.45	24.83	
150	-	-	43.94	51.75	67.38	83.00	25.00	
151	-	-	44.23	52.10	67.82	83.55	25.17	
152	-	-	44.52	52.44	68.27	84.11	25.34	
153	-	-	44.82	52.79	68.72	84.66	25.50	
154	-	-	45.11	53.13	69.17	85.21	25.67	
155	-	-	45.40	53.48	69.62	85.77	25.83	
156	-	-	45.70	53.82	70.07	86.32	26.00	
157	-	-	45.99	54.17	70.52	86.87	26.17	
158	-	-	46.28	54.51	70.97	87.43	26.34	
159	-	-	46.57	54.86	71.42	87.98	26.50	
160	-	-	46.87	55.20	71.87	88.53	26.67	
161	-	-	47.16	55.55	72.32	89.09	26.83	
162	-	-	47.45	55.89	72.77	89.64	27.00	
163	-	-	47.75	56.24	73.21	90.19	27.17	
164	-	-	48.04	56.58	73.66	90.75	17.34	
165	-	-	48.33	56.93	74.11	91.30	27.50	
166	-	-	48.62	57.27	74.56	91.85	27.67	
167	-	-	48.92	57.62	75.01	92.41	27.83	
Notes:	-	-	49.21	57.96	75.46	92.96	28.00	
169	-	-	49.50	58.31	75.91	93.51	28.17	

	Sheet Metal Gauge		Surface Area				
Width	26	24	22	20	18	16	sq. ft./In. ft.
170	-	-	49.80	58.65	76.36	94.07	28.34
171	-	-	50.09	59.00	76.81	94.62	28.50
172	-	-	50.38	59.34	77.26	95.17	28.67
173	(12")	(24")	(48")	(60")	(70")	95.73	28.83
174	-	-	50.97	60.03	78.16	96.28	29.00
175	-	-	51.26	60.38	78.60	96.83	29.17
176	-	-	51.55	60.72	79.05	97.39	29.34
177	-	-	51.85	61.07	79.50	97.94	29.50
178	-	-	52.14	61.41	79.95	98.49	29.67
179	-	-	52.43	61.76	80.40	99.05	29.83
180	-	-	52.73	62.10	80.85	99.60	30.00
181	-	-	53.02	62.45	81.30	100.15	30.17
182	-	-	53.31	62.79	81.75	100.71	30.34
183	-	-	53.60	63.14	82.20	101.26	30.50
184	-	-	53.90	63.48	82.65	101.81	30.67
185	-	-	54.19	63.83	83.10	102.37	30.83
186	-	-	54.48	64.17	83.55	102.92	31.00
187	-	-	54.78	64.52	83.99	103.47	31.17
188	-	-	55.07	64.86	84.44	104.03	31.34
189	-	-	55.36	65.21	84.89	104.58	31.50
190	-	-	55.65	65.55	85.34	105.13	31.67
191	-	-	55.95	65.90	85.79	105.69	31.83
192	-	-	56.24	66.24	86.24	106.24	32.00
193	-	-	56.53	66.59	86.69	106.79	32.17
194	-	-	56.83	66.93	87.14	107.35	32.34
195	-	-	57.12	67.28	87.59	107.90	32.50
196	-	-	57.41	67.62	88.04	108.45	32.67
197	-	-	57.70	67.97	88.49	109.01	32.83
198	-	-	58.00	68.31	88.94	109.56	33.00
199	-	-	58.29	68.66	89.38	110.11	33.17
200	-	-	58.58	69.00	89.83	110.67	33.34
201	-	-	58.88	69.35	90.28	111.22	33.50
202	-	-	59.17	69.69	90.73	111.77	33.67
Notes:	-	-	59.46	70.04	91.18	112.33	33.83
204	-	-	59.76	70.38	91.63	112.88	34.00
205	-	-	60.05	70.73	92.08	113.43	34.17

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated

206	-	-	60.34	71.07	92.53	113.99	34.34
207	-	-	60.63	71.42	92.98	114.54	34.50
Width							
208	-	-	60.93	71.76	93.43	115.09	34.67
209	-	-	61.22	72.11	93.88	115.65	34.83
Depth	26	24	22	20	18		
210	(12")	(24")	(48")	(60")	(60+)		
Inches							
211	-	-	61.51	72.45	94.33	116.20	35.00
212	-	-	61.81	72.80	94.77	116.75	35.17
213	-	-	62.10	73.14	95.22	117.31	35.34
214	-	-	62.39	73.49	95.67	117.86	35.50
215	-	-	62.68	73.83	96.12	118.41	35.67
216	-	-	62.98	74.18	96.57	118.97	35.83
217	-	-	63.27	74.52	97.02	119.52	36.00
218	-	-	63.56	74.87	97.47	120.07	36.17
219	-	-	63.86	75.21	97.92	120.63	36.34
220	-	-	64.15	75.56	98.37	121.18	36.50
221	-	-	64.44	75.90	98.82	121.73	36.67
222	-	-	64.73	76.25	99.27	122.29	36.83
223	-	-	65.03	76.59	99.72	122.84	37.00
224	-	-	65.32	76.94	100.16	123.39	37.17
225	-	-	65.61	77.28	100.61	123.95	37.34
226	-	-	65.91	77.63	101.06	124.50	37.50
227	-	-	66.20	77.97	101.51	125.05	37.67
228	-	-	66.49	78.32	101.96	125.61	37.83
229	-	-	66.79	78.66	102.41	126.16	38.00
230	-	-	67.08	79.01	102.86	126.71	38.17
231	-	-	67.37	79.35	103.31	127.27	38.34
232	-	-	67.66	79.70	103.76	127.82	38.50
233	-	-	67.96	80.04	104.21	128.37	38.67
234	-	-	68.25	80.39	104.66	128.93	38.83
235	-	-	68.54	80.73	105.11	129.48	39.00
236	-	-	68.84	81.08	105.55	130.03	39.17
237	-	-	69.13	81.42	106.00	130.59	39.34
238	-	-	69.42	81.77	106.45	131.14	39.50
239	-	-	69.71	82.11	106.90	131.69	39.67
240	-	-	70.01	82.46	107.35	132.25	39.83
241	-	-	70.30	82.80	107.80	132.80	40.00

Notes:

Sheet Metal Gauge

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.
2. The first column is the sum of the width and depth of the duct. (a 20 x 10 duct equals 30 inches).
3. Columns 2 through 7 give the weight of galvanized steel ducts in pounds per lineal foot.
4. Column 8 gives the ductwork surface area used for estimating insulation.
5. Numbers in parentheses below the sheet metal gauges indicate the maximum duct dimension for the indicated gauge.

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17.13. Galvanized Round Ductwork Weights—Pound per Lineal Foot

GALVANIZED ROUND DUCT WEIGHT

Diameter	Gauge						Surface Area sq.ft./Lin.ft.
	26	24	22	20	18	16	
3	0.89	1.13	1.38	1.63	2.12	2.61	0.79
4	1.19	1.51	1.84	2.17	2.82	3.48	1.05
5	1.48	1.89	2.30	2.71	3.53	4.35	1.31
6	1.78	2.27	2.76	3.25	4.23	5.22	1.57
7	2.08	2.65	3.22	3.79	4.94	6.08	1.83
8	2.37	3.03	3.68	4.34	5.64	6.95	2.09
9	2.67	3.40	4.14	4.88	6.35	7.82	2.36
10	2.96	3.78	4.60	5.42	7.06	8.69	2.62
11	3.26	4.16	5.06	5.96	7.76	9.56	2.88
12	3.56	4.54	5.52	6.50	8.47	10.43	3.14
Notes:	4.15	5.30	6.44	7.59	9.88	12.17	3.67
16	4.74	6.05	7.36	8.67	11.29	13.91	4.19

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.

Diameter	Gauge				Surface Area		
	26	24	22	20	18	16	Sq. Ft./Lin. ft.
18	5.34	6.81	8.28	9.75	12.70	15.65	4.71
20	5.93	7.57	9.20	10.84	14.11	17.38	5.24
22	6.52	8.32	10.12	11.92	15.52	19.12	5.76
24	7.12	9.08	11.04	13.01	16.93	20.86	6.28
26	7.71	9.84	11.96	14.09	18.34	22.60	6.81
28	8.30	10.59	12.88	15.17	19.76	24.34	7.33
30	8.89	11.35	13.80	16.26	21.17	26.08	7.85
32	9.49	12.11	14.72	17.34	22.58	27.81	8.38
34	10.08	12.86	15.64	18.43	23.99	29.55	8.90
36	10.67	13.62	16.56	19.51	25.40	31.29	9.42
38	11.27	14.38	17.48	20.59	26.81	33.03	9.95
40	11.86	15.13	18.40	21.68	28.22	34.77	10.47
42	12.45	15.89	19.32	22.76	29.63	36.51	11.00
44	13.05	16.65	20.24	23.84	31.04	38.24	11.52
46	13.64	17.40	21.17	24.93	32.46	39.98	12.04
48	14.23	18.16	22.09	26.01	33.87	41.72	12.57
50	-	18.92	23.01	27.10	35.28	43.46	13.09
52	-	19.67	23.93	28.18	36.69	45.20	13.61
54	-	20.43	24.85	29.26	38.10	46.94	14.14
56	-	21.18	25.77	30.35	39.51	48.67	14.66
58	-	21.94	26.69	31.43	40.92	50.41	15.18
60	-	22.70	27.61	32.52	42.33	52.15	15.71
62	-	23.45	28.53	33.60	43.74	53.89	16.23
64	-	24.21	29.45	34.68	45.16	55.63	16.76
66	-	24.97	30.37	35.77	46.57	57.37	17.28
68	-	25.72	31.29	36.85	47.98	59.10	17.80
70	-	26.48	32.21	37.93	49.39	60.84	18.33
72	-	27.24	33.13	39.02	50.80	62.58	18.85
74	-	27.99	34.05	40.10	52.21	64.32	19.37
76	-	28.75	34.97	41.19	53.62	66.06	19.90
78	-	29.51	35.89	42.27	55.03	67.80	20.42
80	-	30.26	36.81	43.35	56.44	69.53	20.94
82	-	31.02	37.73	44.44	57.86	71.27	21.47
Notes:	-	31.78	38.65	45.52	59.27	73.01	21.99
86	-	32.53	39.57	46.61	60.68	74.75	22.51
88	-	33.29	40.49	47.69	62.09	76.49	23.04
90	-	34.05	41.41	48.77	63.50	78.23	23.57

1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated.

				Gauge				
90	-	34.05	41.41	48.77	63.50	78.23	23.56	
92	-	34.80	42.33	49.86	64.91	79.96	24.09	
94	26	35.56	43.25	50.94	66.32	81.70	24.61	
96		24	22	20	18	16	25.13	
98		-	37.07	45.09	53.11	69.14	85.18	25.66
100		-	37.83	46.01	54.19	70.55	86.92	26.18
102		-	38.59	46.93	55.28	71.97	88.66	26.70
104		-	39.34	47.85	56.36	73.38	90.39	27.23
106	-	40.10	48.77	57.44	74.79	92.13	27.75	
108	-	40.86	49.69	58.53	76.20	93.87	28.27	
110	-	41.61	50.61	59.61	77.61	95.61	28.80	
112	-	42.37	51.53	60.70	79.02	97.35	29.32	
114	-	43.13	52.45	61.78	80.43	99.09	29.85	
116	-	43.88	53.37	62.86	81.84	100.82	30.37	
118	-	44.64	54.29	63.95	83.25	102.56	30.89	
120	-	45.40	55.21	65.03	84.67	104.30	31.42	
122	-	46.15	56.13	66.11	86.08	106.04	31.94	
124	-	46.91	57.05	67.20	87.49	107.78	32.46	
126	-	47.67	57.97	68.28	88.90	109.52	32.99	
128	-	48.42	58.89	69.37	90.31	111.25	33.51	
130	-	49.18	59.81	70.45	91.72	112.99	34.03	
132	-	49.94	60.73	71.53	93.13	114.73	34.56	
134	-	50.69	61.66	72.62	94.54	116.47	35.08	
136	-	51.45	62.58	73.70	95.95	118.21	35.60	
138	-	52.21	63.50	74.79	97.37	119.95	36.12	
140	-	52.96	64.42	75.87	98.78	121.68	36.65	
142	-	53.72	65.34	76.95	100.19	123.42	37.18	
144	-	54.48	66.26	78.04	101.60	125.16	37.70	

Notes:

- 1. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.**
- 2. Table gives weight of galvanized steel ducts in pounds per lineal foot.**

17.14. Galvanized Flat Oval Ductwork Weights—Pounds per Lineal Foot

GALVANIZED FLAT OVAL DUCTWORK WEIGHT

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
3 × 8	5.1	0.15	1.57	24	2.3
3 × 9	5.6	0.18	1.83	24	2.6
3 × 11	6.0	0.22	2.09	24	3.1
3 × 12	6.4	0.25	2.36	24	3.4
3 × 14	6.7	0.29	2.62	24	3.8
3 × 15	7.0	0.32	2.88	24	4.2
3 × 17	7.3	0.36	3.14	24	4.5
3 × 19	7.5	0.39	3.40	24	4.9
3 × 22	8.0	0.46	3.93	24	5.7
4 × 7	5.7	0.18	1.57	24	2.3
4 × 9	6.2	0.22	1.83	24	2.6
4 × 10	6.7	0.26	2.09	24	3.1
4 × 12	7.2	0.31	2.36	24	3.4
4 × 13	7.6	0.35	2.62	24	3.8
4 × 15	8.0	0.40	2.88	24	4.2
4 × 17	8.4	0.44	3.14	24	4.5
4 × 18	8.5	0.48	3.40	24	4.9
4 × 20	9.0	0.52	3.68	24	5.3
4 × 21	9.5	0.57	3.93	24	5.7
5 × 8	6.6	0.25	1.83	24	2.6
5 × 10	7.3	0.30	2.09	24	3.0
5 × 11	7.9	0.35	2.36	24	3.4
5 × 13	8.4	0.41	2.62	24	3.8
5 × 14	8.8	0.46	2.88	24	4.2
5 × 16	9.3	0.52	3.14	24	4.5
Notes:	9.5	0.57	3.40	24	4.9

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
5 × 19	10.0	0.63	3.66	24	5.3
5 × 21	10.5	0.69	3.93	24	5.7
6 × 8	6.9	0.26	1.47	24	2.6
6 × 9	7.7	0.33	2.09	24	3.0
6 × 11	8.4	0.39	2.36	24	3.4
6 × 12	8.9	0.46	2.62	24	3.8
6 × 14	9.6	0.53	2.88	24	4.2
6 × 15	10.1	0.59	3.14	24	4.5
6 × 17	10.5	0.65	3.40	24	4.9
6 × 19	11.0	0.72	3.66	24	5.3
6 × 20	11.5	0.79	3.93	24	5.7
6 × 22	11.8	0.85	4.18	24	6.0
6 × 23	12.0	0.92	4.45	24	6.4
6 × 25	12.5	0.98	4.71	22	8.3
6 × 28	13.2	1.11	5.23	22	9.2
6 × 30	13.5	1.18	5.50	22	9.7
6 × 31	13.8	1.24	5.76	22	10.1
6 × 33	14.0	1.31	6.02	22	10.6
6 × 34	14.3	1.38	6.28	22	11.0
6 × 36	14.5	1.44	6.54	22	11.5
6 × 37	14.9	1.50	6.80	22	12.0
6 × 39	15.0	1.57	7.07	22	12.4
6 × 41	15.4	1.64	7.33	22	12.9
6 × 44	15.9	1.77	7.85	22	13.8
6 × 45	16.0	1.83	8.12	22	14.3
6 × 52	17.0	2.09	9.16	20	19.0
6 × 59	18.0	2.42	10.47	20	21.7
7 × 10	8.7	0.42	2.36	24	3.4
7 × 12	9.4	0.50	2.62	24	3.8
7 × 13	10.1	0.57	2.88	24	4.2
7 × 15	10.7	0.65	3.14	24	4.5
7 × 16	11.0	0.73	3.40	24	4.9
7 × 18	11.7	0.80	3.67	24	5.3
Notes:	12.0	0.88	3.93	24	5.7
7 × 21	12.5	0.98	4.71	22	8.3

Nominal Flat Oval Size	Equiv. Round	Gross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
9 × 23	15.0	1.39	4.71	24	6.8
10 × 12	11.0	0.66	2.88	24	4.2
10 × 13	11.9	0.77	3.14	24	4.5
10 × 15	12.5	0.87	3.40	24	4.9
10 × 16	13.4	1.00	3.66	24	5.3
10 × 18	14.0	1.09	3.93	24	5.7
10 × 19	14.5	1.20	4.19	24	6.1
10 × 20	14.7	1.25	4.18	24	6.1
10 × 21	15.0	1.31	4.45	24	6.4
10 × 23	15.7	1.42	4.71	24	6.8
10 × 24	16.0	1.53	4.97	24	7.2
10 × 26	16.7	1.63	5.23	22	9.2
10 × 27	17.0	1.75	5.50	22	9.7
10 × 29	17.7	1.86	5.76	22	10.2
10 × 30	18.0	1.96	6.02	22	10.6
10 × 32	18.5	2.07	6.28	22	11.1
10 × 34	19.0	2.18	6.54	22	11.5
10 × 35	19.3	2.29	6.80	22	12.0
10 × 38	20.1	2.51	7.33	22	12.9
10 × 41	20.8	2.73	7.85	22	13.8
10 × 43	21.0	2.84	8.12	22	14.3
10 × 45	21.5	2.95	8.37	22	14.7
10 × 48	22.1	3.16	8.89	22	15.6
10 × 51	22.8	3.39	9.42	20	19.5
10 × 52	23.0	3.49	9.69	20	20.1
10 × 54	23.3	3.60	9.95	20	20.6
10 × 57	23.8	3.82	10.56	20	21.9
10 × 60	24.4	4.04	11.00	20	22.8
10 × 63	25.0	4.25	11.52	20	23.8
10 × 67	25.5	4.47	12.05	20	24.9
10 × 70	26.0	4.69	12.51	20	25.9
10 × 73	26.4	4.91	13.10	18	35.3
10 × 76	27.0	5.13	13.61	18	36.7
Notes	13.0	0.90	3.40	24	4.9

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
11 × 16	13.6	1.00	3.67	24	5.3
11 × 17	14.0	1.11	3.93	24	5.7
11 × 19	15.0	1.26	4.19	24	6.1
11 × 22	16.3	1.50	4.71	24	6.8
11 × 24	17.0	1.62	4.97	24	7.2
12 × 14	13.0	0.92	3.40	24	4.9
12 × 15	13.8	1.05	3.67	24	5.3
12 × 17	14.5	1.18	3.93	24	5.7
12 × 18	15.3	1.31	4.19	24	6.1
12 × 20	16.0	1.44	4.45	24	6.4
12 × 21	16.7	1.57	4.71	24	6.8
12 × 25	18.0	1.83	5.24	22	9.2
12 × 28	19.1	2.09	5.76	22	10.1
12 × 31	20.1	2.36	6.28	22	11.1
12 × 34	20.9	2.62	6.81	22	12.0
12 × 37	21.9	2.88	7.33	22	12.9
12 × 40	22.7	3.14	7.85	22	13.8
12 × 42	23.0	3.27	8.12	22	14.3
12 × 43	23.5	3.40	8.37	22	14.7
12 × 45	24.0	3.53	8.64	22	15.2
12 × 47	24.3	3.67	8.89	22	15.6
12 × 50	25.0	3.93	9.42	20	19.5
12 × 53	25.7	4.19	9.95	20	20.6
12 × 56	26.3	4.45	10.56	20	21.9
12 × 59	26.9	4.71	11.00	20	22.8
12 × 62	27.5	4.98	11.52	20	23.8
12 × 65	28.1	5.23	12.05	20	24.9
12 × 69	28.7	5.51	12.57	20	26.0
12 × 72	29.2	5.76	13.10	18	35.3
12 × 78	30.0	6.28	14.14	18	38.1
12 × 81	31.0	6.54	14.66	18	39.5
14 × 17	16.0	1.37	4.19	24	6.1
14 × 19	17.0	1.53	4.45	24	6.4
14 × 20	17.5	1.68	4.71	24	6.8

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
14 × 22	18.0	1.83	4.97	24	7.2
14 × 23	18.9	1.98	5.23	24	7.6
14 × 27	20.2	2.30	5.76	22	10.1
14 × 28	21.0	2.44	6.02	22	10.6
14 × 30	21.3	2.60	6.28	22	11.0
14 × 31	22.0	2.75	6.54	22	11.5
14 × 33	22.4	2.91	6.80	22	12.0
14 × 34	23.0	3.05	7.07	22	12.4
14 × 36	23.4	3.21	7.33	22	12.9
14 × 38	24.0	3.36	7.59	22	13.3
14 × 39	24.4	3.51	7.85	22	13.8
14 × 41	25.0	3.67	8.12	22	14.3
14 × 42	25.3	3.84	8.37	22	14.7
14 × 45	26.1	4.12	8.89	22	15.6
14 × 49	26.9	4.43	9.42	20	19.5
14 × 52	27.7	4.74	9.95	20	20.6
14 × 55	28.4	5.04	10.56	20	21.9
14 × 58	29.1	5.35	11.00	20	22.8
14 × 61	29.8	5.65	11.52	20	23.9
14 × 64	30.5	5.96	12.05	20	24.9
14 × 67	31.1	6.27	12.57	20	26.0
14 × 71	31.7	6.57	13.10	18	35.9
14 × 77	33.0	7.18	14.14	18	38.1
16 × 19	18.0	1.75	4.71	24	6.8
16 × 21	19.0	1.92	4.97	24	7.2
16 × 22	19.5	2.08	5.23	24	7.6
16 × 24	20.0	2.27	5.50	24	7.9
16 × 25	20.9	2.44	5.76	22	10.2
16 × 29	22.3	2.79	6.28	22	11.0
16 × 30	23.0	2.97	6.54	22	11.5
16 × 32	23.5	3.13	6.80	22	12.0
16 × 33	24.0	3.32	7.07	22	12.4
16 × 35	24.7	3.48	7.33	22	12.9
16 × 36	25.0	3.67	7.59	22	13.3
16 × 38	25.7	3.84	7.85	22	13.8

1. Equivalent round is the diameter of the round duct which will have

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
	26.8 27.7 28.0	4.19 4.53 4.71	8.58 8.89 9.16	22 22 22	14.7 15.6 16.1
16 × 47	28.6	4.88	9.42	22	16.6
16 × 49	29.0	5.06	9.69	20	20.1
16 × 51	29.4	5.23	9.95	20	20.6
16 × 54	30.2	5.59	10.47	20	21.7
16 × 57	31.0	5.93	11.00	20	22.8
16 × 60	31.8	6.28	11.52	20	23.8
16 × 63	32.5	6.61	12.05	20	24.9
16 × 66	33.3	6.98	12.57	20	26.0
16 × 69	34.0	7.33	13.09	20	27.1
16 × 76	35.0	8.03	14.14	18	38.1
16 × 79	36.0	8.38	14.66	18	39.5
18 × 21	19.9	2.16	5.23	24	7.6
18 × 23	21.0	2.36	5.50	24	7.9
18 × 24	21.6	2.56	5.76	24	8.3
18 × 26	22.0	2.75	6.02	22	10.6
18 × 27	23.1	2.95	6.28	22	11.0
18 × 29	24.0	3.14	6.54	22	11.5
18 × 31	24.5	3.35	6.80	22	12.0
18 × 32	25.0	3.53	7.07	22	12.4
18 × 34	25.7	3.73	7.33	22	12.9
18 × 37	27.0	4.13	7.85	22	13.8
18 × 40	28.1	4.53	8.37	22	14.7
18 × 43	29.1	4.92	8.89	22	15.6
18 × 46	30.2	5.31	9.42	22	16.6
18 × 49	31.1	5.70	9.95	20	20.6
18 × 53	32.0	6.10	10.56	20	21.9
18 × 56	32.9	6.49	11.00	20	22.8
18 × 59	33.7	6.88	11.52	20	23.8
18 × 62	34.5	7.26	12.05	20	24.9
Notes	35.3	7.67	12.51	20	25.9
18 × 68	36.0	8.07	13.10	20	27.1

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area Sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
18 × 71	37.0	8.44	13.61	18	36.7
18 × 78	38.0	9.25	14.66	18	39.5
20 × 26	23.6	3.05	6.28	22	11.0
20 × 29	25.2	3.49	6.81	22	12.0
20 × 31	26.0	3.71	7.07	22	12.4
20 × 33	26.6	3.93	7.33	22	12.9
20 × 34	27.0	4.15	7.59	22	13.3
20 × 36	28.0	4.36	7.85	22	13.8
20 × 39	29.2	4.81	8.37	22	14.7
20 × 40	30.0	5.02	8.64	22	15.2
20 × 42	30.3	5.23	8.89	22	15.6
20 × 44	31.0	5.45	9.16	22	16.1
20 × 45	31.4	5.67	9.42	22	16.6
20 × 47	32.0	5.89	9.69	22	17.0
20 × 48	32.5	6.11	9.95	22	17.5
20 × 51	33.4	6.55	10.56	20	21.9
20 × 55	34.4	6.98	11.00	20	22.8
20 × 58	35.3	7.41	11.52	20	23.8
20 × 61	36.2	7.86	12.05	20	24.9
20 × 64	37.1	8.29	12.57	20	26.0
20 × 67	37.9	8.71	13.10	20	27.1
20 × 77	40.0	10.04	14.66	18	39.5
22 × 25	23.9	3.12	6.28	22	11.0
22 × 28	25.6	3.60	6.81	22	12.0
22 × 31	27.2	4.08	7.33	22	12.9
22 × 35	28.7	4.56	7.85	22	13.8
22 × 38	30.0	5.04	8.38	22	14.7
22 × 39	31.0	5.28	8.64	22	15.2
22 × 41	31.3	5.52	8.90	22	15.6
22 × 42	32.0	5.76	9.16	22	16.1
22 × 44	32.5	6.00	9.42	22	16.6
22 × 46	33.0	6.24	9.69	22	17.0
22 × 47	33.7	6.48	9.95	22	17.5
22 × 50	34.8	6.96	10.47	20	21.7

Notes:
1. Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
22 × 53	35.8	7.40	11.00	20	22.8
22 × 57	36.6	7.52	11.52	20	23.8
22 × 60	37.0	8.44	12.04	20	24.9
22 × 63	38.7	8.88	12.57	20	26.0
22 × 66	39.6	9.36	13.09	20	27.1
22 × 69	40.4	9.84	13.61	20	28.2
22 × 75	42.0	10.80	14.66	18	39.5
22 × 82	44.0	11.76	15.71	18	42.3
24 × 27	25.9	3.66	6.81	22	12.0
24 × 30	28.1	4.19	7.33	22	12.9
24 × 33	29.3	4.71	7.85	22	13.8
24 × 37	30.8	5.23	8.38	22	14.7
24 × 40	32.2	5.76	8.90	22	15.6
24 × 41	33.0	6.02	9.16	22	16.1
24 × 43	33.5	6.28	9.42	22	16.6
24 × 44	34.0	6.54	9.69	22	17.1
24 × 46	34.7	6.80	9.95	22	17.5
24 × 49	35.9	7.33	10.47	20	21.7
24 × 52	37.0	7.85	11.00	20	22.8
24 × 55	38.1	8.38	11.52	20	23.8
24 × 59	39.2	8.90	12.04	20	24.9
24 × 62	40.1	9.42	12.57	20	26.0
24 × 65	41.1	9.95	13.09	20	27.1
24 × 68	42.0	10.47	13.61	20	28.2
24 × 74	44.0	11.52	14.66	18	39.5
26 × 29	27.9	4.25	7.33	22	12.9
26 × 32	29.7	4.82	7.85	22	13.8
26 × 35	31.3	5.39	8.38	22	14.7
26 × 39	32.8	5.96	8.90	22	15.6
26 × 42	34.3	6.52	9.42	22	16.6
26 × 45	35.6	7.09	9.95	22	17.5
26 × 48	36.9	7.66	10.47	22	18.4
26 × 51	38.1	8.22	11.00	20	22.8
26 × 54	39.3	8.79	11.52	20	23.8

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq. ft.	Surface Area sq. ft./ln. ft.	Gauge	Weight lbs./ln. ft.
26 × 57	40.4	9.36	12.04	20	24.9
26 × 61	41.5	9.93	12.57	20	26.0
26 × 64	42.5	10.49	13.09	20	27.1
26 × 67	43.5	11.06	13.61	20	28.2
26 × 70	44.4	11.63	14.14	20	29.3
28 × 31	29.9	4.88	7.85	22	13.8
28 × 34	31.7	5.50	8.38	22	14.7
28 × 37	33.4	6.11	8.90	22	15.6
28 × 41	34.9	6.72	9.42	22	16.6
28 × 44	36.4	7.33	9.95	22	17.5
28 × 47	37.8	7.94	10.47	22	18.4
28 × 50	39.1	8.55	11.00	20	22.8
28 × 53	40.3	9.16	11.52	20	23.8
28 × 56	41.5	9.77	12.04	20	24.9
28 × 59	42.6	10.38	12.57	20	26.0
28 × 63	43.8	10.99	13.09	20	27.1
28 × 66	44.8	11.60	13.61	20	28.2
28 × 69	45.8	12.22	14.14	20	29.3
30 × 33	32.0	5.56	8.38	22	14.7
30 × 36	33.7	6.22	8.90	22	15.6
30 × 39	35.4	6.87	9.42	22	16.6
30 × 43	37.0	7.53	9.95	22	17.5
30 × 46	38.5	8.18	10.47	22	18.4
30 × 49	39.9	8.84	11.00	20	22.8
30 × 52	41.2	9.49	11.52	20	23.8
30 × 55	42.5	10.15	12.06	20	25.0
30 × 58	43.7	10.80	12.57	20	26.0
30 × 61	44.9	11.46	13.09	20	27.1
30 × 64	46.0	12.11	13.61	20	28.2
30 × 68	47.1	12.77	14.14	20	29.3
30 × 71	48.2	13.42	14.66	18	39.5
Notes	34.0	6.28	8.90	22	15.6
32 × 38	35.8	6.98	9.42	22	16.6
32 × 41	37.4	7.68	9.95	22	17.5

1. Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq. ft.	Surface Area sq. ft./ln. ft.	Gauge	Weight lbs/ln. ft.
32 × 45	39.0	8.38	10.47	22	18.4
32 × 48	40.0	9.00	11.00	22	19.3
32 × 51	42.0	9.75	11.52	20	18.4
32 × 54	43.3	10.47	12.04	20	24.9
32 × 57	44.6	11.17	12.57	20	26.0
32 × 60	45.9	11.87	13.09	20	27.1
32 × 63	47.1	12.57	13.61	20	28.2
32 × 67	48.3	13.26	14.14	20	29.3
32 × 70	49.4	13.96	14.66	20	30.3
34 × 37	36.0	7.05	9.42	22	16.6
34 × 40	37.8	7.79	9.95	22	17.5
34 × 43	39.5	8.52	10.47	22	18.4
34 × 47	41.1	9.27	11.00	22	19.3
34 × 50	42.6	10.01	11.52	20	23.8
34 × 53	44.1	10.75	12.04	20	24.9
34 × 56	45.5	11.50	12.57	20	26.0
34 × 59	46.8	12.24	13.09	20	27.1
34 × 62	48.1	12.98	13.61	20	28.2
34 × 65	49.3	13.72	14.14	20	29.3
34 × 69	50.5	14.46	14.66	20	30.3
34 × 72	51.6	15.20	15.18	18	31.4
36 × 39	38.0	7.85	9.95	22	17.5
36 × 42	39.8	8.64	10.47	22	18.4
36 × 45	41.5	9.42	11.00	22	19.4
36 × 49	43.1	10.21	11.52	20	23.8
36 × 52	44.7	11.00	12.04	20	24.9
36 × 55	46.2	11.78	12.57	20	26.0
36 × 58	47.6	12.57	13.09	20	27.1
36 × 61	48.9	13.35	13.61	20	28.2
36 × 64	50.2	14.14	14.14	20	29.3
36 × 67	51.1	14.92	14.66	20	30.3
36 × 71	52.7	15.71	15.18	18	40.9
Notes	40.0	8.70	10.47	22	18.4
38 × 44	41.8	9.53	11.00	22	19.3

1. Equivalent round is the diameter of the round duct which will have

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ln.ft.	Gauge	Weight lbs./ln.ft.
38 × 47	45.0	10.50	11.52	22	20.3
38 × 51	45.2	11.19	12.04	20	24.9
38 × 54	46.7	12.02	12.57	20	26.0
38 × 57	48.2	12.85	13.09	20	27.1
38 × 60	49.7	13.68	13.61	20	28.2
38 × 63	51.0	14.51	14.14	20	29.3
38 × 66	52.4	15.34	14.66	20	30.3
38 × 69	53.7	16.16	15.18	20	31.4
40 × 43	42.0	9.60	11.00	22	19.3
40 × 46	43.8	10.47	11.52	22	20.3
40 × 49	45.6	11.34	12.04	20	24.9
40 × 53	47.2	12.21	12.57	20	26.0
40 × 56	48.8	13.09	13.09	20	27.1
40 × 59	50.4	13.96	13.61	20	28.2
40 × 62	51.8	14.83	14.14	20	29.3
40 × 65	53.2	15.71	14.66	20	30.3
40 × 68	54.5	16.58	15.18	20	31.4
40 × 71	55.8	17.45	15.71	18	42.3

Notes:

- 1. Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.**
- 2. To obtain the rectangular duct size, use the Trane Ductulator and equivalent round duct size.**
- 3. Table includes 25 percent allowance for bracing, hangers, reinforcing, joints, and seams. Add 10 percent for insulated ductwork systems.**
- 4. Table lists standard sizes as manufactured by United Sheet Metal, a division of United McGill Corporation.**

17.15. Ductwork Cost Ratios

DUCTWORK COST RATIOS

SMACNA Pressure Class**Installed Cost Ratio**

± ½"	1.00
± 1"	1.05
± 2"	1.15
± 3"	1.40
± 4"	1.50
± 6"	1.60
± 10"	1.80

Aspect Ratios**Installed Cost Ratio****Operating Cost Ratio**

1:1	1.00	1.000
2:1	1.13	1.001
3:1	1.28	1.005
4:1	1.45	1.010
5:1	1.65	1.012
6:1	1.85	1.020
7:1	2.08	1.030

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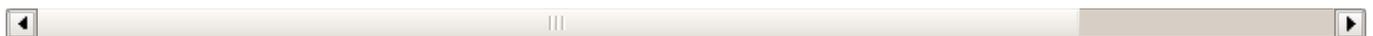
17.16. Friction Loss Correction Factors for Ducts**FRICION LOSS CORRECTION FACTORS FOR DUCTS**

Velocity FPM	Material						
	Galv. Steel Stainless Steel	Duct Liner	Aluminum	Carbon Steel	Fibrous Glass (2)	PVC	Conc or C Blc
500	1.00	1.25	0.98	0.93	1.25	0.93	1.5-1
600	1.00	1.28	0.98	0.92	1.27	0.92	1.5-1
Notes:	1.00	1.30	0.98	0.92	1.30	0.92	1.5-2

Velocity FPM	Material						
800	1.00	1.31	0.97	0.91	1.31	0.91	1.5-2
900	1.00	1.32	0.97	0.90	1.31	0.90	1.5-2
1,000	1.00	1.33	0.97	0.90	1.32	0.90	1.5-2
1,200	1.00	1.36	0.97	0.89	1.34	0.89	1.6-2
1,400	1.00	1.38	0.96	0.88	1.36	0.88	1.6-2
1,600	1.00	1.40	0.96	0.87	1.38	0.87	1.6-2
1,800	1.00	1.41	0.96	0.86	1.39	0.86	1.6-2
2,000	1.00	1.42	0.96	0.85	1.40	0.85	1.7-2
2,500	1.00	1.45	0.95	0.84	1.42	0.84	1.7-2
3,000	1.00	1.47	0.95	0.83	1.43	0.83	1.7-2
3,500	1.00	1.49	0.95	0.83	1.44	0.83	1.8-2
4,000	1.00	1.50	0.94	0.82	1.45	0.82	1.8-2
4,500	1.00	1.52	0.94	0.81	1.46	0.81	1.8-2
5,000	1.00	1.54	0.94	0.80	1.48	0.80	1.8-2
5,500	1.00	1.55	0.93	0.79	1.49	0.79	1.8-2
6,000	1.00	1.56	0.93	0.78	1.50	0.78	1.8-2

Notes:

1. First number indicated is for smooth concrete; second number indicated rough concrete.
2. Flexible ductwork has a friction loss correction factor of 1.5-2.0 times read from friction loss tables, ductulators, etc.



17.17. Velocity Pressures

VELOCITIES VS. VELOCITY PRESSURES

Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.
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Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.
50	0.0002	2,050	0.262	4,050	1.023
100	0.0006	2,100	0.275	4,100	1.048
150	0.001	2,150	0.288	4,150	1.074
200	0.002	2,200	0.302	4,200	1.100
250	0.004	2,250	0.316	4,250	1.126
300	0.006	2,300	0.330	4,300	1.153
350	0.008	2,350	0.344	4,350	1.180
400	0.010	2,400	0.359	4,400	1.207
450	0.013	2,450	0.374	4,450	1.235
500	0.016	2,500	0.390	4,500	1.262
550	0.019	2,550	0.405	4,550	1.291
600	0.022	2,600	0.421	4,600	1.319
650	0.026	2,650	0.438	4,650	1.348
700	0.031	2,700	0.454	4,700	1.377
750	0.035	2,750	0.471	4,750	1.407
800	0.040	2,800	0.489	4,800	1.436
850	0.045	2,850	0.506	4,850	1.466
900	0.050	2,900	0.524	4,900	1.497
950	0.056	2,950	0.543	4,950	1.528
1,000	0.062	3,000	0.561	5,000	1.559
1,050	0.069	3,050	0.580	5,050	1.590
1,100	0.075	3,100	0.599	5,100	1.622
1,150	0.082	3,150	0.619	5,150	1.654
1,200	0.090	3,200	0.638	5,200	1.686
1,250	0.097	3,250	0.659	5,250	1.718
1,300	0.105	3,300	0.679	5,300	1.751
1,350	0.114	3,350	0.700	5,350	1.784
1,400	0.122	3,400	0.721	5,400	1.818
1,450	0.131	3,450	0.742	5,450	1.852
1,500	0.140	3,500	0.764	5,500	1.886
1,550	0.150	3,550	0.786	5,550	1.920
1,600	0.160	3,600	0.808	5,600	1.955
1,650	0.170	3,650	0.831	5,650	1.990
1,700	0.180	3,700	0.853	5,700	2.026
1,750	0.191	3,750	0.877	5,750	2.061
Notes:	0.202	3.800	0.900	5.800	2.097

1,850 Velocity 1,900 FPM 1,950 2,000	0.202 Velocity 0.213 Pressure 0.225 in. W.G. 0.237 0.249	3,850 Velocity 3,900 FPM 3,950 4,000	0.924 Velocity 0.948 Pressure 0.973 in. W.G. 0.998	5,850 Velocity 5,900 FPM 5,950 6,000	2.134 Velocity 2.170 Pressure 2.207 in. W.G. 2.244
6,050 6,100 6,150 6,200 6,250	2.282 2.320 2.358 2.397 2.435	8,050 8,100 8,150 8,200 8,250	4.040 4.090 4.141 4.192 4.243	10,050 10,100 10,150 10,200 10,250	6.297 6.360 6.423 6.486 6.550
6,300 6,350 6,400 6,450 6,500	2.474 2.514 2.554 2.594 2.634	8,300 8,350 8,400 8,450 8,500	4.295 4.347 4.399 4.452 4.504	10,300 10,350 10,400 10,450 10,500	6.614 6.678 6.743 6.808 6.873
6,550 6,600 6,650 6,700 6,750	2.675 2.716 2.757 2.799 2.841	8,550 8,600 8,650 8,700 8,750	4.558 4.611 4.665 4.719 4.773	10,550 10,600 10,650 10,700 10,750	6.939 7.005 7.071 7.138 7.205
6,800 6,850 6,900 6,950 7,000	2.883 2.925 2.968 3.011 3.055	8,800 8,850 8,900 8,950 9,000	4.828 4.883 4.938 4.994 5.050	10,800 10,850 10,900 10,950 11,000	7.272 7.339 7.407 7.475 7.544
7,050 7,100 7,150 7,200 7,250	3.099 3.143 3.187 3.232 3.277	9,050 9,100 9,150 9,200 9,250	5.106 5.163 5.220 5.277 5.334	11,050 11,100 11,150 11,200 11,250	7.612 7.681 7.751 7.820 7.890
7,300 7,350 7,400 7,450 7,500	3.322 3.368 3.414 3.460 3.507	9,300 9,350 9,400 9,450 9,500	5.392 5.450 5.509 5.567 5.627	11,300 11,350 11,400 11,450 11,500	7.961 8.031 8.102 8.173 8.245
Notes: 7,600	3.554 3.601	9,550 9,600	5.686 5.746	11,550 11,600	8.317 8.389

	Height	11	10	9	8	8	7	7	7
	Width	12	14	15	16	18	18	20	19
Duct	Rect.	12	14	15	16	18	18	20	19
Dia.	Size	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
13	in.	13	14	17	18	18	20	20	22
	Height	13	11	11	10	9	9	8	8
15	Width	14	15	17	18	20	20	23	25
	Height	14	12	11	10	10	9	9	9
16	Width	15	16	18	19	20	23	23	25
	Height	15	13	12	11	10	10	9	9
17	Width	16	18	20	21	22	25	25	28
	Height	16	14	13	12	11	11	10	10
18	Width	16	19	21	23	24	25	28	28
	Height	16	15	14	13	12	11	11	10
19	Width	17	20	21	23	24	27	28	30
	Height	17	16	14	13	12	12	11	11
20	Width	18	20	23	25	26	27	30	30
	Height	18	16	15	14	13	12	12	11
21	Width	19	21	24	26	28	29	30	33
	Height	19	17	16	15	14	13	12	12
22	Width	20	23	26	26	28	32	33	36
	Height	20	18	17	15	14	14	13	13
23	Width	21	24	26	28	30	32	35	36
	Height	21	19	17	16	15	14	14	13
24	Width	22	25	27	30	32	34	35	39
	Height	22	20	18	17	16	15	14	14
25	Width	23	25	29	30	32	36	38	39
	Height	23	20	19	17	16	16	15	14
26	Width	24	26	30	32	34	36	38	41
	Height	24	21	20	18	17	16	15	15
27	Width	25	28	30	33	36	38	40	41
	Height	25	22	20	19	18	17	16	15
28	Width	26	29	32	35	36	38	43	44
	Height	26	23	21	20	18	17	17	16

		---	---	---	---	---	---	---	---
29 Duct Dia. 30 in.	Width	27	30	33	35	38	41	43	44
	Rect. Height	27	24	22	20	19	18	17	16
	Size	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
	Width in. Height	27	31	35	37	40	43	45	47
30	Height	27	25	23	21	20	19	18	17
	Width	28	31	35	39	40	43	45	50
31	Height	28	25	23	22	20	19	18	18
	Width	29	33	36	39	42	45	48	50
32	Height	29	26	24	22	21	20	19	18
	Width	30	34	38	40	44	47	50	52
33	Height	30	27	25	23	22	21	20	19
	Width	31	35	39	42	44	47	50	52
34	Height	31	28	26	24	22	21	20	19
	Width	32	36	39	42	46	50	53	55
35	Height	32	29	26	24	23	22	21	20
	Width	33	36	41	44	48	50	53	55
36	Height	33	29	27	25	24	22	21	20
	Width	35	39	44	47	50	54	58	61
38	Height	35	31	29	27	25	24	23	22
	Width	37	41	45	49	52	56	60	63
40	Height	37	33	30	28	26	25	24	23
	Width	38	43	48	51	56	59	63	66
42	Height	38	34	32	29	28	26	25	24
	Width	40	45	50	54	58	61	65	69
44	Height	40	36	33	31	29	27	26	25
	Width	42	48	53	56	60	65	68	72
46	Height	42	38	35	32	30	29	27	26
	Width	44	49	54	60	62	68	70	74
48	Height	44	39	36	34	31	30	28	27
	Width	46	51	57	61	66	70	75	77
50	Height	46	41	38	35	33	31	30	28
	Width	48	54	59	63	68	72	78	83
52	Height	48	43	39	36	34	32	31	30

54	Width	49	55	62	Aspect Ratio		77	80	85
Duct	Height	49	44	41	38	35	34	32	31
	Rect.								
56	Width	51	58	65	72	79	86	93	100
in.	Height	51	46	42	39	37	35	33	32
58	Width	53	60	66	70	76	81	85	91
	Height	53	48	44	40	38	36	34	33
60	Width	55	61	68	74	78	83	90	94
	Height	55	49	45	42	39	37	36	34
62	Width	57	64	71	75	82	88	93	96
	Height	57	51	47	43	41	39	37	35
64	Width	59	65	72	79	84	90	95	99
	Height	59	52	48	45	42	40	38	36
66	Width	60	68	75	81	86	92	98	105
	Height	60	54	50	46	43	41	39	38
68	Width	62	70	77	82	90	95	100	107
	Height	62	56	51	47	45	42	40	39
70	Width	64	71	80	86	92	99	105	110
	Height	64	57	53	49	46	44	42	40
72	Width	66	74	81	88	94	101	108	113
	Height	66	59	54	50	47	45	43	41
74	Width	68	76	84	91	98	104	110	116
	Height	68	61	56	52	49	46	44	42
76	Width	70	78	86	93	100	106	113	118
	Height	70	62	57	53	50	47	45	43
78	Width	71	80	89	95	102	110	115	121
	Height	71	64	59	54	51	49	46	44
80	Width	73	83	90	98	104	113	118	124
	Height	73	66	60	56	52	50	47	45
82	Width	75	84	93	100	108	115	123	129
	Height	75	67	62	57	54	51	49	47
84	Width	77	86	95	103	110	117	125	132
	Height	77	69	63	59	55	52	50	48
86	Width	79	88	97	105	112	119	126	133
	Height	79	71	65	61	57	54	51	49
88	Width	81	90	99	107	114	121	128	135
	Height	81	73	67	63	59	56	53	51
90	Width	83	92	101	109	116	123	130	137
	Height	83	75	69	65	61	58	55	53
92	Width	85	94	103	111	118	125	132	139
	Height	85	77	71	67	63	60	57	55
94	Width	87	96	105	113	120	127	134	141
	Height	87	79	73	69	65	62	59	57
96	Width	89	98	107	115	122	129	136	143
	Height	89	81	75	71	67	64	61	59
98	Width	91	100	109	117	124	131	138	145
	Height	91	83	77	73	69	66	63	61
100	Width	93	102	111	119	126	133	140	147
	Height	93	85	79	75	71	68	65	63

Duct Dia. in.	Rect. Size in.	Aspect Ratio						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
10	Width Height							
11	Width Height	18 6	21 6					
12	Width Height	21 7	21 6	24 6				
13	Width Height	21 7	25 7	24 6	30 6			
14	Width Height	24 8	25 7	28 7	30 6	36 6		
15	Width Height	24 8	28 8	28 7	35 7	36 6	42 6	
16	Width Height	27 9	28 8	32 8	35 7	42 7	42 6	48 6
17	Width Height	27 9	32 9	32 8	35 7	42 7	49 7	48 6
18	Width Height	30 10	32 9	36 9	40 8	42 7	49 7	56 7
19	Width Height	30 10	35 10	36 9	40 8	48 8	49 7	56 7
20	Width Height	33 11	35 10	40 10	45 9	48 8	56 8	56 7
21	Width Height	33 11	39 11	40 10	45 9	54 9	56 8	64 8
22	Width Height	36 12	39 11	44 11	50 10	54 9	56 8	64 8
23	Width Height	39 13	42 12	44 11	50 10	54 9	63 8	64 8
24	Width Height	39 13	42 12	48 12	55 11	60 10	63 9	72 9
Note:	Width	42	46	48	55	60	70	72

	Height	14	13	12	11	10	10	9	
		Aspect Ratio							
26	Width	42	46	52	55	66	70	72	
Duct	Rect.	14	13	13	11	11	10	9	
Dia.	Size	3.00	3.50	4.00	5.00	6.00	7.00	8.00	
27	Width	45	49	52	60	66	70	80	
in.	Height	15	14	13	12	11	10	10	
28	Width	45	49	56	60	66	77	80	
	Height	15	14	14	12	11	11	10	
29	Width	48	53	56	65	72	77	88	
	Height	16	15	14	13	12	11	11	
30	Width	48	53	60	65	72	77	88	
	Height	16	15	15	13	12	11	11	
31	Width	51	56	60	70	78	84	88	
	Height	17	16	15	14	13	12	11	
32	Width	54	56	60	70	78	84	96	
	Height	18	16	15	14	13	12	12	
33	Width	54	60	64	75	78	91	96	
	Height	18	17	16	15	13	13	12	
34	Width	57	60	64	75	84	91	96	
	Height	19	17	16	15	14	13	12	
35	Width	57	63	68	75	84	91	104	
	Height	19	18	17	15	14	13	13	
36	Width	60	63	68	80	90	98	104	
	Height	20	18	17	16	15	14	13	
38	Width	63	67	72	85	96	105	112	
	Height	21	19	18	17	16	15	14	
40	Width	66	70	76	90	96	105	120	
	Height	22	20	19	18	16	15	15	
42	Width	69	74	80	90	102	112	120	
	Height	23	21	20	18	17	16	15	
44	Width	72	81	84	95	108	119	128	
	Height	24	23	21	19	18	17	16	
Note:	Width	75	84	88	100	114	126	136	
	Height	25	24	22	20	19	18	17	

Duct Dia. in.	Rect. Height	Aspect Ratio						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
48	Width Height	78 26	88 25	92 23	105 21	120 20	126 18	136 17
50	Width Height	81 27	91 26	96 24	110 22	120 20	133 19	144 18
52	Width Height	84 28	95 27	100 25	115 23	126 21	140 20	152 19
54	Width Height	90 30	98 28	104 26	120 24	132 22	147 21	160 20
56	Width Height	93 31	102 29	108 27	125 25	138 23	147 21	160 20
58	Width Height	96 32	105 30	112 28	130 26	144 24	154 22	168 21
60	Width Height	99 33	109 31	116 29	130 26	144 24	161 23	
62	Width Height	102 34	112 32	120 30	135 27	150 25	168 24	
64	Width Height	105 35	116 33	124 31	140 28	156 26		
66	Width Height	108 36	119 34	128 32	145 29	162 27		
68	Width Height	111 37	123 35	132 33	150 30	168 28		
70	Width Height	114 38	126 36	136 34	155 31			
72	Width Height	117 39	130 37	140 35	160 32			
74	Width Height	123 41	133 38	144 36	165 33			
76	Width Height	126 42	137 39	148 37	165 33			
Note:	Width Height	129 43	140 40	152 38				

1. Shaded areas and bold numbers exceed the recommended

80	Width	132	144	156	Aspect Ratio			
Duct	Height	44	41	39				
82	Dia.	3.50	3.75	4.00	5.00	6.00	7.00	8.00
	in.	45	42	40				
84	Width	138	151	164				
	Height	46	43	41				
86	Width	141	154	168				
	Height	47	44	42				
88	Width	144	158					
	Height	48	45					
90	Width	147	161					
	Height	49	46					
92	Width	150	165					
	Height	50	47					
94	Width	153	168					
	Height	51	48					
96	Width	159						
	Height	53						
98	Width	162						
	Height	54						
100	Width	165						
	Height	55						
102	Width	168						
	Height	56						
104	Width							
	Height							

Note:

1. Shaded areas and bold numbers exceed the recommended maximum 4:1 aspect ratio.

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	3	3.5	4	4.5	5	5.5	6	7	8	9	10
3.0	3.3										
3.5	3.5	3.8									
4.0		4.1	4.4								
4.5	3.8	4.3	4.6	4.9							
5.0	4.0	4.6	4.9	5.2	5.5						
	4.2										
5.5	4.4	4.8	5.1	5.4	5.7	6.0					
6	4.6	5.0	5.3	5.7	6.0	6.3	6.6				
7	4.9	5.3	5.7	6.1	6.4	6.8	7.1	7.7			
8	5.2	5.7	6.1	6.5	6.9	7.2	7.6	8.2	8.7		
9	5.5	6.0	6.4	6.9	7.3	7.6	8.0	8.7	9.3	9.8	
10	5.7	6.3	6.7	7.2	7.6	8.0	8.4	9.1	9.8	10.4	10.9
11	6.0	6.5	7.0	7.5	8.0	8.4	8.8	9.5	10.2	10.9	11.5
12	6.2	6.8	7.3	7.8	8.3	8.7	9.1	9.9	10.7	11.3	12.0
13	6.4	7.0	7.6	8.1	8.6	9.0	9.5	10.3	11.1	11.8	12.4
14	6.6	7.2	7.8	8.4	8.9	9.3	9.8	10.8	11.4	12.2	12.9
15	6.8	7.5	8.0	8.6	9.1	9.6	10.1	11.0	11.8	12.6	13.3
16	7.0	7.7	8.3	8.8	9.4	9.9	10.4	11.3	12.2	13.0	13.7
17	7.2	7.9	8.5	9.1	9.6	10.2	10.7	11.6	12.5	13.4	14.1
18	7.3	8.0	8.7	9.3	9.9	10.4	11.0	11.9	12.9	13.7	14.5
19	7.5	8.2	8.9	9.5	10.1	10.7	11.2	12.2	13.2	14.1	14.9
20	7.7	8.4	9.1	9.7	10.3	10.9	11.5	12.6	13.5	14.4	15.2
22	8.0	8.7	9.5	10.1	10.8	11.4	12.0	13.0	14.1	15.0	15.9
24	8.3	9.1	9.8	10.5	11.2	11.8	12.4	13.5	14.6	15.6	16.5
26	8.5	9.4	10.1	10.9	11.5	12.2	12.8	14.0	15.1	16.2	17.1
28	8.8	9.6	10.4	11.2	11.9	12.6	13.2	14.5	15.6	16.7	17.7
30	9.0	9.9	10.7	11.5	12.2	13.0	13.6	14.9	16.1	17.2	18.3
32		10.2	11.0	11.8	12.6	13.3	14.0	15.3	16.5	17.7	18.8
34		10.4	11.3	12.2	12.9	13.6	14.4	15.7	17.0	18.2	19.3
36		10.7	11.5	12.4	13.2	14.0	14.7	16.1	17.4	18.6	19.8
38			11.8	12.7	13.5	14.3	15.0	16.5	17.8	19.0	20.2
40			12.0	13.1	13.8	14.7	15.3	16.8	18.2	19.5	20.7
42				13.2	14.0	14.9	15.6	17.1	18.5	19.9	21.1
44				13.4	14.3	15.1	15.9	17.5	18.9	20.3	21.5
46				13.7	14.6	15.4	16.2	17.8	19.3	20.6	21.9
48					14.8	15.7	16.5	18.1	19.6	21.0	22.3

A/B	12	13	14	15	16	17	18	19	20	22	24
6											
7											
8											
9											
10											
11											
12	13.1										
13	13.7	14.2									
14	14.2	14.7	15.3								
15	14.6	15.3	15.8	16.4							
16	15.1	15.7	16.4	16.9	17.5						
17	15.6	16.2	16.8	17.4	18.0	18.6					
18	16.0	16.7	17.3	17.9	18.5	19.1	19.7				
19	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8			
20	16.8	17.5	18.2	18.9	19.5	20.1	20.7	21.3	21.9		
22	17.6	18.3	19.1	19.8	20.4	21.1	21.7	22.3	22.9	24.0	
24	18.3	19.1	19.9	20.6	21.3	22.0	22.7	23.3	23.9	25.1	26.2
26	19.0	19.8	20.6	21.4	22.1	22.9	23.5	24.2	24.9	26.1	27.2
28	19.6	20.5	21.3	22.1	22.9	23.7	24.4	25.1	25.8	27.1	28.2
30	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.6	28.0	29.1
32	20.8	21.8	22.7	23.5	24.4	25.2	26.0	26.7	27.5	28.9	30.0
34	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	31.0
36	21.9	22.9	23.9	24.8	25.7	26.6	27.4	28.2	29.0	30.5	32.0
38	22.4	23.5	24.5	25.4	26.4	27.2	28.1	28.9	29.8	31.3	32.8
40	22.9	24.0	25.0	26.0	27.0	27.9	28.8	29.6	30.5	32.1	33.5
42	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.3	31.2	32.8	34.5
44	23.9	25.0	26.1	27.1	28.1	29.1	30.0	30.9	31.8	33.5	35.5
46	24.4	25.5	26.6	27.7	28.7	29.7	30.6	31.6	32.5	34.2	35.8
48	24.8	26.0	27.1	28.2	29.2	30.2	31.2	32.2	33.1	34.9	36.5
50	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8	33.7	35.5	37.5
52	25.7	26.9	28.0	29.2	30.3	31.3	32.3	33.3	34.3	36.2	37.8
54	26.1	27.3	28.5	29.7	30.8	31.8	32.9	33.9	34.9	36.8	38.5
56	26.5	27.7	28.9	30.1	31.2	32.3	33.4	34.4	35.4	37.4	39.5
58	26.9	28.2	29.4	30.6	31.7	32.8	33.9	35.0	36.0	38.0	39.8
60	27.3	28.6	29.8	31.0	32.2	33.3	34.4	35.5	36.5	38.5	40.5

A \ B	28	30	32	34	36	38	40	42	44	46	48
13											
14											
15											
16											
17											
18											
19											
20											
22											
24											
26											
28	30.6										
30	31.7	32.8									
32	32.7	33.9	35.0								
34	33.7	34.9	36.1	37.2							
36	34.6	35.9	37.1	38.2	39.4						
38	35.6	36.8	38.1	39.3	40.4	41.5					
40	36.4	37.8	39.0	40.3	41.5	42.6	43.7				
42	37.3	38.7	40.0	41.3	42.5	43.7	44.8	45.9			
44	38.1	39.5	40.9	42.2	43.5	44.7	45.8	47.0	48.1		
46	38.9	40.4	41.8	43.1	44.4	45.7	46.9	48.0	49.2	50.3	
48	39.7	41.2	42.6	44.0	45.3	46.6	47.9	49.1	50.2	51.4	52.5
50	40.5	42.0	43.6	44.9	46.2	47.5	48.8	50.0	51.2	52.4	53.5
52	41.2	42.8	44.3	45.7	47.1	48.4	49.7	51.0	52.2	53.4	54.5
54	41.9	43.5	45.1	46.5	48.0	49.3	50.7	52.0	53.2	54.4	55.5
56	42.7	44.3	45.8	47.3	48.8	50.2	51.6	52.9	54.2	55.4	56.5
58	43.3	45.0	46.6	48.1	49.6	51.0	52.4	53.8	55.1	56.4	57.5
60	44.0	45.7	47.3	48.9	50.4	51.9	53.3	54.7	60.0	57.3	58.5
62	44.7	46.4	48.0	49.6	51.2	52.7	54.1	55.5	56.9	58.2	59.3
64	45.3	47.1	48.7	50.4	51.9	53.5	54.9	56.4	57.8	59.1	60.2
66	46.0	47.7	49.4	51.1	52.7	54.2	55.7	57.2	58.6	60.0	61.1
68	46.6	48.4	50.1	51.8	53.4	55.0	56.5	58.0	59.4	60.8	62.0
70	47.2	49.0	50.8	52.5	54.1	55.7	57.3	58.8	60.3	61.7	63.0
72	47.8	49.6	51.4	53.2	54.8	56.5	58.0	59.6	61.1	62.5	63.8
74	48.4	50.3	52.1	53.8	55.5	57.2	58.8	60.3	61.9	63.3	64.6

76 A/B	28 48.9	30 50.9	32 52.7	34 54.5	36 56.2	38 57.9	40 59.5	42 61.1	44 62.6	46 64.1	48 65.8
78	49.5	51.4	53.3	55.1	56.9	58.6	60.2	61.8	63.4	64.9	66.4
80	50.1	52.0	53.9	55.8	57.5	59.3	60.9	62.6	64.1	65.7	67.1
82	50.6	52.6	54.6	56.4	58.2	59.9	61.6	63.3	64.9	66.5	68.0
84	51.1	53.2	55.1	57.0	58.8	60.6	62.3	64.0	65.6	67.2	68.7
86	51.7	53.7	55.7	57.6	59.4	61.2	63.0	64.7	66.3	67.9	69.4
88	52.2	54.3	56.3	58.2	60.1	61.9	63.6	65.4	67.0	68.7	70.1
90	52.7	54.8	56.8	58.8	60.7	62.5	64.3	66.0	67.7	69.4	71.0
92	53.2	55.3	57.4	59.3	61.3	63.1	64.9	66.7	68.4	70.1	71.7
94	53.7	55.9	57.9	59.9	61.9	63.7	65.6	67.3	69.1	70.8	72.4
96	54.2	56.4	58.4	60.5	62.4	64.3	66.2	68.0	69.7	71.5	73.1
98	54.7	56.9	59.0	61.1	63.0	64.9	66.8	68.6	70.4	72.2	73.8
100	55.2	57.4	59.5	61.6	63.6	65.5	67.4	69.2	71	72.8	74.4



ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	52	54	56	58	60	62	64	66	68	70	72
50											
52	56.8										
54	57.9	59.0									
56	59.0	60.1	61.2								
58	60.0	61.2	62.3	63.4							
60	61.0	62.2	63.4	64.5	65.6						
62	62.0	63.2	64.4	65.5	66.7	67.8					
64	63.0	64.2	65.4	66.6	67.7	69.9	70.0				
66	63.9	65.2	66.4	67.6	68.8	69.9	71.0	72.1			
68	64.9	66.2	67.4	68.6	69.8	71.0	72.1	73.2	74.3		
70	65.8	67.1	68.3	69.6	70.8	72.0	73.2	74.3	75.4	76.5	
72	66.7	68.0	69.3	70.6	71.8	73.0	74.2	75.4	76.5	77.6	78.7
74	67.5	68.9	70.2	71.5	72.7	74.0	75.2	76.4	77.5	78.7	79.8
76	68.4	69.8	71.1	72.4	73.7	75.0	76.2	77.4	78.6	79.7	80.8
78	69.3	70.6	72.0	73.3	74.6	75.9	77.1	78.4	79.6	80.7	81.8
80	70.1	71.6	72.9	74.2	75.4	76.9	78.1	79.4	80.6	81.8	82.9
82	70.9	72.3	73.7	75.1	76.4	77.8	79.0	80.3	81.5	82.8	84.0
84	71.7	72.6	74.6	76.0	77.3	78.7	80.0	81.3	82.5	83.8	85.0
86	72.5	73.3	75.4	76.8	78.2	79.6	80.9	82.2	83.5	84.7	85.9
88	73.3	74.0	76.3	77.7	79.1	80.5	81.8	83.1	84.4	85.7	86.9
90	74.1	75.6	77.1	78.5	79.9	81.3	82.7	84.0	85.3	86.6	87.9
92	74.9	76.4	77.9	79.3	80.8	82.2	83.5	85.4	86.2	87.5	88.8
94	75.6	77.2	78.7	80.1	81.6	83.0	84.4	86.0	87.1	88.4	89.7
96	76.3	77.9	79.4	80.9	82.4	83.8	85.3	86.6	88.0	89.3	90.6
98	77.1	78.7	80.2	81.7	83.2	84.7	86.1	87.5	88.9	90.2	91.5
100	77.8	79.4	81	82.5	84	85.5	86.9	88.3	89.7	91.1	92.4



ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	76	78	80	82	84	86	88	90	92	94
70										
72										
74										
76	83.1									
78	84.2	85.3								
80	85.2	86.4	87.5							
82	86.3	87.4	88.5	89.6						
84	87.3	88.5	89.6	90.7	91.8					
86	88.3	89.5	90.7	91.8	92.9	94.0				
88	89.3	90.5	91.7	92.9	94.0	95.1	96.2			
90	90.3	91.5	92.7	93.9	95.0	96.2	97.3	98.4		
92	91.3	92.5	93.7	94.9	96.1	97.2	98.4	99.5	100.6	
94	92.3	93.5	94.7	95.9	97.1	98.3	99.4	100.6	101.1	102.
96	93.2	94.5	95.7	96.9	98.1	99.3	100.5	101.6	102.7	103.
98	94.2	95.5	96.7	97.9	99.1	100.3	101.5	102.7	103.8	104.
100	95.1	96.4	97.6	98.9	100.1	101.3	102.5	103.7	104.8	106

Note:

1. Shaded areas and bold numbers exceed the recommended maximum



Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 17: Air Distribution Systems, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 18: Piping Systems, General

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18. Part 18: Piping Systems, General

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18.01. Piping Materials and Properties

A. Steel pipe and Type L copper pipe are the most common pipe materials used in HVAC applications.

B. Steel Pipe

1. Standard steel pipe sizes: 1/2", 3/4", 1", 1-1/4", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", 24", 30", 36", 42", 48", 54", 60", 72", 84", and 96".
2. Nonstandard steel pipe sizes: 5", 22", 26", 28", 32", and 34" are not standard sizes and not readily available in all locations.
3. Standard steel pipe is the most common steel pipe used in HVAC applications.
4. Standard and XS steel pipe are available in sizes through 96 inch.
5. XXS steel pipe is available in sizes through 12 inch.
6. Schedule 40 steel pipe is available in sizes through 96 inch.
7. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.
8. Standard and Schedule 40 steel pipe have the same dimensions and flow for 10 inch and smaller.
9. XS and Schedule 80 steel pipe have the same dimensions and flow for 8 inch and smaller.
10. XXS and Schedule 160 have no relationship for dimensions or flow.

11. Steel pipe is manufactured in accordance with ASTM Standards A53 and A106.
12. The ASTM standards refer to steel pipe grades A and B. Grade A steel pipe has a lower tensile strength and is not generally used for HVAC applications.
13. The ASTM standards refer to steel pipe Types E, S, and F.
 - a. Type E (also referred to as ERW) steel pipe refers to electric resistance welded steel pipe.
 - b. Type S steel pipe refers to seamless steel pipe.
 - c. Type F steel pipe refers to furnace-butt welded steel pipe. This type is generally not used in HVAC applications and is only available in Grade A.

C. Copper Pipe

1. Standard copper pipe sizes: 1/2", 3/4", 1", 1-1/4", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", and 12".
2. Copper pipe is available in Types K, L, and M.
3. Types K, L, and M copper may be hard drawn or annealed (soft) temper.
4. Hard drawn copper pipe has higher allowable stress than annealed copper pipe.
5. Types K, L, and M designate decreasing wall thicknesses (Type K copper pipe has the thickest wall, while type M copper pipe has the thinnest wall).
6. Type K is generally used for higher pressure/temperature applications and for direct burial.
7. Type L copper pipe is the most common copper pipe used in HVAC applications.
8. Type M copper pipe should not be used where subject to external damage.
9. Copper pipe is manufactured in accordance with ASTM Standard B88.

D. Stainless Steel Pipe

1. Standard stainless steel pipe sizes: 1/2", 3/4", 1", 1-1/4", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", and 24".
2. Schedule 5 and 10 stainless steel pipe are available in sizes through 24 inch.

E. In the following piping tables ...

1. Uninsulated piping: Add 20 percent for hangers and supports.
2. Insulated piping: Add 25 percent for hangers, supports, and insulation.

F. Piping installations are generally governed by one of the following three codes ...

1. ASME B31.1-1998: Power Piping:
 - a. Applicable to electric generating stations, industrial and institutional plants, central and district heating/cooling plants, and geothermal heating.
2. ASME B31.3-1999: Process Piping:
 - a. Applicable to petroleum refineries, chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants.
3. ASME B31.9-1996: Building Services Piping:
 - a. Applicable to industrial, institutional, commercial, and public buildings and multiunit residences.
 - b. Most HVAC applications fall under ASME B31.9 requirements.

PROPERTIES OF COPPER PIPE

Pipe Size in.	Type	Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area, sq.in.	Weight (1)		
						Pipe lbs./ft.	Water lbs./ft.	Total lbs./ft.
1/2	K	0.527	0.049	0.625	0.218	0.301	0.095	0.396
	L	0.545	0.040	0.625	0.233	0.250	0.101	0.351
	M	0.569	0.028	0.625	0.254	0.179	0.110	0.289
3/4	K	0.745	0.065	0.875	0.436	0.562	0.189	0.751
	L	0.785	0.045	0.875	0.484	0.399	0.210	0.609
	M	0.811	0.032	0.875	0.517	0.288	0.224	0.512
1	K	0.995	0.065	1.125	0.778	0.736	0.337	1.073
	L	1.025	0.050	1.125	0.825	0.574	0.357	0.932
	M	1.055	0.035	1.125	0.874	0.407	0.379	0.786
1-1/4	K	1.245	0.065	1.375	1.217	0.909	0.527	1.437
	L	1.265	0.055	1.375	1.257	0.775	0.545	1.320
	M	1.291	0.042	1.375	1.309	0.598	0.567	1.165

		1.291	0.042	1.575	1.509	0.998	0.987	1.109
1- Pipe Size in.	K L M Type	1.481 1.505 1.527 Inside Dia. in.	0.072 0.060 0.049 Wall Thick in.	1.625 1.625 1.625 Outside Dia. in.	1.723 1.779 1.831 Area, sq.in.	1.194 1.003 0.825 Pipe lbs./ft.	0.746 0.771 0.793 Water lbs./ft.	1.941 1.774 1.618 Total lbs./ft.
2	K	1.959	0.083	2.125	3.014	1.810	1.306	3.116
	L	1.985	0.070	2.125	3.095	1.536	1.341	2.877
	M	2.009	0.058	2.125	3.170	1.280	1.373	2.654
2- 1/2	K	2.435	0.095	2.625	4.657	2.567	2.018	4.585
	L	2.465	0.080	2.625	4.772	2.174	2.068	4.242
	M	2.495	0.065	2.625	4.889	1.777	2.118	3.895
3	K	2.907	0.109	3.125	6.637	3.511	2.876	6.387
	L	2.945	0.090	3.125	6.812	2.917	2.951	5.868
	M	2.981	0.072	3.125	6.979	2.348	3.024	5.371
4	K	3.857	0.134	4.125	11.684	5.712	5.062	10.77
	L	3.905	0.110	4.125	11.977	4.717	5.189	9.906
	M	3.935	0.095	4.125	12.161	4.089	5.269	9.358
5	K	4.805	0.160	5.125	18.133	8.484	7.856	16.34
	L	4.875	0.125	5.125	18.665	6.675	8.087	14.76
	M	4.907	0.109	5.125	18.911	5.839	8.193	14.03
6	K	5.741	0.192	6.125	25.886	12.166	11.215	23.38
	L	5.845	0.140	6.125	26.832	8.949	11.625	20.57
	M	5.881	0.122	6.125	27.164	7.822	11.769	19.59
8	K	7.583	0.271	8.125	45.162	22.732	19.566	42.29
	L	7.725	0.200	8.125	46.869	16.928	20.306	37.23
	M	7.785	0.170	8.125	47.600	14.443	20.623	35.06
10	K	9.449	0.338	10.125	70.123	35.330	30.381	65.71
	L	9.625	0.250	10.125	72.760	26.367	31.523	57.89
	M	9.701	0.212	10.125	73.913	22.445	32.023	54.46
12	K	11.315	0.405	12.125	100.554	50.695	43.565	94.25
	L	11.565	0.280	12.125	105.046	35.422	45.511	80.93
	M	11.617	0.254	12.125	105.993	32.203	45.921	78.12



PROPERTIES OF STEEL PIPE

Weight

Pipe Size	Schedule	Schedule	Inside Dia.	Wall Thick	Outside Dia. in.	Area	Pipe	Weight
in.			in.	in.		sq.in.	lbs./ft.	Water
								lbs./ft.
1/2	10	-	0.674	0.083	0.840	0.357	0.671	0.155
	40	STD	0.622	0.109	0.840	0.304	0.851	0.132
	80	XS	0.546	0.147	0.840	0.234	1.088	0.101
	160	-	0.466	0.187	0.840	0.171	1.304	0.074
	-	XXS	0.252	0.294	0.840	0.050	1.714	0.022
3/4	10	-	0.884	0.083	1.050	0.614	0.857	0.266
	40	STD	0.824	0.113	1.050	0.533	1.131	0.231
	80	XS	0.742	0.154	1.050	0.432	1.474	0.187
	160	-	0.614	0.218	1.050	0.296	1.937	0.128
	-	XXS	0.434	0.308	1.050	0.148	2.441	0.064
1	10	-	1.097	0.109	1.315	0.945	1.404	0.409
	40	STD	1.049	0.133	1.315	0.864	1.679	0.374
	80	XS	0.957	0.179	1.315	0.719	2.172	0.312
	160	-	0.815	0.250	1.315	0.522	2.844	0.226
	-	XXS	0.599	0.358	1.315	0.282	3.659	0.122
1-1/4	10	-	1.442	0.109	1.660	1.633	1.806	0.708
	40	STD	1.380	0.140	1.660	1.496	2.273	0.648
	80	XS	1.278	0.191	1.660	1.283	2.997	0.556
	160	-	1.160	0.250	1.660	1.057	3.765	0.458
	-	XXS	0.896	0.382	1.660	0.631	5.214	0.273
1-1/2	10	-	1.682	0.109	1.900	2.222	2.085	0.963
	40	STD	1.610	0.145	1.900	2.036	2.718	0.882
	80	XS	1.500	0.200	1.900	1.767	3.631	0.766
	160	-	1.338	0.281	1.900	1.406	4.859	0.609
	-	XXS	1.100	0.400	1.900	0.950	6.408	0.412
2	10	-	2.157	0.109	2.375	3.654	2.638	1.583
	40	STD	2.067	0.154	2.375	3.356	3.653	1.454
	80	XS	1.939	0.218	2.375	2.953	5.022	1.279
	160	-	1.689	0.343	2.375	2.241	7.444	0.971
	-	XXS	1.503	0.436	2.375	1.774	9.029	0.769
2-1/2	10	-	2.635	0.120	2.875	5.453	3.531	2.363
	40	STD	2.469	0.203	2.875	4.788	5.793	2.074
	80	XS	2.323	0.276	2.875	4.238	7.661	1.836

Pipe Size in.	Schedule	Inside Dia.	Wall Thickness in.	Outside Dia. in.	Area sq.in.	Pipe lbs./ft.	Water lbs./ft.	Weight
	160	-	2.125	0.375	2.875	3.547	10.013	1.067
	-	XXS	1.771	0.552	2.875	2.463	13.695	1.067
	40	STD	3.068	0.116	3.500	8.347	4.332	3.616
	80	XS	2.900	0.300	3.500	7.393	7.576	3.203
	160	-	2.626	0.437	3.500	6.605	10.253	2.862
4	-	XXS	2.300	0.600	3.500	5.416	14.296	2.346
	10	-	4.260	0.120	4.500	4.155	18.584	1.800
	40	STD	4.026	0.237	4.500	14.253	5.614	6.175
	80	XS	3.826	0.337	4.500	12.730	10.791	5.515
	160	-	3.438	0.531	4.500	11.497	14.984	4.981
5	-	XXS	3.152	0.674	4.500	9.283	22.509	4.022
	10	-	5.295	0.134	5.563	7.803	27.541	3.381
	40	STD	5.047	0.258	5.563	22.020	7.770	9.540
	80	XS	4.813	0.375	5.563	20.006	14.618	8.667
	160	-	4.313	0.625	5.563	18.194	20.778	7.882
6	-	XXS	4.063	0.750	5.563	14.610	32.962	6.330
	10	-	6.357	0.134	6.625	12.965	38.553	5.617
	40	STD	6.065	0.280	6.625	31.739	9.290	13.751
	80	XS	5.761	0.432	6.625	28.890	18.974	12.517
	160	-	5.189	0.718	6.625	26.067	28.574	11.293
8	-	XXS	4.897	0.864	6.625	21.147	45.297	9.162
	10	-	8.329	0.148	8.625	18.834	53.161	8.160
	20	-	8.125	0.250	8.625	54.485	13.399	23.605
	30	-	8.071	0.277	8.625	51.849	22.362	22.463
	40	STD	7.981	0.322	8.625	51.162	24.697	22.166
	80	XS	7.625	0.500	8.625	50.027	28.554	21.674
	160	-	6.813	0.906	8.625	45.664	43.388	19.784
10	-	XXS	6.875	0.875	8.625	37.122	72.425	16.083
	10	-	10.420	0.165	10.750	36.456	74.691	15.794
	20	-	10.250	0.250	10.750	85.276	18.653	36.945
	30	-	10.136	0.307	10.750	82.516	28.036	35.750
	40	STD	10.020	0.365	10.750	80.691	34.241	34.959
	60	XS	9.750	0.500	10.750	78.854	40.484	34.163
	80	-	9.564	0.593	10.750	74.662	54.736	32.347
	140	XXS	8.750	1.000	10.750	71.840	64.328	31.125
160	-	8.500	1.125	10.750	60.132	104.132	26.052	
					56.745	115.647	24.585	

			Outside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Pipe lbs./ft.	Weight Water lbs./ft.
12 Pipe Size in.	10	-	12.390	0.180	12.750	120.568	24.165	52.236
	20	-	12.250	0.250	12.750	117.859	33.376	51.062
	30	-	12.090	0.350	12.750	114.800	43.774	49.737
	-	STD	12.000	0.375	12.750	113.097	49.563	48.999
	40	-	11.938	0.406	12.750	111.932	53.526	48.494
	-	XS	11.750	0.500	12.750	108.434	65.416	46.979
	80	-	11.376	0.687	12.750	101.641	88.510	44.036
	120	XXS	10.750	1.000	12.750	90.763	125.492	39.323
160	-	10.126	1.312	12.750	80.531	160.274	34.890	
14	10	-	13.500	0.250	14.000	143.139	36.713	62.014
	20	-	13.376	0.312	14.000	140.521	45.611	60.880
	30	STD	13.250	0.375	14.000	137.886	54.569	59.739
	40	-	13.126	0.437	14.000	135.318	63.302	58.626
	-	XS	13.000	0.500	14.000	132.732	72.091	57.506
	80	-	12.500	0.750	14.000	122.718	106.134	53.167
	160	-	11.188	1.406	14.000	98.309	189.116	42.592
16	10	-	15.500	0.250	16.000	188.692	42.053	81.750
	20	-	15.376	0.312	16.000	185.685	52.276	80.447
	30	STD	15.250	0.375	16.000	182.654	62.579	79.134
	40	XS	15.000	0.500	16.000	176.715	82.772	76.561
	80	-	14.314	0.843	16.000	160.921	136.465	69.718
	160	-	12.814	1.593	16.000	128.961	245.114	55.872
18	10	-	17.500	0.250	18.000	240.528	47.393	104.208
	20	-	17.376	0.312	18.000	237.132	58.940	102.737
	-	STD	17.250	0.375	18.000	233.705	70.589	101.252
	30	-	17.126	0.437	18.000	230.357	81.971	99.802
	-	XS	17.000	0.500	18.000	226.980	93.452	98.338
	40	-	16.876	0.562	18.000	223.681	104.668	96.909
	80	-	16.126	0.937	18.000	204.241	170.755	88.487
	160	-	14.438	1.781	18.000	163.721	308.509	70.932
20	10	-	19.500	0.250	20.000	298.648	52.733	129.388
	20	STD	19.250	0.375	20.000	291.039	78.600	126.092
	30	XS	19.000	0.500	20.000	283.529	104.132	122.838
	40	-	18.814	0.593	20.000	278.005	122.911	120.445
	80	-	17.938	1.031	20.000	252.719	208.873	109.490
	160	-	16.064	1.968	20.000	202.674	379.008	87.808
22	10	-	21.500	0.250	22.000	362.050	58.074	157.200

Pipe Size in.	Schedule	-	Inside Dia.	Wall Thickness in.	Outside Dia. in.	Area sq.in.	Pipe lbs./ft.	Weight
								Water lbs./ft.
22	10	-	21.500	0.250	22.000	363.050	58.074	157.290
	20	STD	21.250	0.375	22.000	354.656	86.610	153.654
	30	XS	21.000	0.500	22.000	346.361	114.812	150.060
	160	-	17.750	2.125	22.000	306.354	250.818	132.727
24	10	-	23.500	0.250	24.000	433.736	63.414	187.915
	20	STD	23.250	0.375	24.000	424.557	94.620	183.938
	-	XS	23.000	0.500	24.000	415.476	125.492	180.003
	30	-	22.876	0.562	24.000	411.008	140.681	178.068
	40	-	22.626	0.687	24.000	402.073	171.054	174.197
	80	-	21.564	1.218	24.000	365.215	296.359	158.228
	160	-	19.314	2.343	24.000	292.978	541.938	126.932
26	10	-	25.376	0.312	26.000	505.750	85.598	219.115
	-	STD	25.250	0.375	26.000	500.740	102.630	216.944
	20	XS	25.000	0.500	26.000	490.874	136.173	212.670
28	10	-	27.376	0.312	28.000	588.613	92.263	255.015
	-	STD	27.250	0.375	28.000	583.207	110.640	252.673
	20	XS	27.000	0.500	28.000	572.555	146.853	248.058
	30	-	26.750	0.625	28.000	562.001	182.732	243.485
30	10	-	29.376	0.312	30.000	677.759	98.927	293.637
	-	STD	29.250	0.375	30.000	671.957	118.650	291.123
	20	XS	29.000	0.500	30.000	660.520	157.533	286.168
	30	-	28.750	0.625	30.000	649.181	196.082	281.255
	40	-	28.500	0.688	29.876	637.940	214.473	276.385
32	10	-	31.376	0.312	32.000	773.188	105.591	334.981
	-	STD	31.250	0.375	32.000	766.990	126.660	332.296
	20	XS	31.000	0.500	32.000	754.768	168.213	327.001
	30	-	30.750	0.625	32.000	742.643	209.432	321.748
	40	-	30.624	0.688	32.000	736.569	230.080	319.116
34	10	-	33.376	0.312	34.000	874.900	112.256	379.048
	-	STD	33.250	0.375	34.000	868.307	134.671	376.191
	20	XS	33.000	0.500	34.000	855.299	178.893	370.555
	30	-	32.750	0.625	34.000	842.389	222.782	364.962
	40	-	32.624	0.688	34.000	835.919	244.776	362.159
36	10	-	35.376	0.312	36.000	982.895	118.920	425.836
	-	STD	35.250	0.375	36.000	975.906	142.681	422.808
	20	XS	35.000	0.500	36.000	962.113	189.574	416.832

Size in. Pipe	Schedule		Dia. in. Inside	Thick in. Wall	Outside Dia. in.	Area sq.in.	Pipe lbs./ft.	water Weight (1) lbs./ft.
	Size	Schedule						
in.	10	-	0.674	0.083	0.840	0.396	0.549	0.172
			0.674	0.083	0.840	0.357	0.684	0.155
3/4	5	-	0.920	0.065	1.050	0.665	0.697	0.288
	10	-	0.884	0.083	1.050	0.614	0.874	0.266
1	5	-	1.185	0.065	1.315	1.103	0.885	0.478
	10	-	1.097	0.109	1.315	0.945	1.432	0.409
1- 1/4	5	-	1.530	0.065	1.660	1.839	1.129	0.797
	10	-	1.442	0.109	1.660	1.633	1.842	0.708
1- 1/2	5	-	1.770	0.065	1.900	2.461	1.299	1.066
	10	-	1.682	0.109	1.900	2.222	2.127	0.963
2	5	-	2.245	0.065	2.375	3.958	1.636	1.715
	10	-	2.157	0.109	2.375	3.654	2.691	1.583
2- 1/2	5	-	2.709	0.083	2.875	5.764	2.524	2.497
	10	-	2.635	0.120	2.875	5.453	3.601	2.363
3	5	-	3.334	0.083	3.500	8.730	3.090	3.782
	10	-	3.260	0.120	3.500	8.347	4.419	3.616
4	5	-	4.334	0.083	4.500	14.753	3.994	6.392
	10	-	4.260	0.120	4.500	14.253	5.726	6.175
5	5	-	5.345	0.109	5.563	22.438	6.476	9.721
	10	-	5.295	0.134	5.563	22.020	7.925	9.540
6	5	-	6.407	0.109	6.625	32.240	7.737	13.968
	10	-	6.357	0.134	6.625	31.739	9.475	13.751
8	5	-	8.407	0.109	8.625	55.510	10.112	24.050
	10	-	8.329	0.148	8.625	54.485	13.667	23.605
10	5	-	10.482	0.134	10.750	86.294	15.497	37.386
	10	-	10.420	0.165	10.750	85.276	19.026	36.945
12	5	-	12.438	0.156	12.750	121.504	21.403	52.641
	10	-	12.390	0.180	12.750	120.568	24.648	52.236
14	5	-	13.688	0.156	14.000	147.153	23.527	63.754
	10	-	13.624	0.188	14.000	145.780	28.287	63.159
16	5	-	15.670	0.165	16.000	197.854	28.462	82.552

Pipe Size in.	Schedule		Inside Dia. in.	Wall Thick in.	Outside Dia. in.	Area sq.in.	Pipe lbs./ft.	Water lbs./ft.
10	5	-	15.670	0.188	16.000	192.854	28.403	83.553
	10	-	15.624	0.188	16.000	191.723	32.384	83.965
18	5	-	17.670	0.165	18.000	245.224	33.058	106.243
	10	-	17.624	0.188	18.000	243.849	36.480	105.690
20	5	-	19.624	0.188	20.000	302.458	40.576	131.039
	10	-	19.564	0.218	20.000	300.611	46.979	130.239
22	5	-	21.624	0.188	22.000	367.250	44.672	159.110
	10	-	21.564	0.218	22.000	365.215	51.729	158.228
24	5	-	23.564	0.218	24.000	436.102	56.479	188.940
	10	-	23.500	0.250	24.000	433.736	64.682	187.915



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18.02. Pipe Support and Pipe Spacing

HORIZONTAL PIPE SUPPORT SPACING

Maximum Horizontal Hanger Spacing Feet

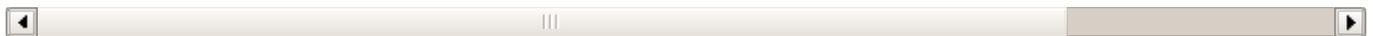
Pipe Size	Steel			Copper		
	Recommend	Water Systems	Vapor Systems	Recommend	Water Systems	Vapor Systems
1/2	6	7	8	5	5	6
3/4	6	7	9	5	5	7
1	6	7	9	6	6	8
1-	6	7	9	6	7	9
1/4	6	9	12	6	8	10
1-	7	10	13	7	8	11
1/2						
2						
2-	10	11	14	8	9	13
1/2	10	12	15	10	10	14
3	10	14	17	10	12	16
4						
Note:	10	16	19	10	13	18
6	10	17	21	10	14	20

1. Recommended pipe support spacing is less than the maximum to meet

8	12	19	24	10	16	23
10	12	22	26	10	18	25
12	12	23	30	10	19	28
14	12	25	30	-	-	-
16	12	27	35	-	-	-
18	12	28	37	-	-	-
20	12	30	39	-	-	-
22	12	30	39	-	-	-
24	12	32	42	-	-	-
26	12	32	42	-	-	-
28	12	32	42	-	-	-
30	12	33	44	-	-	-
32	12	33	44	-	-	-
34	12	33	44	-	-	-
36	12	33	44	-	-	-
42	12	33	44	-	-	-
48	12	32	42	-	-	-
54	12	33	44	-	-	-
60	12	33	44	-	-	-
72	12	33	44	-	-	-
84	12	33	44	-	-	-
96	12	33	44	-	-	-

Note:

1. Recommended pipe support spacing is less than the maximum to more evenly distribute weight over a building's structural system. Consult the structural engineer for additional guidance on pipe support spacing, especially in joist construction.



VERTICAL PIPE SUPPORT SPACING

**Maximum Vertical Support
Spacing Feet**

Pipe Size	Steel	Copper	Support
8" and Smaller	Every other floor and base of all pipe risers	Every floor and base of all pipe risers	Steel extension pipe clamps
10"-12"	Every other floor and base of all pipe risers	Every floor and base of all pipe risers	Steel extension pipe clamps
14"-24"	Every other floor and base of all pipe risers	Not applicable	Steel extension pipe clamps
26"-96"	Every floor and base of all pipe risers	Not applicable	Steel extension pipe clamps

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size	Pipe Size										
	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6
1/2	7.5	-	-	-	-	-	-	-	-	-	-
3/4	8.0	8.0	-	-	-	-	-	-	-	-	-
1	8.0	8.5	8.5	-	-	-	-	-	-	-	-
1-1/4	8.5	8.5	8.5	9.0	-	-	-	-	-	-	-
1-1/2	8.5	8.5	9.0	9.0	9.0	-	-	--	-	-	-
2	9.0	9.0	9.5	9.5	9.5	10.0	-	-	-	-	-
2-1/2	10.0	10.0	10.5	10.5	10.5	11.0	12.0	-	-	-	-
3	10.0	10.5	10.5	11.0	11.0	11.5	12.5	12.5	-	-	-
4	11.5	11.5	12.0	12.0	12.0	12.5	13.5	14.0	15.0	-	-

1- 1/4 1- 1/2 2	Minimum Centerline-to-Centerline Dimensions, Inches										
	Pipe Size										
	8	10	12	14	16	18	20	22	24	26	28
2- 1/2	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
8	19.5	-	-	-	-	-	-	-	-	-	-
10	21.0	22.0	-	-	-	-	-	-	-	-	-
12	22.5	23.5	25.0	-	-	-	-	-	-	-	-
14	23.5	24.5	26.0	27.0	-	-	-	-	-	-	-
16	24.5	26.0	27.5	28.5	30.0	-	-	-	-	-	-
18	25.5	26.5	28.0	29.0	30.5	31.0	-	-	-	-	-
20	26.5	28.0	29.5	30.5	31.5	32.5	33.5	-	-	-	-
22	27.5	29.0	30.5	31.5	32.5	33.5	34.5	35.5	-	-	-
24	29.0	30.0	31.5	32.5	34.0	34.5	36.0	37.0	38.0	-	-
26	30.0	31.0	33.0	34.0	35.0	36.0	37.0	38.0	39.5	40.5	-
28	31.0	32.5	34.0	35.0	36.0	37.0	38.0	39.0	40.5	41.5	42
30	32.5	33.5	35.0	36.0	37.5	38.0	39.5	40.5	41.5	42.5	44
32	34.0	35.0	36.5	37.4	39.0	39.5	41.0	42.0	43.0	44.0	45
34	35.0	36.0	37.5	38.5	40.0	40.5	42.0	43.0	44.0	45.0	46
36	36.0	37.0	38.5	39.5	41.0	41.5	43.0	44.0	45.0	46.5	47
42	39.5	40.5	42.0	41.0	44.5	45.0	46.5	47.5	48.5	50.0	51
48	42.5	44.0	45.5	46.5	47.5	48.5	49.5	51.0	52.0	53.0	54
54	46.0	47.5	49.0	50.0	51.0	52.0	53.0	54.0	55.5	56.5	57
60	49.5	50.5	52.0	53.0	54.5	55.0	56.5	57.5	58.5	60.0	61
72	56.0	57.5	59.0	60.0	61.0	62.0	63.0	64.5	65.5	66.5	67
84	63.0	64.0	65.5	66.5	68.0	68.5	70.0	71.0	72.0	73.5	74
96	69.5	71.0	72.5	73.5	74.5	75.5	76.5	78.0	79.0	80.0	81

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches

Pipe Size

Pipe Size	30	32	34	36	42	48	54	60	72	84
1/2	-	-	-	-	-	-	-	-	-	-
3/4	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-
1-	-	-	-	-	-	-	-	-	-	-
1/4	-	-	-	-	-	-	-	-	-	-
1-	-	-	-	-	-	-	-	-	-	-
1/2	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-
2-	-	-	-	-	-	-	-	-	-	-
1/2	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-
30	45.0	-	-	-	-	-	-	-	-	-
32	46.5	48.0	-	-	-	-	-	-	-	-
Notes:	47.5	49.0	50.0	-	-	-	-	-	-	-
36	48.5	50.0	51.0	52.0	-	-	-	-	-	-

1. Table based on 40 degree pipe-to-pipe angle. All dimensions are minimum centerline-to-centerline dimensions.

	Minimum Centerline-to-Centerline Dimensions, Inches									
42	52.0	53.5	54.5	55.5	59.0					
48	55.5	57.0	58.0	59.0	62.5	65.5	-	-	-	
54	58.5	60.0	61.0	62.5	66.0	69.0	72.5	-	-	-
60 Pipe Size	63.0	63.5	64.5	65.5	69.0	72.5	75.0	76.0	- 72	- 84
72	69.0	70.5	71.5	72.5	76.0	79.0	82.5	86.0	92.5	-
84	75.4	77.0	78.0	79.0	82.5	86.0	89.5	92.5	99.5	106.0
96	82.5	84.0	85.0	86.0	89.5	92.5	96.0	99.5	106.0	113.0

Notes:

- 1. Table based on schedule 40 pipe and includes the outside dimensions flanges, fittings, etc.**
- 2. Insulation over flanges, fittings, etc., is as follows:
Pipe sizes 2" and smaller: 1-1/2" Insulation
Pipe sizes 2-1/2" and larger: 2" Insulation**
- 3. The spaces between fittings are as follows:
Space between two pipes 3" and smaller: 1"
Space between one pipe 3" and smaller, and one pipe 4" and larger: 1"
Space between two pipes 4" and larger: 2"**
- 4. For schedule 80 and 160 pipe and 300 lb. fittings, add the following:
Pipe sizes 4" and smaller: 1"
Pipe sizes 5"-12": 1-1/2"
Pipe sizes 14" and larger: 2"**
- 5. Tables do not include space for valve handles and stems, expansion joints, expansion loops, or pipe guides.**



18.03. Pipe Expansion

A. Expansion Loops (See Part 3)

1. L-Bends. Anchor force = 500 lbs./dia. in.
2. Z-Bends. Anchor force = 200-500 lbs./dia. in.
3. U-Bends. Anchor force = 200 lbs./dia. in.

4. Locate anchors at beam locations, and avoid anchor locations at steel bar joists if at all possible.
5. The following expansion tables were created using the equations in Part 3.

THERMAL EXPANSION OF METAL PIPE

Linear Thermal Expansion Inches/100 Feet

Saturated Steam Pressure Psig	Temperature °F	Carbon Steel	Stainless Steel	Copper
-	-30	-0.19	-0.30	-0.32
-	-20	-0.12	-0.20	-0.21
-	-10	-0.06	-0.10	-0.11
-	0	0	0	0
-	10	0.08	0.11	0.12
-	20	0.15	0.22	0.24
-14.6	32	0.24	0.36	0.37
-14.6	40	0.30	0.45	0.45
-14.5	50	0.38	0.56	0.57
-14.4	60	0.46	0.67	0.68
-14.3	70	0.53	0.78	0.79
-14.2	80	0.61	0.90	0.90
-14.0	90	0.68	1.01	1.02
-13.7	100	0.76	1.12	1.13
-13.0	120	0.91	1.35	1.37
-11.8	140	1.06	1.57	1.59
-10.0	160	1.22	1.79	1.80
-7.2	180	1.37	2.02	2.05
-3.2	200	1.52	2.24	2.30
0	212	1.62	2.38	2.43
2.5	220	1.69	2.48	2.52
10.3	240	1.85	2.71	2.76
20.7	260	2.02	2.94	2.99
34.6	280	2.18	3.17	3.22

Saturated Steam Pressure Psig	Temperature °F	Linear Thermal Expansion Inches/100 Feet		
		Carbon Steel	Stainless Steel	Copper
52.3	300	2.35	3.40	3.46
75.0	320	2.53	3.64	3.70
103.3	340	2.70	3.88	3.94
138.3	360	2.88	4.11	4.18
181.1	380	3.05	4.35	4.42
232.6	400	3.23	4.59	4.87
294.1	420	3.41	4.83	4.91
366.9	440	3.60	5.07	5.15
452.2	460	3.78	5.32	5.41
551.4	480	3.97	5.56	5.65
666.1	500	4.15	5.80	5.91
797.7	520	4.35	6.05	6.15
947.8	540	4.54	6.29	6.41
1118	560	4.74	6.54	6.64
1311	580	4.93	6.78	6.92
1528	600	5.13	7.03	7.18
1772	620	5.34	7.28	7.43
2045	640	5.54	7.53	7.69
2351	660	5.75	7.79	7.95
2693	680	5.95	8.04	8.20
3079	700	6.16	8.29	8.47
-	720	6.37	8.55	8.71
-	740	6.59	8.81	9.00
-	760	6.80	9.07	9.26
-	780	7.02	9.33	9.53
-	800	7.23	9.59	9.79
-	820	7.45	9.85	10.07
-	840	7.67	10.12	10.31
-	860	7.90	10.38	10.61
-	880	8.12	10.65	10.97
-	900	8.34	10.91	11.16
-	920	8.56	11.18	11.42
Notes:	940	8.77	11.45	11.71
-	960	8.99	11.73	11.98
1. Table based on ASTM A53, Grade B, steel pipe.	980	9.20	12.00	12.27
2. Temperature range applicable through 400° F.	1000	9.42	12.27	12.54

Notes:**Linear Thermal Expansion Inches/100 Feet**

1. Table based on ASTM A53, Grade B, steel pipe.
Saturated

2. Temperature range applicable through 400 °F.
Steam Temperature Carbon Steel Stainless Steel Copper
Pressure °F Steel Steel

3. Table also applicable to copper tube.
Psig

4. For equations and diagrams relating to pipe expansion, see Part 3 Equations.

5. L-bend, Z-bend, and U-bend or loop dimensions are minimum dimensions; we recommend rounding up to nearest 1/2 foot (H = 2W).

PIPE EXPANSION L-BENDS**Expansion of Longest Leg**

Pipe Size	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
1/2	5'9"	7'0"	8'2"	9'2"	10'0"	11'6"	12'9"	14'0"
3/4	6'6"	8'4"	9'3"	10'4"	11'3"	13'0"	14'8"	16'0"
1	7'2"	8'9"	10'2"	11'4"	12'6"	14'4"	16'0"	17'6"
1-1/4	8'0"	9'10"	11'4"	12'8"	14'0"	16'2"	18'0"	19'8"
1-1/2	8'8"	10'6"	12'2"	13'8"	15'0"	17'2"	19'3"	21'0"
2	9'8"	11'9"	13'8"	15'2"	16'8"	19'3"	21'6"	23'6"
2-1/2	10'8"	13'0"	15'0"	16'9"	18'4"	21'2"	23'8"	26'0"
3	11'8"	14'4"	16'6"	18'6"	20'2"	23'4"	26'2"	28'8"
4	13'3"	16'2"	18'8"	21'0"	23'0"	26'6"	29'8"	32'6"
5	14'8"	18'0"	20'9"	23'3"	25'6"	29'6"	32'10"	36'0"
6	16'2"	19'8"	22'8"	25'4"	27'9"	32'2"	35'10"	39'3"
8	18'4"	22'6"	26'0"	29'0"	31'8"	36'8"	41'0"	44'10"
10	20'6"	25'0"	29'9"	32'4"	35'6"	40'10"	45'8"	50'0"
12	22'3"	27'3"	31'6"	35'2"	38'6"	44'6"	49'9"	54'6"
14	23'4"	28'8"	33'0"	36'10"	40'4"	46'8"	52'2"	57'2"
16	25'0"	30'6"	35'3"	39'6"	43'2"	50'0"	55'8"	61'0"
18	26'6"	32'4"	37'6"	41'9"	45'9"	52'10"	59'2"	64'10"

	Expansion of Longest Leg							
20	27'10"	34'2"	39'6"	44'0"	48'3"	55'8"	62'3"	68'3"
Pipe Size	22	29'3"	35'1"	41'4"	46'2"	50'8"	58'6"	65'4"
	24	30'6"	37'1/2"	43'2"	48'1/2"	52'10"	61'0"	68'5"
	26	31'9"	39'0"	45'0"	50'3"	55'0"	63'6"	71'0"
28	33'0"	40'4"	46'8"	52'2"	57'2"	66'0"	73'8"	80'9"
30	34'2"	41'9"	48'3"	54'0"	59'2"	68'3"	76'3"	83'8"
32	35'3"	43'2"	50'0"	55'8"	61'0"	70'6"	78'9"	86'4"
34	36'4"	44'6"	51'4"	57'6"	63'0"	72'8"	81'2"	89'0"
36	37'6"	45'9"	52'10"	59'2"	64'9"	74'9"	83'8"	91'6"
42	40'6"	49'6"	57'2"	63'10"	70'0"	80'9"	90'3"	99'10"
48	43'2"	52'10"	61'0"	68'3"	74'9"	86'4"	96'5"	105'8"
54	45'9"	56'1"	64'9"	72'4"	79'3"	91'6"	102'4"	112'1"
60	48'3"	59'1"	68'3"	76'3"	83'7"	96'6"	107'10"	118'2"
72	52'10"	64'9"	74'9"	83'7"	91'6"	105'8"	118'2"	129'5"
84	57'1"	69'11"	80'9"	90'3"	98'10"	114'2"	127'7"	140'0"
96	61'0"	74'9"	86'4"	96'6"	105'8"	122'0"	136'5"	149'6"

PIPE EXPANSION Z-BENDS

Anchor-to-Anchor Expansion

Pipe Size	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
1/2	3'8"	4'6"	5'2"	5'10"	6'5"	7'4"	8'2"	9'0"
3/4	4'2"	5'2"	6'2"	6'8"	7'3"	8'6"	9'4"	10'3"
1	4'8"	5'8"	6'6"	7'4"	8'0"	9'2"	10'4"	11'3"
1-1/4	5'2"	6'4"	7'4"	8'2"	9'0"	10'4"	11'8"	12'8"
1-1/2	5'6"	6'10"	7'10"	8'9"	9'7"	11'0"	12'4"	13'6"
2	6'2"	7'8"	8'9"	9'9"	10'8"	12'4"	13'10"	15'2"
2-1/2	6'10"	8'4"	9'8"	10'9"	11'9"	13'8"	15'2"	16'8"
3	7'6"	9'2"	10'8"	12'0"	13'0"	15'0"	16'9"	18'4"
4	8'6"	10'6"	12'0"	13'6"	14'9"	17'0"	19'0"	20'10"
5	9'6"	11'8"	13'4"	15'0"	16'6"	19'0"	21'2"	23'2"
6	10'4"	12'8"	14'6"	16'4"	18'0"	20'8"	23'0"	25'3"
8	11'9"	14'6"	16'8"	18'8"	20'4"	23'6"	26'4"	28'10"
10	13'2"	16'2"	18'6"	20'9"	22'9"	26'3"	29'4"	32'2"

Pipe Size	Anchor-to-Anchor Expansion							
	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
12	14'4"	17'6"	20'3"	22'8"	24'9"	28'8"	32'0"	35'0"
14	15'0"	18'4"	21'2"	23'8"	26'0"	30'0"	33'6"	36'8"
16	16'0"	19'8"	22'8"	25'4"	27'9"	32'0"	35'9"	39'3"
18	17'0"	20'10"	24'0"	26'10"	29'6"	34'0"	38'0"	41'8"
20	18'0"	22'0"	25'3"	28'4"	31'0"	35'9"	40'0"	43'10"
22	18'10"	23'0"	26'8"	29'8"	32'6"	37'8"	42'0"	46'0"
24	19'8"	24'0"	27'9"	31'0"	34'0"	39'2"	43'10"	48'0"
26	20'6"	25'0"	28'10"	32'4"	35'4"	40'10"	45'8"	50'0"
28	21'2"	26'0"	30'0"	33'6"	36'8"	42'4"	47'4"	52'0"
30	22'0"	26'10"	31'0"	34'8"	38'0"	43'10"	49'0"	53'8"
32	22'8"	27'9"	32'0"	35'10"	39'3"	45'4"	50'8"	55'6"
34	23'4"	28'8"	33'0"	37'0"	40'6"	46'8"	52'2"	57'2"
36	24'0"	29'6"	34'0"	38'0"	41'8"	48'0"	53'8"	58'10"
42	26'0"	31'9"	36'8"	41'0"	45'0"	52'0"	58'0"	63'6"
48	27'9"	34'0"	39'3"	43'10"	48'0"	55'6"	62'0"	67'11"
54	29'5"	36'0"	41'7"	46'6"	50'11"	58'10"	65'9"	72'0"
60	31'0"	38'0"	43'10"	49'0"	53'8"	62'0"	69'4"	75'11"
72	34'0"	41'7"	48'0"	53'8"	58'10"	67'11"	75'11"	83'2"
84	36'8"	44'11"	51'11"	58'0"	63'6"	73'4"	82'0"	89'10"
96	39'3"	48'0"	55'6"	62'0"	67'11"	78'5"	87'8"	96'0"

PIPE EXPANSION U-BENDS OR LOOPS

Anchor-to-Anchor Expansion

Pipe Size	1"		1-1/2"		2"		2-1/2"	
	W	H	W	H	W	H	W	H
1/2	1'2"	2'4"	1'6"	3'0"	1'8"	3'4"	1'10"	3'8"
3/4	1'4"	2'8"	1'8"	3'4"	1'10"	3'8"	2'2"	4'4"
1	1'6"	3'0"	1'9"	3'6"	2'0"	4'0"	2'4"	4'8"
1-1/4	1'8"	3'4"	2'0"	4'0"	2'4"	4'8"	2'8"	5'4"
1-1/2	1'9"	3'6"	2'2"	4'4"	2'6"	5'0"	2'9"	5'6"
2	1'11"	3'10"	2'4"	4'8"	2'9"	5'6"	3'2"	6'4"
2-1/2	2'2"	4'4"	2'8"	5'4"	3'0"	6'0"	3'3"	6'6"

Anchor-to-Anchor Expansion								
	1"		1-1/2"		2"		2-1/2"	
Pipe Size	W	H	W	H	W	H	W	H
3	2'4"	4'8"	3'0"	6'0"	3'4"	6'8"	3'9"	7'6"
4	2'8"	5'4"	3'3"	6'6"	3'9"	7'6"	4'2"	8'4"
5	3'0"	6'0"	3'8"	7'4"	4'2"	8'4"	4'8"	9'4"
6	3'3"	6'6"	4'0"	8'0"	4'7"	9'2"	5'2"	10'4"
8	3'8"	7'4"	4'6"	9'0"	5'2"	10'4"	5'10"	11'8"
10	4'2"	8'4"	5'0"	10'0"	5'10"	11'8"	6'6"	13'0"
12	4'6"	9'0"	5'6"	11'0"	6'4"	12'8"	7'2"	14'4"
14	4'8"	9'4"	5'9"	11'6"	6'8"	13'4"	7'6"	15'0"
16	5'0"	10'0"	6'2"	12'4"	7'1"	14'2"	8'0"	16'0"
18	5'4"	10'8"	6'6"	13'0"	7'6"	15'0"	8'6"	17'0"
20	5'8"	11'4"	7'0"	14'0"	7'11"	15'9"	8'10"	17'8"
22	5'10"	11'8"	7'3"	14'6"	8'3"	16'6"	9'3"	18'6"
24	6'1"	12'2"	7'6"	15'0"	8'8"	17'4"	9'8"	19'4"
26	6'5"	13'0"	7'10"	15'8"	9'0"	18'0"	10'2"	20'4"
28	6'8"	13'4"	8'2"	16'4"	9'4"	18'8"	10'6"	21'0"
30	6'10"	13'8"	8'6"	17'0"	9'8"	19'4"	11'0"	21'8"
32	7'1"	14'2"	8'8"	17'4"	10'0"	20'0"	11'2"	22'4"
34	7'4"	14'8"	9'0"	18'0"	10'4"	20'8"	11'6"	23'0"
36	7'6"	15'0"	9'2"	18'4"	10'8"	21'4"	12'0"	23'8"
42	8'1"	16'2"	10'0"	20'0"	11'6"	23'0"	12'9"	25'6"
48	8'8"	17'4"	10'7"	21'2"	12'3"	24'6"	13'8"	27'4"
54	9'2"	18'4"	11'3"	22'6"	13'0"	26'0"	14'6"	29'0"
60	9'8"	19'4"	11'10"	23'8"	13'8"	27'4"	15'3"	30'6"
72	10'7"	21'2"	13'0"	26'0"	15'0"	30'0"	16'9"	33'6"
84	11'5"	22'10"	14'0"	28'0"	16'2"	32'4"	18'1"	36'2"
96	12'3"	24'6"	15'0"	30'0"	17'3"	34'6"	19'4"	38'8"

PIPE EXPANSION U-BENDS OR LOOPS

Anchor-to-Anchor Expansion								
	3"		4"		5"		6"	
Pipe Size	W	H	W	H	W	H	W	H
1/2	2'0"	4'0"	2'4"	4'8"	2'8"	5'4"	2'10"	5'8"
3/4	2'4"	4'8"	2'8"	5'4"	3'0"	6'0"	3'3"	6'6"

	Anchor-to-Anchor Expansion		Anchor-to-Anchor Expansion		Anchor-to-Anchor Expansion		Anchor-to-Anchor Expansion	
1	2'6"	5'0"	3'0"	6'0"	4'6"	6'8"	3'6"	7'0"
1-1/4	2'10"	3'5'8"	3'3"	4'6'6"	3'8"	5'7'4"	4'0"	6'8'0"
1-1/2 Pipe Size	3'0"	6'0"	3'6"	7'0"	3'10"	7'8"	4'3"	8'6"
	3'4" ^W	6'8" ^H	4'0" ^W	8'0" ^H	4'4" ^W	8'8" ^H	4'9" ^W	9'6" ^H
2-1/2	3'8"	7'4"	4'3"	8'6"	4'10"	9'10"	5'2"	10'4"
3	4'1"	8'2"	4'8"	9'4"	5'4"	10'8"	5'9"	11'8"
4	4'7"	9'2"	5'4"	10'8"	5'10"	11'8"	6'6"	13'0"
5	5'2"	10'4"	6'0"	12'0"	6'8"	13'4"	7'3"	14'6"
6	5'7"	11'2"	6'6"	13'0"	7'2"	14'4"	8'0"	16'0"
8	6'4"	12'8"	7'4"	14'8"	8'4"	16'8"	9'0"	18'0"
10	7'1"	14'2"	8'2"	16'4"	9'2"	18'4"	10'0"	20'0"
12	7'9"	15'6"	9'0"	18'0"	10'0"	20'0"	11'0"	22'0"
14	8'1"	16'2"	9'4"	18'8"	10'6"	21'0"	11'6"	23'0"
16	8'8"	17'4"	10'0"	20'0"	11'2"	22'4"	12'3"	24'6"
18	9'2"	18'4"	10'8"	21'4"	11'10"	23'8"	13'0"	26'0"
20	9'8"	19'4"	11'2"	22'4"	12'6"	25'0"	13'8"	27'4"
22	10'2"	20'4"	11'8"	23'4"	13'2"	26'4"	14'4"	28'8"
24	10'8"	21'4"	12'3"	24'6"	13'8"	27'4"	15'0"	30'0"
26	11'0"	22'0"	12'9"	25'6"	14'4"	28'8"	15'7"	31'2"
28	11'6"	23'0"	13'2"	26'4"	14'10"	29'8"	16'2"	32'4"
30	12'0"	23'8"	13'8"	27'4"	15'4"	30'8"	16'9"	33'6"
32	12'3"	24'6"	14'2"	28'4"	15'10"	31'8"	17'3"	34'6"
34	12'8"	25'4"	14'6"	29'0"	16'4"	32'8"	18'0"	36'0"
36	13'0"	26'0"	15'0"	30'0"	16'10"	33'8"	18'4"	36'8"
42	14'0"	28'0"	16'2"	32'4"	18'2"	36'4"	20'0"	40'0"
48	15'0"	30'0"	17'4"	34'8"	19'4"	38'8"	21'2"	42'4"
54	15'11"	31'10"	18'4"	36'8"	20'6"	41'0"	22'5"	44'10"
60	16'9"	33'6"	19'4"	38'8"	21'7"	43'2"	23'8"	47'4"
72	18'4"	36'8"	21'2"	42'4"	23'8"	47'4"	25'11"	51'10"
84	19'10"	39'8"	22'10"	45'8"	25'7"	51'2"	28'0"	56'0"
96	21'2"	42'4"	24'5"	48'10"	27'4"	54'8"	29'11"	59'10"

PIPE EXPANSION U-BENDS OR LOOPS

Anchor-to-Anchor Expansion

Anchor-to-Anchor Expansion

7"
7"

8"
8"

10"
10"

12"
12"

Pipe Size	7"		8"		10"		12"	
	W W	H H	W W	H H	W W	H H	W W	H H
1/2	3'2"	6'4"	3'3"	6'6"	3'8"	7'4"	4'0"	8'0"
3/4	3'6"	7'0"	3'8"	7'4"	4'2"	8'4"	4'6"	9'0"
1	3'10"	7'8"	4'0"	8'0"	4'7"	9'2"	5'0"	10'0"
1-1/4	4'4"	8'8"	4'7"	9'2"	5'1"	10'2"	5'7"	11'2"
1-1/2	4'8"	9'4"	5'0"	10'0"	5'6"	11'0"	6'0"	12'0"
2	5'2"	10'4"	5'6"	11'0"	6'1"	12'2"	6'8"	13'4"
2-1/2	5'8"	11'4"	6'0"	12'0"	6'8"	13'4"	7'4"	14'8"
3	6'2"	12'4"	6'8"	13'4"	7'6"	15'0"	8'1"	16'2"
4	7'0"	14'0"	7'6"	15'0"	8'6"	17'0"	9'2"	18'4"
5	7'10"	15'8"	8'4"	16'8"	9'4"	18'8"	10'2"	20'4"
6	8'6"	17'0"	9'2"	18'4"	10'2"	20'4"	11'2"	22'4"
8	9'8"	19'4"	10'4"	20'8"	11'7"	23'2"	12'8"	25'4"
10	10'10"	21'8"	11'7"	23'2"	13'0"	26'0"	14'2"	28'4"
12	11'10"	23'8"	12'7"	25'2"	14'0"	28'0"	15'6"	31'0"
14	12'4"	24'8"	13'3"	26'6"	14'9"	29'6"	16'2"	32'4"
16	13'2"	26'4"	14'2"	28'4"	15'9"	31'6"	17'3"	34'6"
18	14'0"	28'0"	15'0"	30'0"	16'9"	33'6"	18'4"	36'8"
20	14'10"	29'8"	15'9"	31'6"	17'8"	35'4"	19'4"	38'8"
22	15'6"	31'0"	16'7"	33'2"	18'6"	37'0"	20'3"	40'6"
24	16'2"	32'4"	17'4"	34'8"	19'4"	38'8"	21'2"	42'4"
26	16'10"	33'8"	18'0"	36'0"	20'0"	40'0"	22'0"	44'0"
28	17'6"	35'0"	18'8"	37'4"	21'0"	42'0"	23'0"	46'0"
30	18'2"	36'4"	19'4"	38'8"	21'7"	43'2"	23'8"	47'4"
32	18'8"	37'4"	20'0"	40'0"	22'4"	44'8"	24'6"	49'0"
34	19'4"	38'8"	20'8"	41'4"	23'0"	46'0"	25'2"	50'4"
36	19'10"	39'8"	21'2"	42'4"	23'8"	47'4"	26'0"	52'0"
42	21'6"	43'0"	23'0"	46'0"	25'6"	51'0"	28'0"	56'0"
48	22'10"	45'8"	24'5"	48'10"	27'4"	54'8"	30'0"	60'0"
54	24'3"	48'6"	25'11"	51'10"	29'0"	58'0"	31'9"	63'6"
60	25'7"	51'2"	27'4"	54'8"	30'6"	61'0"	33'6"	67'0"
72	22'8"	47'4"	20'11"	50'10"	22'5"	66'10"	26'8"	72'4"

72	25'0"	77'4"	29'11"	39'10"	35'5"	60'10"	30'0"	75'4"
84	30'3"	60'6"	32'4"	64'8"	36'1"	72'2"	39'7"	69'2"
96	32'4"	7"64'8"	34'7"	8"69'2"	38'8"	10"77'4"	42'4"	12"84'8"

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18.04. ASME B31 Piping Code Comparison

ASME B31 PIPING CODE COMPARISON

Item	Power Piping ASME B31.1- 1998	Process Piping ASME B31.3- 1996	Building Services Piping ASME B31.9-1996
Application	Power and auxiliary piping for electric generating stations, industrial and institutional plants, central and district heating/cooling plants, and geothermal heating systems.	Petroleum refineries, chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants.	Industrial, institutional, commercial, and public buildings and multiunit residences.
Services	Systems include, but are not limited to, steam, water, oil, gas, and air.	Systems include, but are not limited to, raw, intermediate, and finished chemicals, petroleum products, gas, steam air water, fluidized solids, refrigerants, and cryogenic fluids.	Systems include, but are not limited to, water for heating and cooling, condensing water, steam or other condensate, other nontoxic liquids, steam, vacuum, other nontoxic,

<p style="text-align: center;">Item</p>	<p style="text-align: center;">Power Piping ASME B31.1- 1998</p>	<p style="text-align: center;">Process Piping ASME B31.3- 1996</p>	<p style="text-align: center;">Building Services Piping ASME B31.9-1996 nonflammable gases and combustible liquid including fuel oil.</p>
<p>General Limitations</p>	<p>This code does not apply to building services piping within the property limits or buildings of industrial and institutional facilities, which is in the scope of ASME B31.9 except that piping beyond the limitations of material, size, temperature, pressure, and service specified in ASME B31.9 shall conform to the requirements of ASME B31.1. This code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code (BPVC) Section I.</p>	<p>This code excludes piping systems for internal gauge pressures above zero but less than 15 psig, provided the fluid is nonflammable, nontoxic, and not damaging to human tissue and its temperature is from -20°F through 366°F. This code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code Section I and boiler external piping, which is required to conform to ASME B31.1.</p>	<p>This code prescribes requirements for the design, materials, fabrication, installation, inspection, examination, and testing of piping systems for building services. It includes piping systems in the building or within the property limits. This code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code Section I and boiler external piping, which is required to conform to ASME B31.1.</p>
<p>Pipe Size Limitations</p>	<p>No limit</p>	<p>No limit</p>	<p>Carbon steel 30" nominal pipe size and 0.5" wall (30" wall steel pipe)</p>

Item	Power Piping ASME B31.1- 1998	Process Piping ASME B31.3- 1996	xs steel pipe) Building Copper—12" Services nominal pipe size Piping ASME Stainless steel— B31.9-1996 12" of nominal pipe size and 0.5" wall
Pressure Limitations	No limit	No limit	Steam and condensate—150 psig Liquids—350 psig Vacuum—1 atmosphere external pressure Compressed air and gas—150 psig
Temperature Limitations	No limit	No limit	Steam and condensate—366°F Maximum (150 psig) Other gases and vapors—200°F maximum Nonflammable liquids—250°F maximum Minimum temperature all services—0°F
Bypass Requirements	All bypasses must be in accordance with MSS-SP-45. Pipe weight shall be minimum Schedule 80.	Bypasses not addressed—recommend the following B31.1	Bypasses not addressed—recommend the following B31.1
Class I Boiler Systems—ASME	Boiler external piping is	Boiler external piping is	Boiler external piping is

<p>BPVC Section I</p> <p>Item</p>	<p>governed by Power Piping ASME B31.1-1998. All other piping may be governed by this code within the limitations of the code.</p>	<p>governed by Process Piping ASME B31.3-1996. All other piping may be governed by this code within the limitations of the code.</p>	<p>governed by Building Services Piping ASME B31.9-1996. All other piping may be governed by this code within the limitations of the code.</p>
<p>Class IV Boiler Systems— ASME BPVC Section IV</p>	<p>All piping, including boiler external piping, may be governed by this code within the limitations of the code.</p>	<p>All piping, including boiler external piping, may be governed by this code within the limitations of the code.</p>	<p>All piping, including boiler external piping, may be governed by this code within the limitations of the code.</p>

Class I Boiler Systems

1. Class I Steam Boiler Systems are constructed for Working Pressures above 15 psig.
2. Class I Hot Water Boiler Systems are constructed for Working Pressures above 160 psig and/or Working Temperatures above 250°F.

Class IV Boiler Systems

1. Class IV Steam Boiler Systems are constructed with a maximum Working Pressure of 15 psig.
2. Class IV Hot Water Boiler Systems are constructed with a maximum Working Pressure of 160 psig and a maximum Working Temperature of 250°F.

Class I Boiler External Piping

1. Steam Boiler Piping—ASME Code piping is required from the boiler through the 1st stop check valve to the 2nd stop valve.
2. Steam Boiler Feedwater Piping—ASME Code piping is required from the boiler through the 1st stop valve to the check valve for single boiler feedwater installations and from the boiler through the 1st stop valve and through the check valve to the 2nd stop valve at the feedwater control valve

for multiple boiler installations.

- | | | | |
|-------------|--|--|---|
| Item | Power Piping
ASME B31.1-
1998 | Process Piping
ASME B31.3-
1996 | Building
Services
Piping
ASME
B31.9-1996 |
|-------------|--|--|---|
3. Steam Boiler Bottom Blowdown Piping—ASME Code Piping is required from the boiler through the 1st stop valve to the 2nd stop valve.
 4. Steam Boiler Surface Blowdown Piping—ASME Code Piping is required from the boiler to the 1st stop valve.
 5. Steam and Hot Water Boiler Drain Piping—ASME Code Piping is required from the boiler through the 1st stop valve to the 2nd stop valve.
 6. Hot Water Boiler Supply and Return Piping—ASME Code piping is required from the boiler through the 1st stop check valve to the 2nd stop valve on both the supply and return piping.

Class IV Boiler External Piping

1. All Class IV Boiler External Piping is governed by the respective piping system code.

ASME B31 PIPING CODE COMPARISON

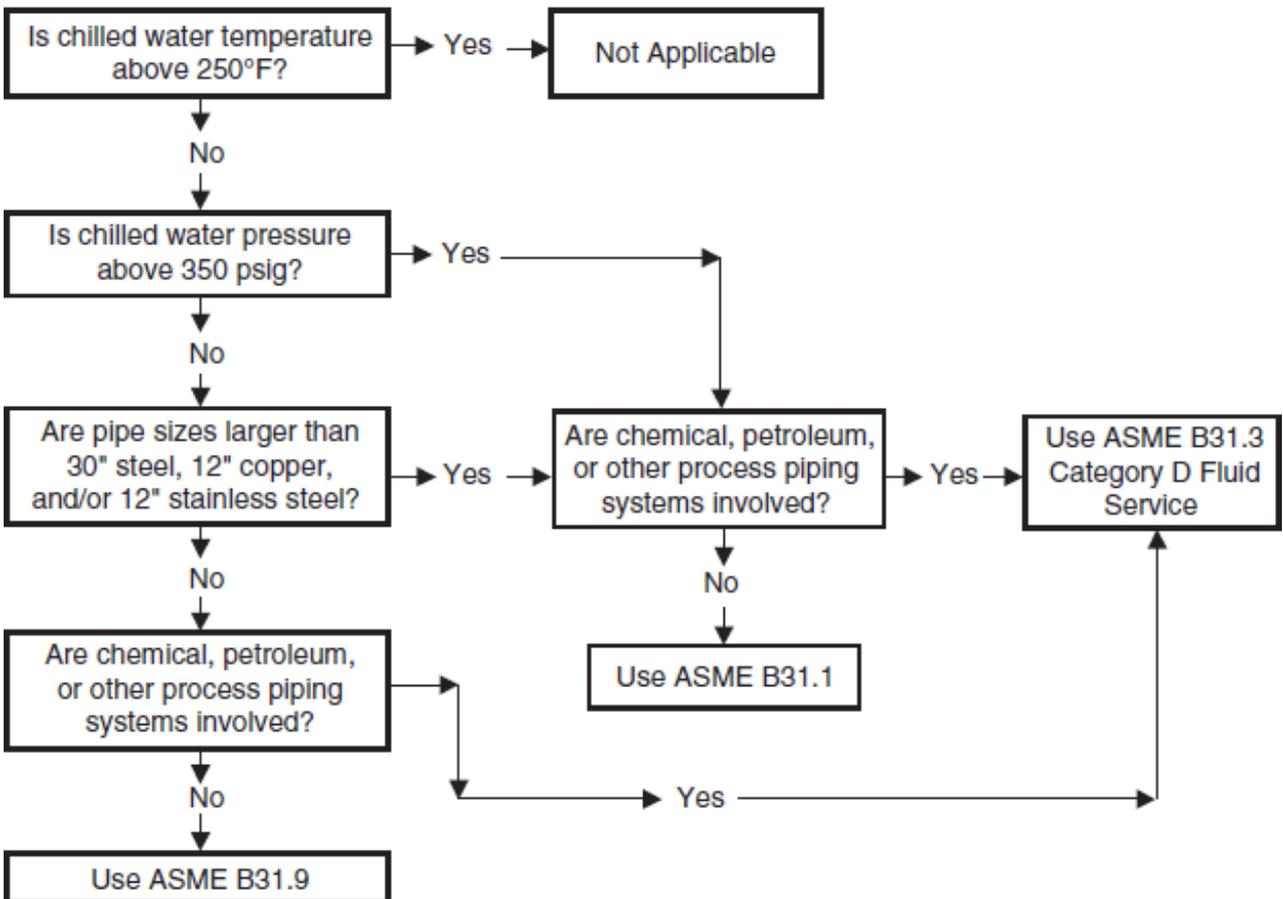
Item	Power Piping ASME B31.1- 1998	Process Piping ASME B31.3- 1996	Building Services Piping ASME B31.9- 1996
Piping Classifications	No classifications required by this code. The code deals with and governs all piping under its jurisdiction the same.		No classifications required by this code. The code deals with and governs all piping under its jurisdiction the same.
Low Temp Chilled Water (0-40°F)		D	
Chilled Water (40-60°F)		D	
Condenser Water (60-110°F)		D	

(60–110°F)			Building
Low Temp Heating Water (110–250°F) Item	Power Piping ASME B31.1- 1998	Process Piping ASME B31.3- 1996	Services Piping ASME B31.9- 1996
High Temp Heating Water (250–450°F)		N—Except Boiler Ext. Piping B31.1 applicable	
Low Press. Steam (15 psig and Less)		N	
High Press. Steam (Above 15 psig)		N—Except Boiler Ext. Piping B31.1 applicable	
Hydrostatic Pressure Testing	Test Medium—Water, unless subject to freezing	Test Medium—Water, unless subject to freezing	Test Medium—Water, unless subject to freezing
	Boiler External Piping—ASME BPVC Section I	N/A	N/A
	Nonboiler External Piping—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.	Category D or N Fluid Service—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.	Nonboiler External Piping—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.
	All Other Services—1.5 times the design pressure but not to exceed the max. allowable system		All Other Services—1.5 times the design pressure but not to exceed the max. allowable system

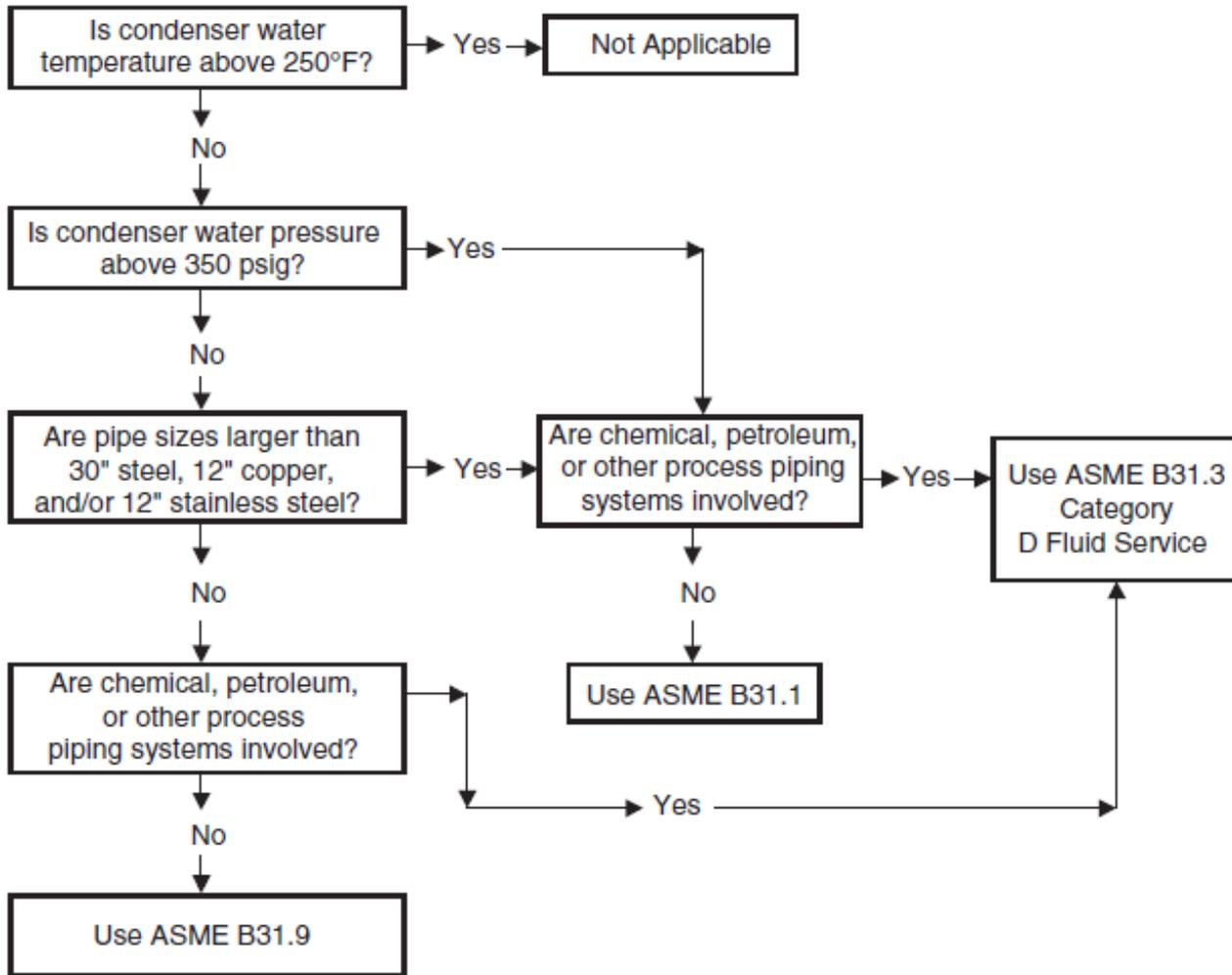
<p style="text-align: center;">Item</p>	<p style="text-align: center;">pressure for a minimum of 10 minutes. Power Piping ASME B31.1- 1998</p>	<p style="text-align: center;">Process Piping ASME B31.3- 1996</p>	<p style="text-align: center;">pressure for a minimum of 10? minutes. Building Services Piping ASME B31.9- 1996</p>
<p>Examination, Inspection, and Testing Requirements</p>	<p>The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the owner.</p>	<p>The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the owner.</p>	<p>The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the owner.</p>
	<p>Class I Steam & Hot Water Systems— Nondestructive testing and visual examinations are required by this code. Percentage and types of tests performed must be agreed upon.</p>	<p>Category D Fluid Service—Visual Examination.</p>	<p>All Services— Visual Examinations.</p>
	<p>Class IV Steam & Hot Water Systems—Visual Examination only. All other services—Visual Examination only.</p>	<p>Category N Fluid Service—Visual Examination, 5% Random Examination of components, fabrication, welds, and installation. Random</p>	<p>If more rigorous examination or testing is required, it must be mutually agreed upon</p>

Item	Power Piping ASME B31.1- 1998	radiographic or Process Piping ASME B31.3- of ASME B31.3- 1996 circumferential butt welds.	Building Services Piping ASME B31.9- 1996
	If more rigorous examination or testing is required, it must be mutually agreed upon.	If more rigorous examination or testing is required, it must be mutually agreed upon.	.
Nondestructive Testing	Radiographic Ultrasonic Eddy current Liquid penetrant Magnetic particle Hardness tests	Radiographic Ultrasonic Eddy current Liquid penetrant Magnetic particle Hardness tests	Radiographic Ultrasonic Eddy current Liquid penetrant Magnetic particle Hardness tests

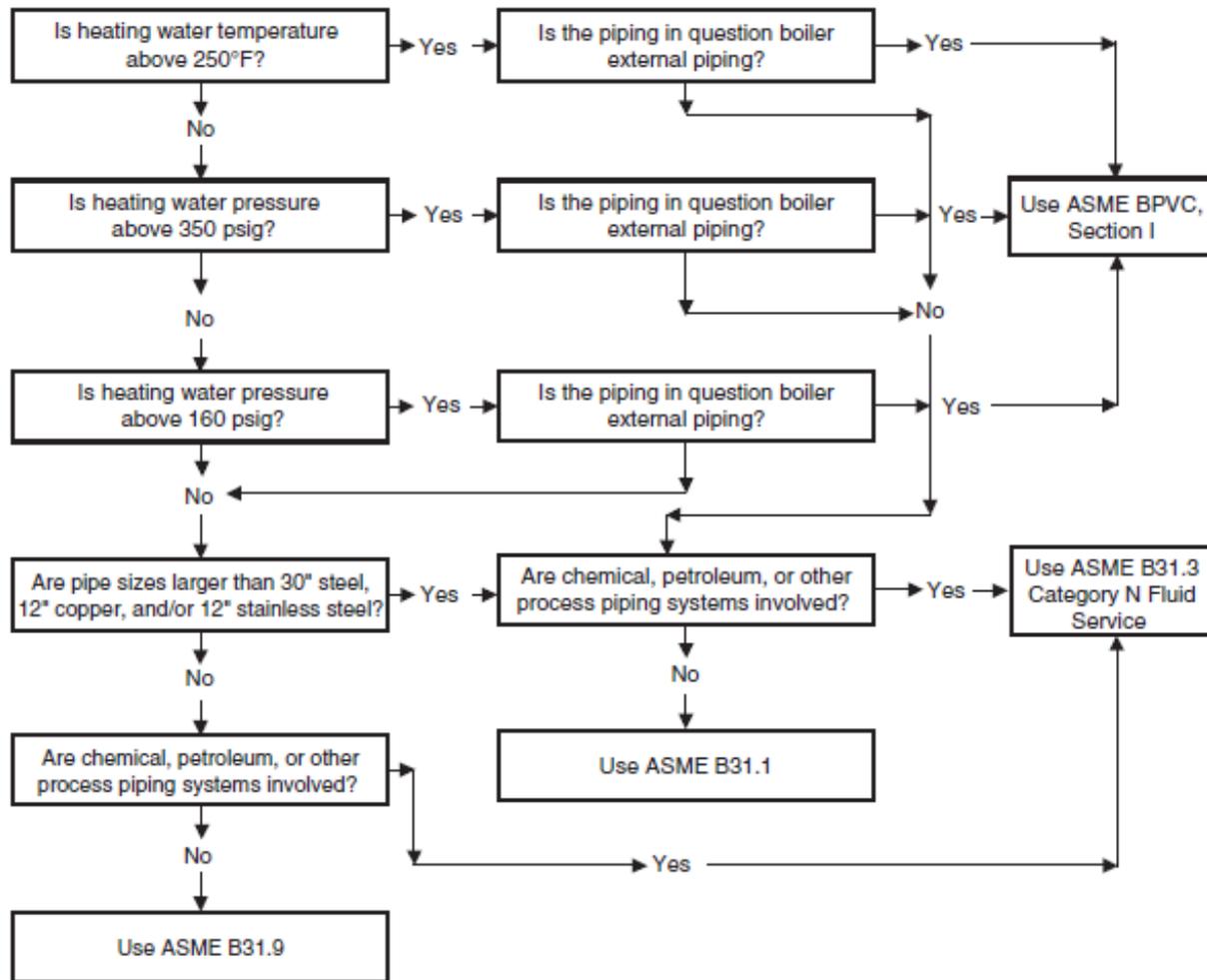
ASME B31 Chilled Water System Decision Diagram Chilled Water Systems (0–60°F)



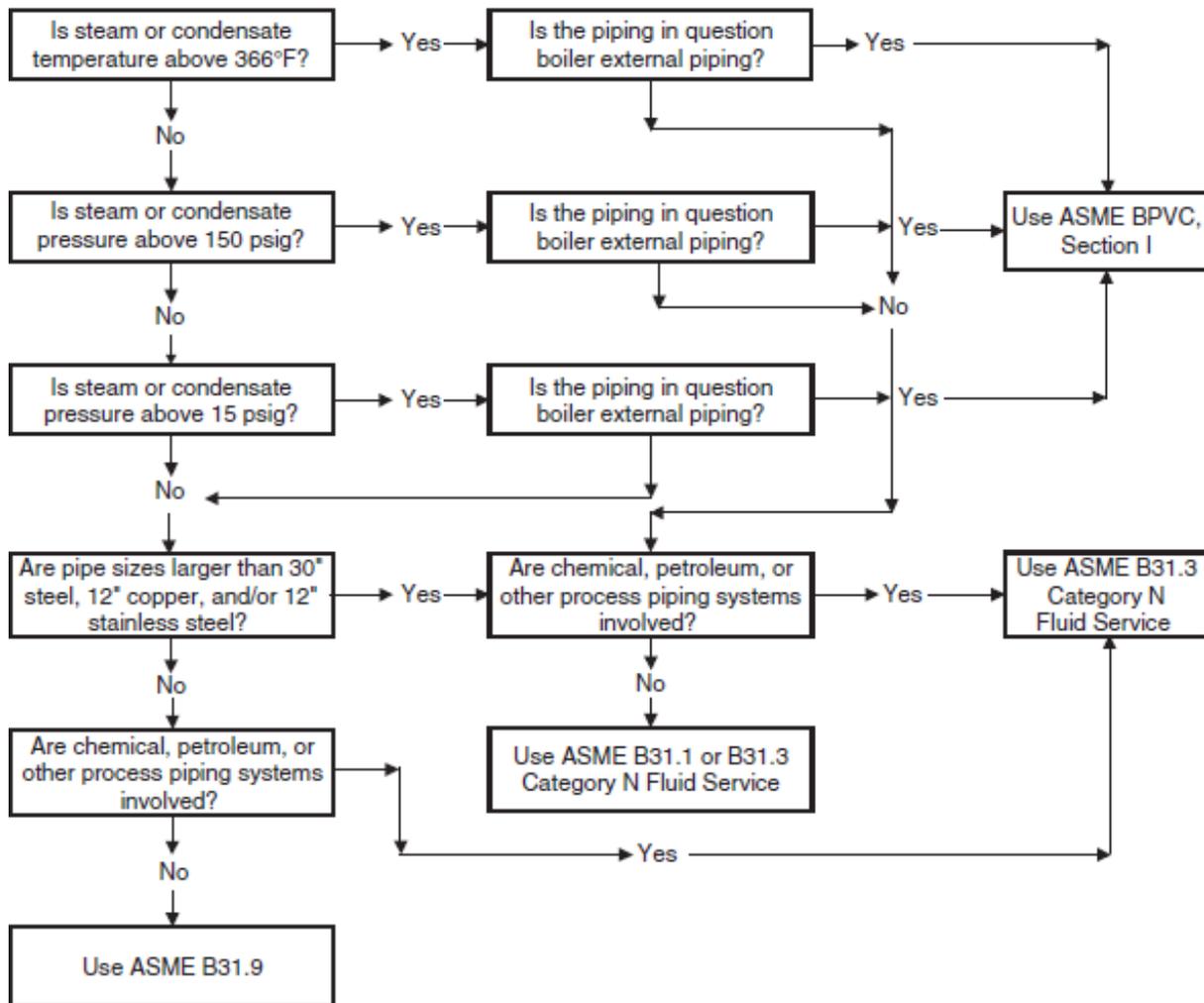
ASME B31 Condenser Water System Decision Diagram Condenser Water Systems (60–110°F)



ASME B31 Heating Water System Decision Diagram Heating Water Systems (110–450°F)



ASME B31 Steam and Steam Condensate System Decision Diagram Steam and Steam Condensate Systems (0–300 psig)



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18.05. Galvanic Action

- A. **Galvanic action results from the electrochemical variation in the potential of metallic ions. If two metals of different potentials are placed in an electrolytic medium (i.e., water), the one with the higher potential will act as an anode and will corrode. The metal with the lower potential, being the cathode, will be unchanged. The greater the separation of the two metals on the following chart, the greater the speed and severity of the corrosion. The following list is in order of their anodic-cathodic characteristics (i.e., metals listed in the following will corrode those listed previously—for example, copper will corrode steel).**

Magnesium Alloys

Alclad 3S

Aluminum Alloys

Low-Carbon Steel

Cast Iron

Stainless Steel, Type 410

Stainless Steel, Type 430

Stainless Steel, Type 404

Stainless Steel, Type 304

Stainless Steel, Type 316

Hastelloy A

Lead-Tin Alloys

Brass

Copper

Bronze

90/10 Copper-Nickel

70/30 Copper-Nickel

Inconel

Silver

Stainless Steel (passive)

Monel

Hastelloy C

Titanium

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18.06. Piping System Installation Hierarchy (Easiest to Hardest to Install)

A. Natural Gas, Medical Gases, and Laboratory Gases, Easiest to Install

- B. Chilled Water, Heating Water, Domestic Cold and Hot Water Systems, and Other Closed HVAC and Plumbing Systems**
- C. Steam and Steam Condensate**
- D. Refrigeration Piping Systems**
- E. Sanitary Systems, Storm Water Systems, AC Condensate Systems, Hardest to Install**

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18.07. Valves

A. Valve Types

1. Balancing valves:
 - a. Duty: Balancing, shutoff (manual or automatic).
 - b. A valve specially designed for system balancing.
2. Ball valves full port:
 - a. Duty: Shutoff.
 - b. A valve with a sphere-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn. The opening in the spherical flow device is the same size or close to the same size as the pipe.
3. Ball valves, reduced port:
 - a. Duty: Balancing, shutoff.
 - b. A valve with a sphere-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn. The opening in the spherical flow device is smaller than the pipe size.
4. Butterfly valves:
 - a. Duty: Shutoff, balancing.
 - b. A valve with a disc-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn.
5. Check valves:

- a. Duty: Control flow direction.
 - b. A valve opened by the flow of fluid in one direction that closes automatically to prevent flow in the reverse direction. (Types: Ball, Disc, Globe, Piston, Stop, Swing.)
6. Gate valves:
- a. Duty: Shutoff.
 - b. A valve with a wedge- or gate-shaped internal flow device that moves on an axis perpendicular to the direction of flow.
 - c. This valve is obsolete in today's hydronic piping systems (it is replaced by ball and butterfly valves).
7. Globe valves:
- a. Duty: Throttling.
 - b. A valve with a disc or plug that moves on an axis perpendicular to the valve seat.
8. Plug valves:
- a. Duty: Shutoff, balancing.
 - b. A valve with a cylindrical or cone-shaped internal flow device that rotates open and closed to permit flow, or obstruct flow, through the valve. The valve goes from full open to full close in a quarter turn.
9. Control Valves. Control valves are mechanical devices used to control the flow of steam, water, gas, and other fluids.
- a. *2-Way*. Temperature control, modulate flow to controlled device, variable flow system.
 - b. *3-Way Mixing*. Temperature control, modulate flow to controlled device, constant flow system; two inlets and one outlet.
 - c. *3-Way Diverting*. Used to divert flow; generally cannot modulate flow—Two positions; one inlet and two outlets.
 - d. *Quick Opening Control Valves*. Quick opening control valves produce a wide free port area with a relatively small percentage of total valve stem stroke. The maximum flow is approached as the valve begins to open.

- e. *e. Linear Control Valves.* Linear control valves produce free port areas directly related to valve stem stroke. The opening and flow are related in direct proportion.
- f. *f. Equal Percentage Control Valves.* Equal percentage control valves produce an equal percentage increase in the free port area with each equal increment of valve stem stroke. Each equal increment of opening increases flow by an equal percentage over the previous value (most common HVAC control valve).
- g. Control valves are normally smaller than line size unless used in two-position applications (open/closed).
- h. Control valves should normally be sized to provide 20–60 percent of the total system pressure drop.
 - 1. Water system control valves should be selected with a pressure drop equal to 2–3 times the pressure drop of the controlled device.
OR
Water system control valves should be selected with a pressure drop equal to 10 ft or the pressure drop of the controlled device, whichever is greater.
OR
Water system control valves for constant flow systems should be sized to provide 25 percent of the total system pressure drop.
OR
Water system control valves for variable flow systems should be sized to provide 10 percent of the total system pressure drop or 50 percent of the total available system pressure.
 - 2. Steam control valves should be selected with a pressure drop equal to 75 percent of the inlet steam pressure.
- 10. Specialty valves:
 - a. Triple-duty valves: Combination check, balancing, and shutoff.
 - b. Backflow preventer: prevent contamination of domestic water system. For HVAC applications, use reduced pressure zone backflow preventers.
- 11. Valves used for balancing need not be line size. Balancing valves should be selected for the midrange of its adjustment.

B. Valve Terms

1. *Actuator*. A mechanical, hydraulic, electric, or pneumatic device or mechanism used to operate a valve.
2. *Adjustable Travel Stop*. A mechanism used to limit the internal flow device travel.
3. *Back Face*. The side of the flange opposite the gasket.
4. *Blind Flange*. A flange with a sealed end to provide a pressure tight closure of a flanged opening.
5. *Body*. The pressure containing shell of a valve or fitting with ends for connection to the piping system.
6. *Bonnet*. A valve body component that contains an opening for the stem. The bonnet may be bolted (Bolted Bonnet), threaded (Threaded Bonnet), or a union (Union Bonnet).
7. *Bronze Mounted*. The seating surfaces of the valve are made of brass or bronze.
8. *Butt Welding Joints*. A joint made to pipes, valves, and fittings with ends adapted for welding by abutting the ends and welding them together.
9. *Chainwheel*. A manual actuator that uses a chain-driven wheel to turn the valve flow device by turning the stem, handwheel, or gearing.
10. *Cock*. A form of a plug valve.
11. *Cold Working Pressure*. Maximum pressure at which a valve or fitting is allowed to operate at ambient temperature.
12. *Concentric Reducer*. A reducer in which both openings are on the same centerline.
13. *Eccentric Reducer*. A reducer with the small end off-center.
14. *Elbow, Long Radius*. An elbow with a centerline turning radius of 1-1/2 times the nominal pipe size of the elbow.
15. *Elbow, Short Radius*. An elbow with a centerline turning radius of one times the nominal pipe size of the elbow.
16. *Face-to-Face Dimension*. The dimension from the face of the inlet to the face of the outlet of the valve or fitting.

17. *Female End*. Internally threaded portion of a pipe, valve, or fitting.
18. *Flanged Joint*. A joint made with an annular collar designed to permit a bolted connection.
19. *Grooved Joint* or *Mechanical Joint*. A joint made with a special mechanical device using a circumferential groove cut into or pressed into the pipes, valves, and fittings to retain a coupling member.
20. *Handwheel*. The valve handle shaped in the form of a wheel.
21. *Inside Screw*. The screw mechanism that moves the internal flow device located within the valve body.
22. *Insulating Unions (Dielectric Unions)*. Used in piping systems to prevent dissimilar metals from coming into direct contact with each other. (See Galvanic Action Paragraph.)
23. *Male End*. Externally threaded portion of pipes, valves, or fittings.
24. *Memory Stop*. A device that allows for the repeatable operation of a valve at a position other than full open or full closed, often used to set or mark a balance position.
25. *Nipple*. A short piece of pipe with both ends externally threaded.
26. *Nominal Pipe Size (NPS)*. The standard pipe size, but not necessarily the actual dimension.
27. *Nonrising Stem*. When the valve is operated, the stem does not rise through the bonnet; the internal flow device rises on the stem.
28. *Outside Screw and Yoke (OS&Y)*. The valve packing is located between the stem threads and the valve body. The valve has a threaded stem that is visible.
29. *Packing*. A material that seals around the movable penetration of the valve stem.
30. *Rising Stem*. When the valve is operated, the stem rises through the bonnet and the internal flow device is moved up or down by the moving stem.

31. *Safety-Relief Valves*. A valve that automatically relieves the system pressure when the internal pressure exceeds a set value. Safety-relief valves may operate on pressure only or on a combination of pressure and temperature.
- Safety Valve*. An automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. A safety valve is used primarily for gas or vapor service.
 - Relief Valve*. An automatic pressure relieving device actuated by the static pressure upstream of the valve that opens further with the increase in pressure over the opening pressure. A relief valve is used primarily for liquid service.
 - Safety Relief Valve*. An automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.
 - Safety, Relief, and Safety Relief Valve testing is dictated by the Insurance Underwriter.
32. *Seat*. The portion of the valve that the internal flow device presses against to form a tight seal for shutoff.
33. *Slow Opening Valve*. A valve that requires at least five 360-degree turns of the operating mechanism to change from fully closed to fully open.
34. *Socket Welding Joint*. A joint made with a socket configuration to fit the ends of the pipes, valves, or fittings, which is then fillet welded in place.
35. *Soldered Joint*. A joint made with pipes, valves, or fittings in which the joining is accomplished by soldering or brazing.
36. *Stem*. A device that operates the internal flow control device.
37. *Threaded Joint*. A joint made with pipes, valves, or fittings in which the joining is accomplished by threading the components.
38. *Union*. A fitting that allows the assembly or disassembly of the piping system without rotating the piping.

C. Valve Abbreviations

TE	Threaded End
FE	Flanged End
SE	Solder End

BWE	Butt Weld End
SWE	Socket Weld End
TB	Threaded Bonnet
BB	Bolted Bonnet
UB	Union Bonnet
TC	Threaded Cap
BC	Bolted Cap
UC	Union Cap
IBBM	Iron Body, Bronze Mounted
DI	Ductile Iron
SB	Silver Brazed
DD	Double Disc
SW	Solid Wedge Disc
RWD	Resilient Wedge Disc
FW	Flexible Wedge
HW	Handwheel
NRS	Non-Rising Stem
RS	Rising Stem
OS&Y	Outside Screw & Yoke
ISNRS	Inside Screw NRS
ISRS	Inside Screw RS
FF	Flat Face
RF	Raised Face
HF	Hard Faced
MJ	Mechanical Joint
RJ	Ring Type Joint
F&D	Face and Drilled Flange
OWB	Open Welded Bonnet

CWP	Cold Working Pressure
OWG	Oil, Water, Gas, Pressure
SWP	Steam Working Pressure
WOG	Water, Oil, Gas, Pressure
WWP	Water Working Pressure
FTTG	Fitting
FLG	Flange
DWV	Drainage-Waste-Vent Fitting
NPS	Nominal Pipe Size
IPS	Iron Pipe Size
NPT	National Standard Pipe Thread Taper

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18.08. Strainers

A. Strainers shall be full line size.

B. Water Systems

1. Strainer type:

a. 2" and smaller:	"Y" Type.
b. 2-1/2" to 16":	Basket type.
c. 18" and larger:	Multiple basket type.

2. Strainer perforation size:

a. 4" and smaller:	0.057" dia. perforations.
b. 5" and larger:	0.125" dia. perforations.
c. Double perforation diameter for condenser water systems.	

C. Steam Systems

1. Strainer type: "Y" Type.

2. Strainer perforation size:

- a. 2" and smaller: 0.033" dia. perforations.
- b. 2-1/2" and larger: 3/64" dia. perforations.

D. Strainer Pressure Drops, Water Systems: Pressure drops listed in the following are based on the GPM and pipe sizing of 4.0 ft./100 ft. pressure drop or 10 ft./sec. velocity.

- 1. 1-1/2" and smaller (Y type and Basket type):
 - a. Pressure drop < 1.0 PSI, 2.31 ft. H₂O.
- 2. 2"-4" (Y type and Basket type):
 - a. Pressure drop: 1.0 PSI, 2.31 ft. H₂O.
- 3. 5" and larger:
 - a. Y-type pressure drop 1.5 PSI, 3.46 ft H₂O
 - b. Basket-type pressure drop 1.0 PSI, 2.31 ft. H₂O

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 18: Piping Systems, General, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 19: Hydronic (Water) Piping Systems

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19. Part 19: Hydronic (Water) Piping Systems

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19.01. Hydronic Pipe Sizing

- A. **4.0 ft./100 ft. Maximum pressure drop**
- B. **8 FPS Maximum velocity occupied areas**
- C. **10 FPS Maximum velocity unoccupied areas**
- D. **Minimum pipe velocity 1.5 FPS, even under low load/flow conditions.**
- E. **Pipe sizing tables are applicable to closed and open hydronic piping systems.**
- F. **See the following pipe sizing tables for copper, steel, and stainless steel.**

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19.02. Friction Loss Estimate

- A. **$1.5 \times \text{System Length (ft.)} \times \text{Friction Rate (ft./100 ft.)}$**
- B. **Pipe Friction Estimate: 3.0 to 3.5 ft./100 ft.**

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19.03. Pipe Testing

- A. **$1.5 \times \text{System Working Pressure}$**
- B. **100 psi Minimum**

19.04. Hydronic System Pipe Sizing Tables

HYDRONIC PIPING SYSTEMS—TYPE K COPPER PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.0	1.2	1.4		Pressure drop with these	pipe	governs sizes	
3/4	2.4	3.0	3.5					
1	5.2	6.4	7.4					
1-	9	12	13					
1/4	15	18	21	21				
1-	31	38	44	38				
1/2								
2								
2-	55	67	78	58	73			
1/2	87	107	123	83	103	124		
3	183	224	258	146	182	219		
4								
5	324	397	458	226	283	339	452	
6	515	631	729	323	403	484	645	
8	1,064	1,304		563	704	845	1,126	1,408
10	1,887	Velocity	governs	874	1,093	1,311	1,749	2,186
12	3,015	with these	pipe sizes	1,254	1,567	1,880	2,507	3,134



HYDRONIC PIPING SYSTEMS—TYPE L COPPER PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.1	1.3	1.5		Pressure drop with these	pipe	governs sizes	
3/4	2.8	3.4	4.0					
1	5.7	6.9	8.0					
1-	10	12	14					
1/4	16	19	22	22				
1-	32	39	45	39				
1/2								
2								
2-	57	69	80	59				
1/2	90	111	128	85	106	127		
3	189	231	267	149	187	224		
4								
5	337	412	476	233	291	349	465	
6	540	662	764	335	418	502	669	
8	1,117	1,368		584	730	877	1,169	1,461
10	1,980	Velocity	governs	907	1,134	1,361	1,814	2,268
12	3,191	with these	pipe sizes	1,310	1,637	1,965	2,619	3,274

HYDRONIC PIPING SYSTEMS—TYPE M COPPER PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.				Velocity—ft./sec.			
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.2	1.5	1.7		Pressure with these	drop pipe	governs sizes	
3/4	3.1	3.7	4.3					
1	6.1	7.5	8.6					
1-	10	13	15	16				
1/4	16	20	23	23				
1-	33	41	47	40				
1/2								
2								
2-	58	72	83	61	76			
1/2	93	114	132	87	109	131		
3	192	236	272	152	190	227		
4								
5	342	419	484	236	295	354	472	
6	549	672	776	339	423	508	677	
8	1,140	1,396		593	742	890	1,187	1,484
10	2,020	Velocity	governs	922	1,152	1,382	1,843	2,304
12	3,228	with these	pipe sizes	1,321	1,652	1,982	2,643	3,304

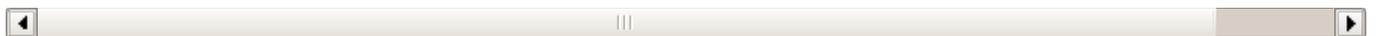


HYDRONIC PIPING SYSTEMS—STANDARD STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.				Velocity—ft./sec.			
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.5	1.9	2.1		Pressure with these	drop pipe	governs sizes	
3/4	3.2	3.9	4.5					
1	6.0	7.4	8.5					
1-	12	15	18	19				
1/4	19	23	26	25				

1- 1/2 Pipe Size	Friction Rate—ft./100 ft.		Water Flow—GPM					Velocity—ft./sec.
	36	44	51	60	75	90	108	
2- 1/2	57 2.0 100	70 3.0 123	80 4.0 142	60 4.0 92	75 5.0 115	90 6.0 138	108 8.0	1
3	204	250	289	159	198	238		
4								
5	368	451	521	249	312	374	499	
6	595	729	841	360	450	540	720	
8	1,216	1,489		624	780	936	1,247	1.5
10	2,198	governs pipe with sizes		983	1,229	1,475	1,966	2.4
12	3,512			1,410	1,763	2,115	2,820	3.5
14				1,719	2,149	2,579	3,438	4.2
16	Velocity these			2,277	2,847	3,416	4,554	5.6
18				2,914	3,642	4,371	5,827	7.2
20				3,629	4,536	5,443	7,257	9.0
22				4,422	5,527	6,633	8,843	11
24				5,293	6,616	7,940	10,586	13
26				6,243	7,804	9,364	12,486	15
28				7,271	9,089	10,907	14,542	18
30				8,378	10,472	12,566	16,755	20
32				9,562	11,953	14,344	19,125	23
34				10,826	13,532	16,238	21,651	27
36	12,167			15,209	18,251	24,334	30	
42	16,662			20,827	24,992	33,323	41	
48	21,861			27,327	32,792	43,722	54	
54	27,766	34,707	41,649	55,532	69			
60	34,375	42,969	51,563	68,751	85			
72	49,710	62,137	74,564	99,419	12			
84	67,864	84,830	101,796	135,728	16			
96	88,838	111,048	133,257	177,677	22			



HYDRONIC PIPING SYSTEMS—XS STEEL PIPE

Water Flow—GPM

Water Flow—GPM

Pipe Size	Friction Rate—ft./100			Velocity—ft./sec.				1
	Friction Rate—ft./100			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	
1/2	1.1	1.3	1.5	4.0	5.0	6.0	8.0	1
3/4	2.4	3.0	3.4	4.0	5.0	6.0	8.0	1
1	4.7	5.8	6.7					
1-1/4	10	12	14					
1-1/2	15	19	22					
2	30	37	43	37	66	124	215	1
2-1/2	48	59	69	53				
3	87	106	123	82				
4	179	219	253	143				
5	325	399	460	227	284	340	454	1,4
6	520	637	736	325	406	487	650	
8	1,080	1,322		569	712	854	1,139	
10	2,047	governs	with	931	1,164	1,396	1,862	
12	3,325	pipe	sizes	1,352	1,690	2,028	2,704	3,3
14				1,655	2,069	2,482	3,310	4,3
16	Velocity these			2,203	2,754	3,305	4,406	5,5
18				2,830	3,537	4,245	5,660	7,0
20				3,535	4,419	5,302	7,070	8,8
22				4,318	5,398	6,477	8,637	10
24				5,180	6,475	7,770	10,360	12
26				6,120	7,650	9,180	12,240	15
28				7,138	8,923	10,708	14,277	17
30				8,235	10,294	12,353	16,470	20
32				9,410	11,763	14,115	18,820	23
34				10,663	13,329	15,995	21,327	26
36				11,995	14,994	17,993	23,990	29
42				16,460	20,575	24,690	32,921	41
48				21,630	27,038	32,446	43,261	54

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	
54				27,506	34,382	41,258	55,011	68
60				34,086	42,607	51,129	68,172	85
72				49,361	61,702	74,042	98,723	12
84				67,457	84,321	101,185	134,914	16
96				88,373	110,466	132,559	176,745	22



HYDRONIC PIPING SYSTEMS—XXS STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	0.1	0.2	0.2		Pressure drop with these	pipe	governs sizes	
3/4	0.6	0.7	0.8					
1	1.4	1.7	1.9					
1-1/4	4	5	6					
1-1/2	7	8	10					
2	15	19	22	22				
2-1/2	24	29	34	31				
3	47	58	67	52	65			
4	108	132	152	97	122	146		
5	209	256	296	162	202	242		1,157
6	341	417	482	235	294	352	470	
8	825	1,010		463	579	694	926	
10	1,545	Velocity	governs	750	937	1,125	1,499	1,874
12	2,639	with these	pipe sizes	1,132	1,414	1,697	2,263	2,829

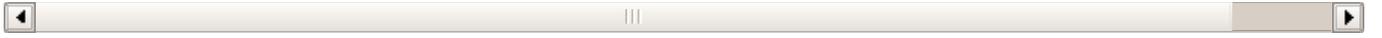


HYDRONIC PIPING SYSTEMS—SCHEDULE 40 STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Water Flow—GPM				Pipe Size				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0					
1/2	1.5	1.9	2.1	4.0	5.0	6.0	8.0	1				
3/4	3.2	3.9	4.5									
1	6.0	7.4	8.5	Pressure with these	governs sizes							
1-	12	15	18						19			
1/4	19	23	26						25			
1-	36	44	51						42			
1/2									52			
2												
2-	57	70	80						60	75		
1/2	100	123	142						92	115	138	
3	204	250	289						159	198	238	
4												
5	368	451	521	249	312	374	499	1				
6	595	729	841	360	450	540	720					
8	1,216	1,489		624	780	936	1,247	1				
10	2,198	governs pipe	with sizes	983	1,229	1,475	1,966	2				
12	3, 65			1,396	1,744	2,093	2,791	3				
14				1,687	2,109	2,531	3,374	4				
16	Velocity these			2,203	2,754	3,305	4,406	5				
18				2,789	3,486	4,183	5,577	6				
20				3,466	4,333	5,199	6,932	8				
22				-	-	-	-					
24	5,013			6,266	7,519	10,026	12,532					
26	-			-	-	-	-					
28	-			-	-	-	-					
30	7,954	9,942	11,930	15,907	19,884							
32	9,183	11,479	13,775	18,366	22,958							
34	10,422	13,027	15,633	20,844	26,055							
36	11,655	14,569	17,482	23,310	29,137							
42	16,061	20,077	24,092	32,123	40,153							
48	21,173	26,466	31,759	42,345	52,932							
54	26,989	33,736	40,484	53,978	67,473							

Pipe Size	Friction Rate—ft./100 ft.	Water Flow—GPM	Velocity—ft./sec.				
			2.0	3.0	4.0	5.0	6.0
60	33,511	48,888	60,836	73,003	97,337	121,671	166,617
66	47,669	67,021	83,308	99,970	133,293	166,617	218,612
72	66,647	83,308	109,306	131,167	174,890	218,612	
96	87,445	109,306	131,167	174,890	218,612		



HYDRONIC PIPING SYSTEMS—SCHEDULE 80 STEEL PIPE

Water Flow—GPM

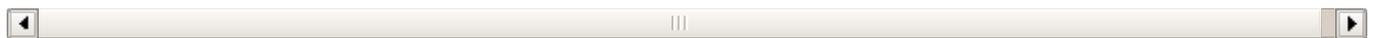
Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.1	1.3	1.5		Pressure drop with these	governs pipe sizes		
3/4	2.4	3.0	3.4					
1	4.7	5.8	6.7					
1-	10	12	14					
1/4	15	19	22	22				
1-	30	37	43	37				
1/2								
2								
2-	48	59	69	53	66			
1/2	87	106	123	82	103	124		
3	179	219	253	143	179	215		
4								
5	325	399	460	227	284	340	454	1,423
6	520	637	736	325	406	487	650	
8	1,080	1,322		569	712	854	1,139	
10	1,947	governs pipe	with sizes	896	1,120	1,344	1,791	2,239
12	3,057			1,267	1,584	1,901	2,534	3,168
14				1,530	1,912	2,295	3,060	3,825
16	Velocity these			2,006	2,508	3,009	4,013	5,016
18				2,546	3,183	3,820	5,093	6,366
20				3,151	3,938	4,726	6,302	7,877
22	3,819			4,774	5,729	7,639	9,549	
24	4,553			5,692	6,830	9,107	11,383	



HYDRONIC PIPING SYSTEMS—SCHEDULE 160 STEEL PIPE

Water Flow—GPM

Pipe Size	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	0.7	0.9	1.0		Pressure drop with these	drop pipe	governs sizes	
3/4	1.5	1.8	2.1					
1	3.1	3.8	4.4					
1-1/4	8	10	11					
1-1/2	11	14	16		28			
2	21	26	30					
2-1/2	38	47	54	44	55	174		
3	67	82	95	68	84			
4	135	166	191	116	145			
5	244	299	346	182	228			
6	396	485	560	264	330	273	527	1,136
8	805	986		455	568	395	682	
10	1,433	1,755	with sizes	707	884	1,061	1,415	
12	2,259			1,004	1,255	1,506	2,008	
14	2,928			1,226	1,532	1,839	2,451	2,510
16	Velocity these governs pipe			1,608	2,010	2,412	3,216	4,020
18			2,041	2,551	3,062	4,082	5,103	
20			2,527	3,159	3,790	5,054	6,317	
22	3,085	3,856		4,628	6,170	7,713		
24	3,653	4,566		5,479	7,305	9,132		



HYDRONIC PIPING SYSTEMS—SCHEDULE 5 STAINLESS STEEL PIPE

Pipe Size	Friction Rate—ft./100 ft.	Water Flow—GPM	Pressure drop with these	governs pipe sizes				
				Velocity—ft./sec.	8.0	10.0	12.0	14.0
1/2	1.9	2.3	2.7	2.0	5.0	6.0	8.0	10.0
3/4	3.8	4.7	5.6	4.0	5.0	6.0	8.0	10.0
1-	142.0	173.0	204.0	24.0	5.0	6.0	8.0	10.0
1/4	21	25	29	28				
1-	40	49	56	46	57			
1/2								
2								
2-	67	83	95	68	85			
1/2	118	144	166	104	130	156		
3	237	290	335	178	222	267		
4								
5	417	511	590	275	343	412	549	
6	672	823	951	396	495	594	791	
8	1,359	1,664		679	849	1,019	1,359	1,698
10	2,433	governs pipe	with sizes	1,063	1,329	1,595	2,126	2,658
12				1,503	1,879	2,255	3,006	3,758
14				1,818	2,272	2,726	3,635	4,544
16	Velocity these			2,390	2,988	3,585	4,781	5,976
18				3,041	3,802	4,562	6,083	7,604
20				3,748	4,685	5,622	7,496	9,370
22				4,553	5,692	6,830	9,107	11,383
24				5,408	6,760	8,111	10,815	13,519

Notes:

- 1. Maximum recommended pressure drop: 4 ft./100 ft.**
- 2. Maximum recommended velocity (occupied areas): 8 FPS.**
- 3. Maximum recommended velocity (unoccupied areas, shafts, tunnels, etc.): 10 FPS.**
- 4. Standard steel pipe and Type L copper pipe are the most common pipe materials used in HVAC applications.**
- 5. Tables are applicable to closed and open hydronic piping systems.**
- 6. Pipe sizes 5", 22", 26", 28", 32", and 34" are not standard sizes and**

are not readily available in all locations.

Water Flow—GPM

7. Pipe Types K, L, and M copper pipe are available in sizes up through 12 inch. Friction Rate—pp/100 ft. Velocity—ft./sec.

8. Standard and XS steel pipe are available in sizes through 96 inch. 2.0 3.0 4.0 4.0 5.0 6.0 8.0 10.0

9. XXS steel pipe is available in sizes through 12 inch.

0. Schedule 40 steel pipe is available in sizes through 96 inch.

1. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.

2. Schedule 5 and 10 stainless steel pipe are available in sizes through 24 inch.

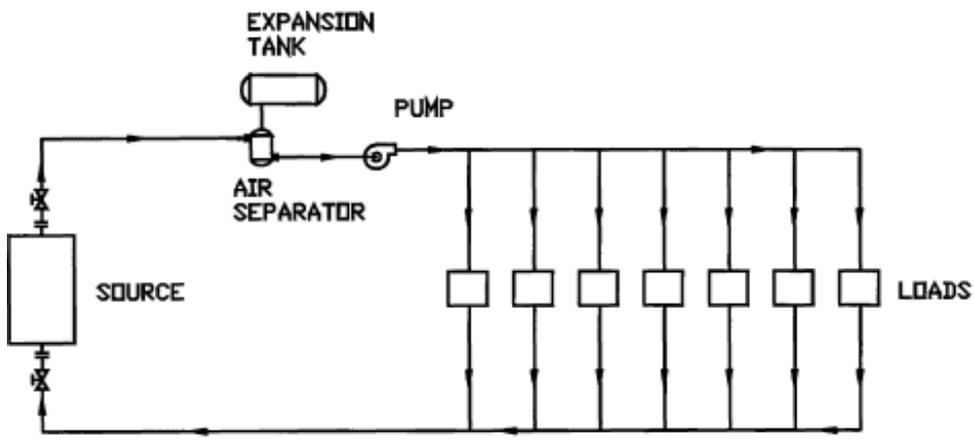
3. Standard and Schedule 40 steel pipe have the same dimensions and flow for 10 inch and smaller.

4. XS and Schedule 80 steel pipe have the same dimensions and flow for 8 inch and smaller.

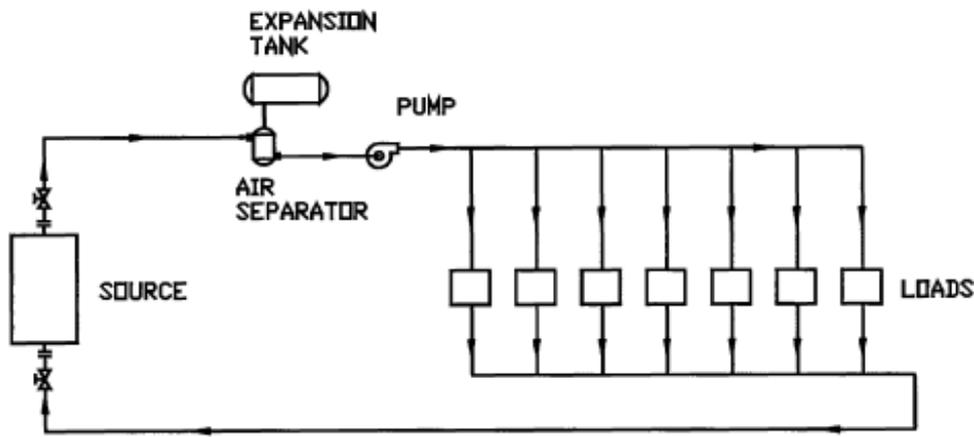
5. XXS and Schedule 160 have no relationship for dimensions or flow.

19.05. Hydronic System Designs and Terminology

- A. ***Closed Piping Systems.*** Piping systems with no more than one point of interface with a compressible gas (generally air). Examples: Chilled Water and Heating Water Systems.
- B. ***Open Piping Systems.*** Piping systems with more than one point of interface with a compressible gas (generally air). Example: Condenser Water Systems
- C. ***Reverse Return Systems.*** Where the length of supply and return piping is nearly equal. Reverse return systems are nearly self-balancing (see Figs. 19.1 through 19.5).



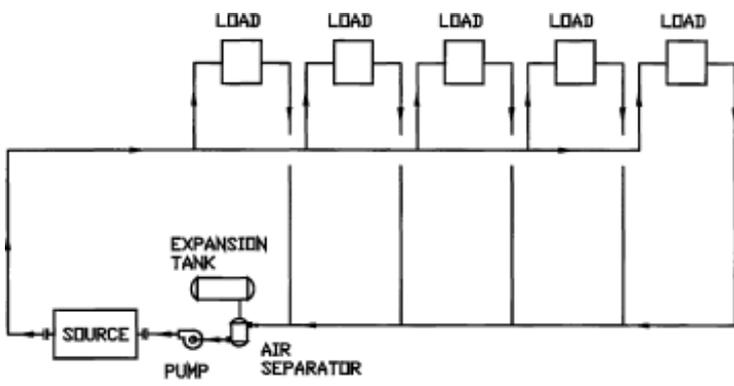
DIRECT RETURN HYDRONIC SYSTEM



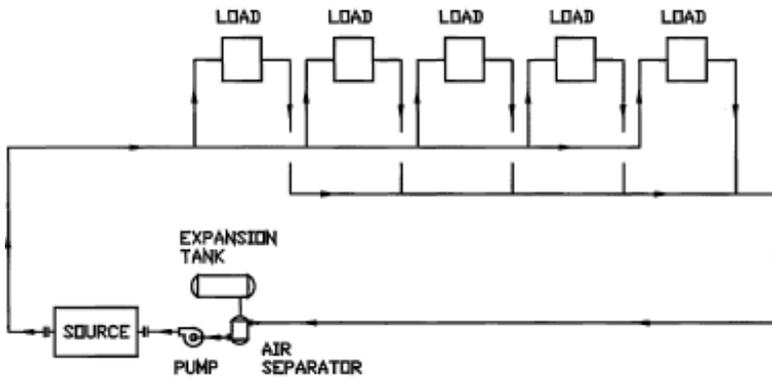
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Figure 19.1. HYDRONIC SYSTEM RETURN TYPES.



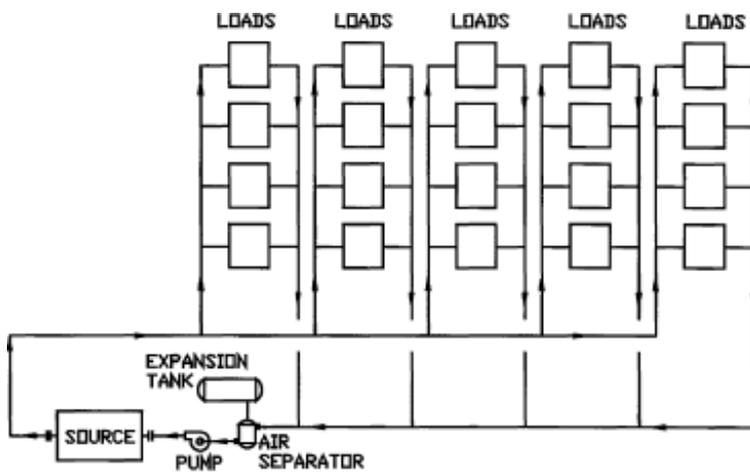
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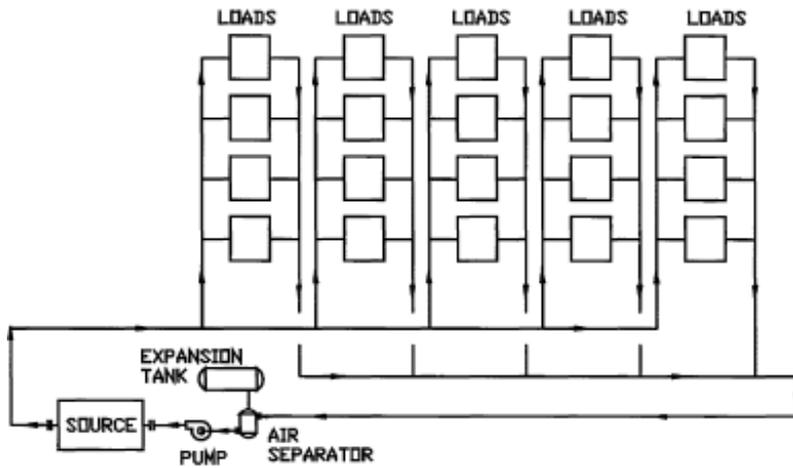
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Figure 19.2. HYDRONIC SYSTEM RETURN TYPES.



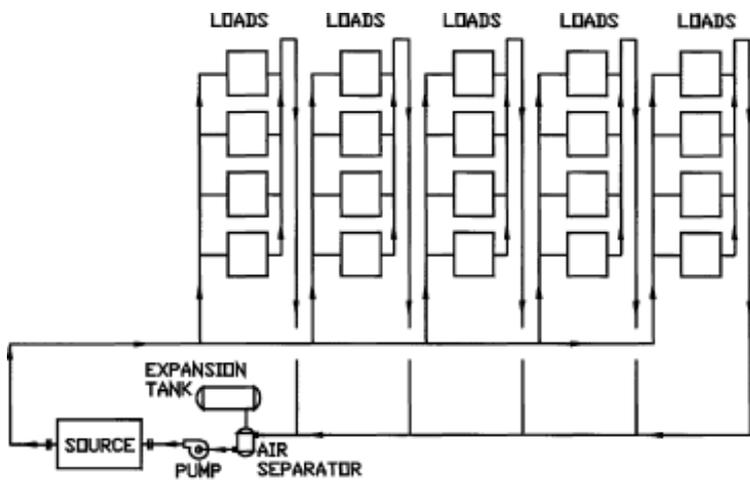
DIRECT RETURN RISER & DIRECT RETURN MAINS



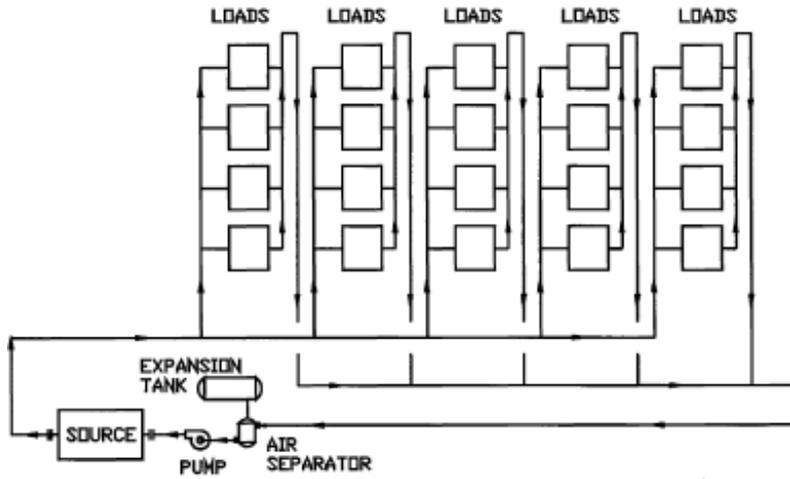
DIRECT RETURN RISER & REVERSE RETURN MAINS

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Figure 19.3. HYDRONIC SYSTEM RETURN TYPES.



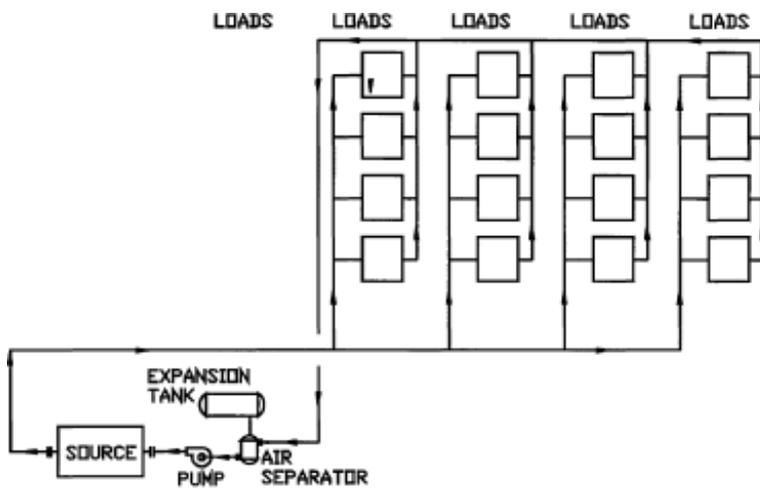
REVERSE RETURN RISER & DIRECT RETURN MAINS



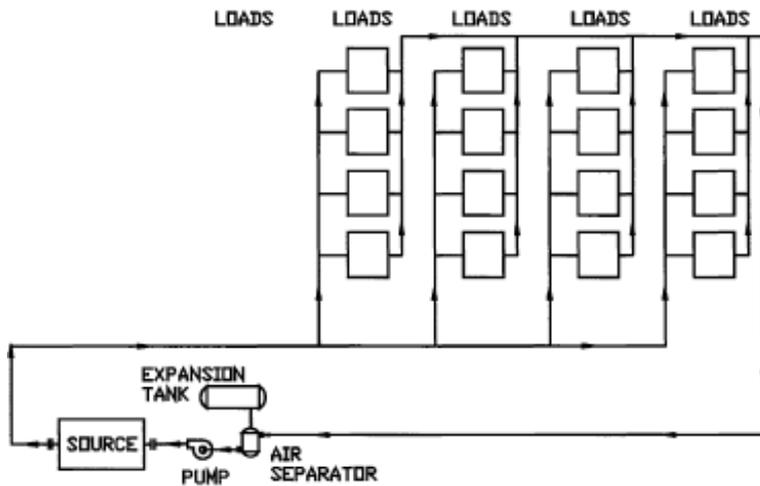
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Figure 19.4. HYDRONIC SYSTEM RETURN TYPES.



REVERSE RETURN RISER & DIRECT RETURN MAINS



REVERSE RETURN RISER & REVERSE RETURN MAINS

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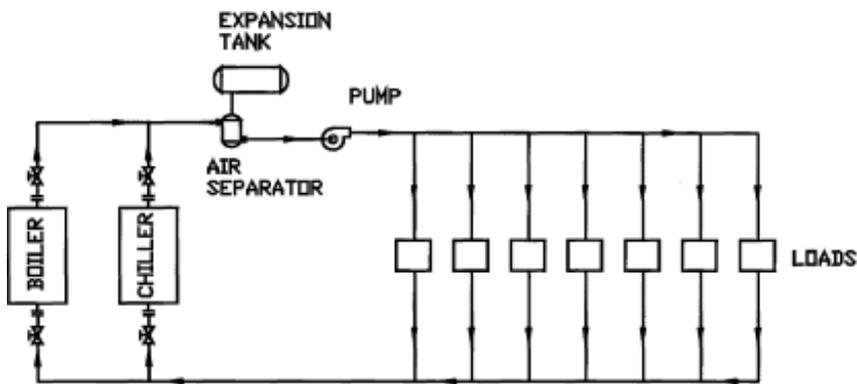
Figure 19.5. HYDRONIC SYSTEM RETURN TYPES.

D. **Direct Return Systems.** Where the length of supply and return piping is unequal. Direct return systems are more difficult to balance (see **Figs. 19.1** through **19.5**).

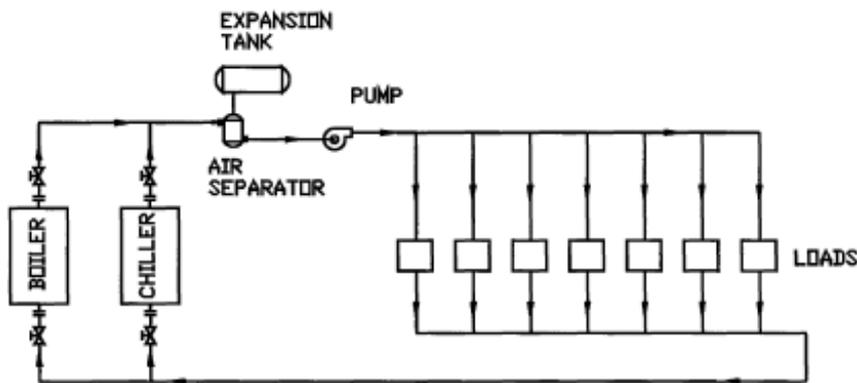
E. **One-Pipe Systems**

1. One-pipe systems are constant volume flow systems.
2. *All Series Flow Arrangements.* Total circulation flows through every terminal user with lower inlet supply temperatures with each successive terminal device.
3. *Diverted Series Flow Arrangements.* Part of the flow goes through the terminal unit, while the remainder is diverted around the terminal unit using a resistance device (balancing valve, fixed orifice, diverting tees, or flow control devices).

F. **Two-Pipe Systems (See Fig. 19.6)**



DIRECT RETURN HYDRONIC SYSTEM



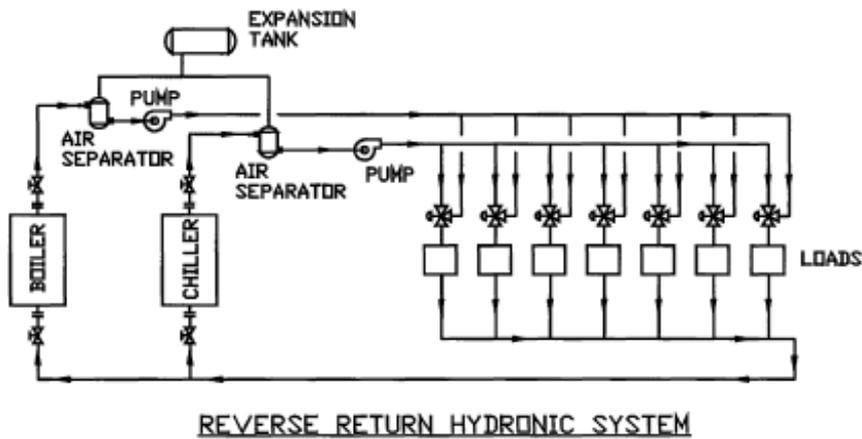
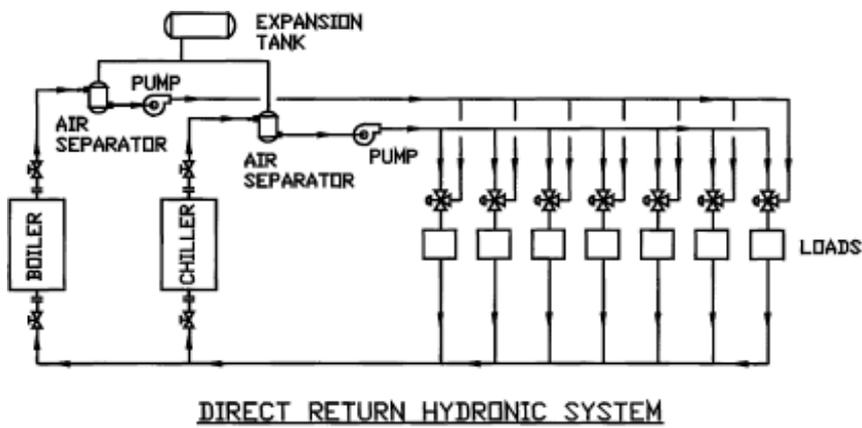
REVERSE RETURN HYDRONIC SYSTEM

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Figure 19.6. TWO-PIPE HYDRONIC SYSTEMS.

1. The same piping is used to circulate chilled water and heating water.
2. Two-pipe systems are either constant volume flow or variable volume flow systems.
3. *Direct Return Systems.* In these systems, it is critical to provide proper balancing devices (balancing valves or flow control devices).
4. *Reverse Return Systems.* Generally limited to small systems, these systems will simplify balancing.

G. Three-Pipe Systems (Obsolete; See Fig. 19.7)



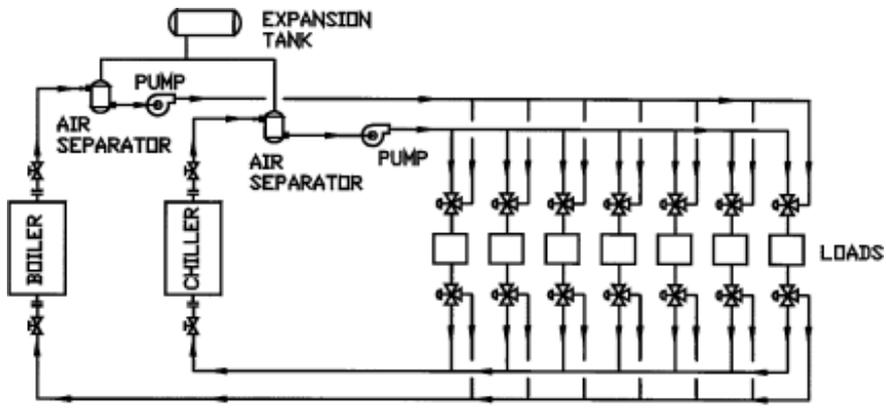
NOTE: 3-PIPE HYDRONIC SYSTEMS ARE OBSOLETE AND ARE NOT USED IN THE DESIGN OF HVAC SYSTEMS TODAY.

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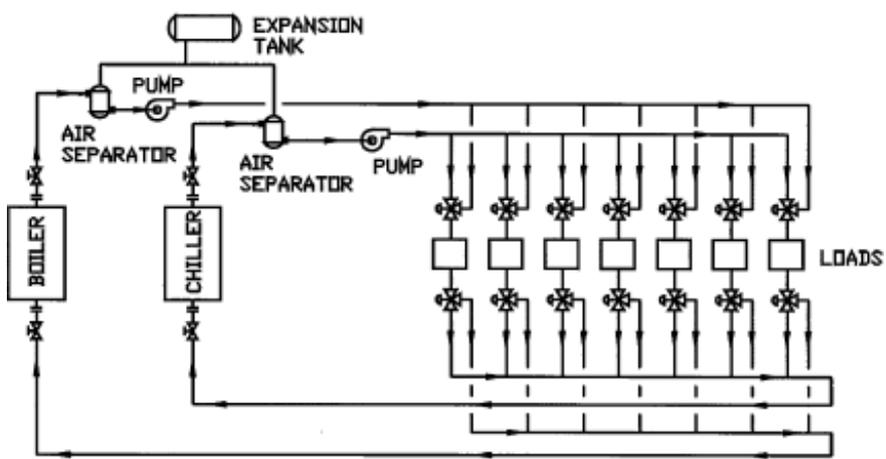
Figure 19.7. THREE-PIPE HYDRONIC SYSTEMS.

1. Separate chilled water and heating water supply piping; common return piping is used to circulate chilled water and heating water.

H. **Four-Pipe Systems (See Figs. 19.8 and 19.9)**



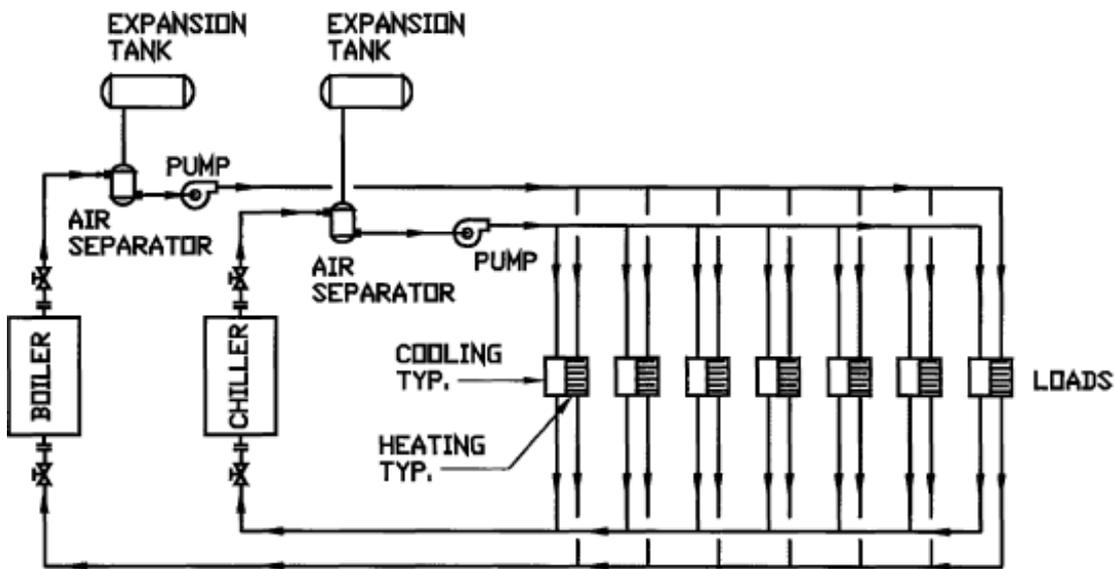
DIRECT RETURN HYDRONIC SYSTEM



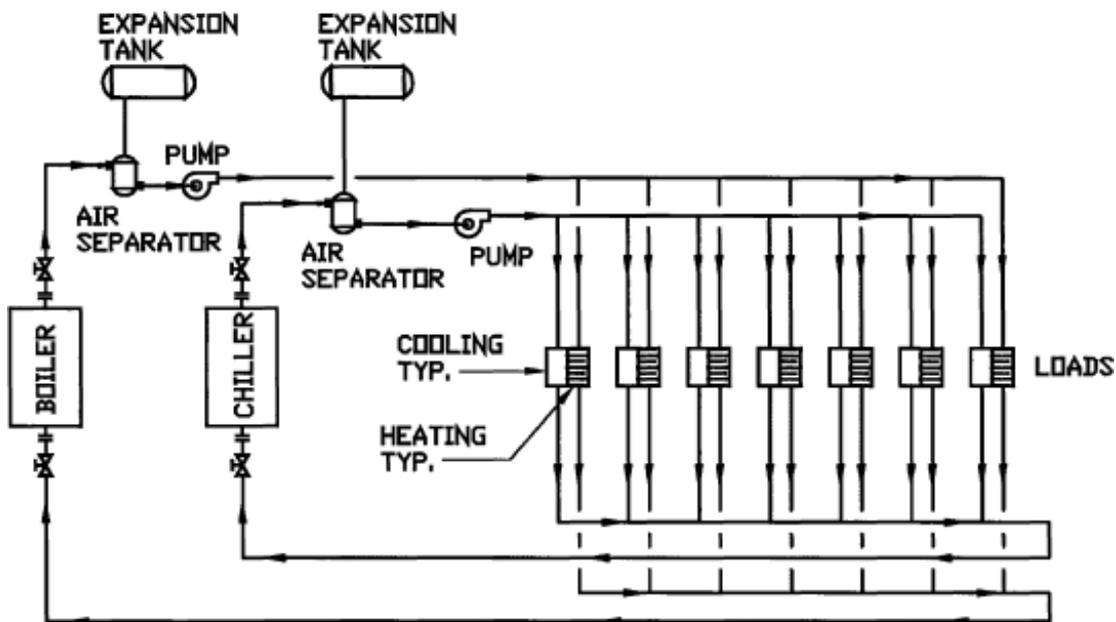
REVERSE RETURN HYDRONIC SYSTEM

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Figure 19.8. FOUR-PIPE HYDRONIC SYSTEMS COMMON LOAD SYSTEMS.



DIRECT RETURN HYDRONIC SYSTEM



REVERSE RETURN HYDRONIC SYSTEM

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Figure 19.9. FOUR-PIPE HYDRONIC SYSTEMS INDEPENDENT LOAD SYSTEMS.

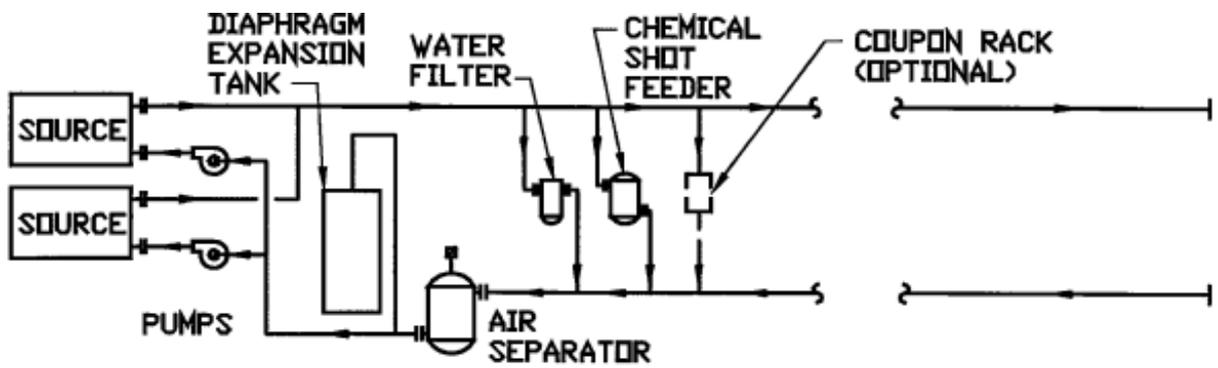
1. Separate supply and return piping (two separate systems) are used to circulate chilled water and heating water.
2. Four-pipe systems are either constant volume flow or variable volume flow systems.
3. *Direct Return Systems.* In these systems, it is critical to provide proper balancing devices (balancing valves or flow control devices).
4. *Reverse Return Systems.* Generally limited to small systems. These systems will simplify balancing.

I. Ring or Loop Type Systems

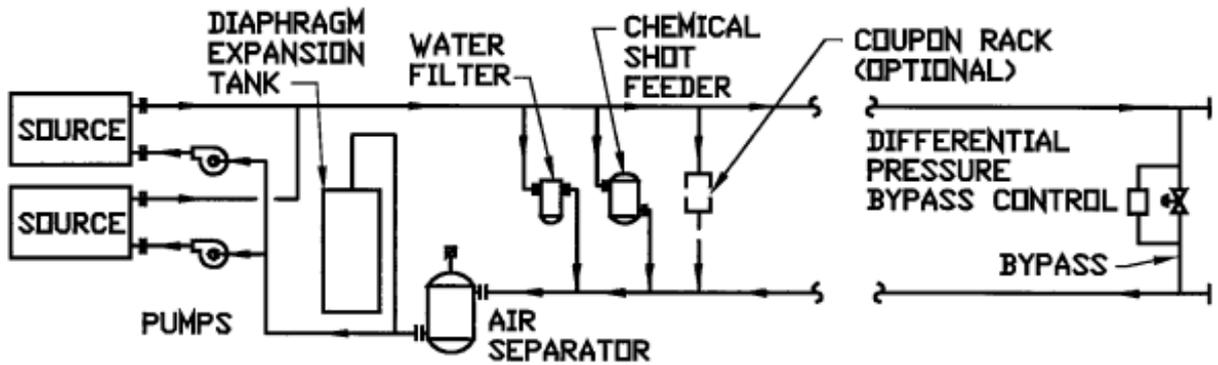
1. Piping systems that are laid out to form a loop with the supply and return mains parallel to each other.
2. Constant volume flow or variable volume flow systems.
3. They provide flexibility for future additions and provide service reliability.
4. These can be designed with better diversity factors.
5. During shutdown for emergency or scheduled repairs, maintenance, or modifications, loads, especially critical loads, can be fed from other direction or leg.
6. Isolation valves must be provided at critical junctions and between all major lateral connections so mains can be isolated and flow rerouted.
7. Flows and pressure distribution must be estimated by trial and error or by computer.

J. Constant Volume Flow Systems

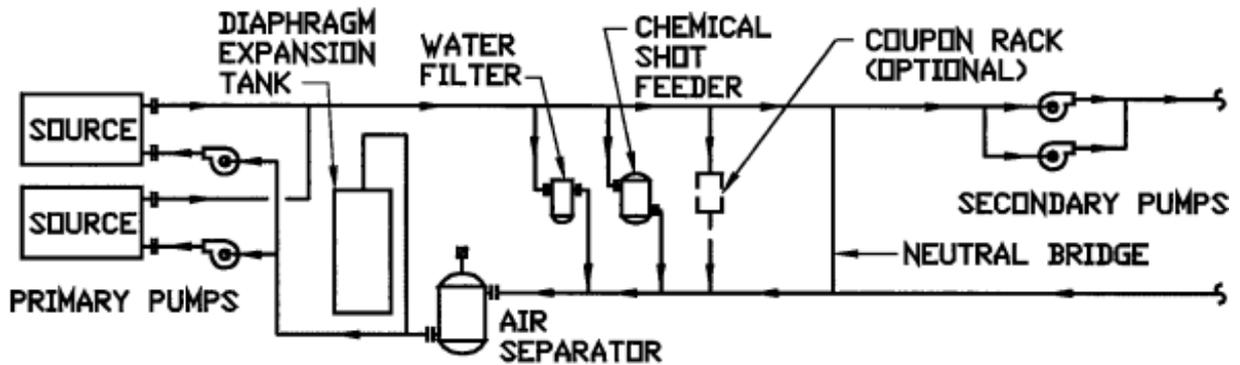
1. *Direct Connected Terminals*. Flow created by a main pump through three-way valves.
2. *Indirect Connected Terminals*. Flow created by a separate pump with a bypass and without output controls.
 - a. Permit variable volume flow systems.
 - b. Subcircuits can be operated with high pump heads without penalizing the main pump.
 - c. Require excess flow in the main circulating system.
3. Constant volume flow systems are limited to (see [Figs. 19.10](#) and [19.11](#)):



CONSTANT FLOW AT SOURCE & TERMINAL EQUIPMENT
(3-WAY CONTROL VALVES)



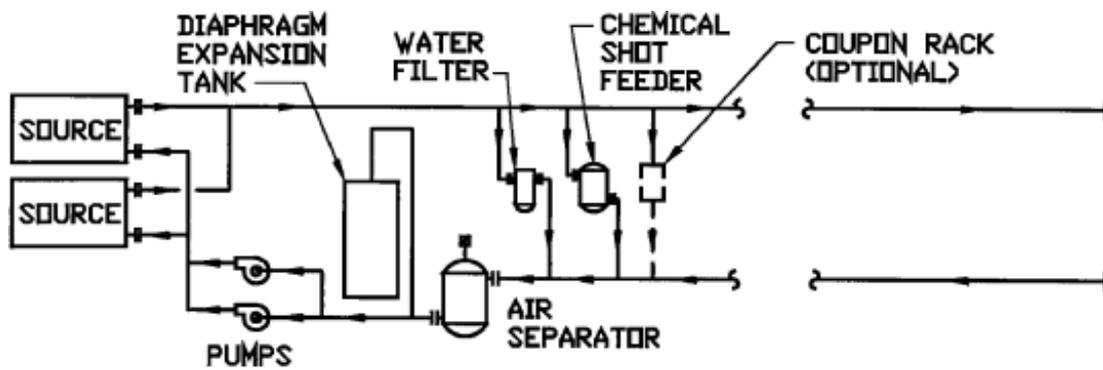
CONSTANT OR VARIABLE FLOW AT SOURCE
VARIABLE FLOW AT TERMINAL EQUIPMENT
(2-WAY CONTROL VALVES)



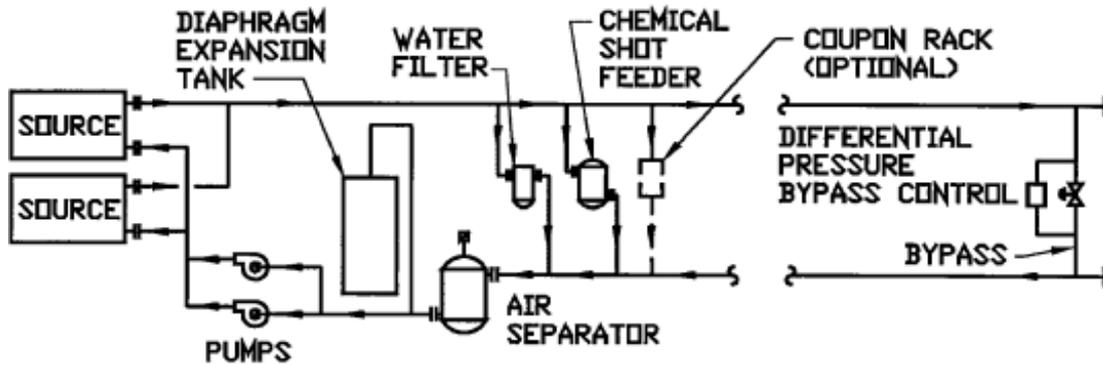
CONSTANT OR VARIABLE FLOW PRIMARY,
VARIABLE FLOW SECONDARY
(2-WAY CONTROL VALVES)

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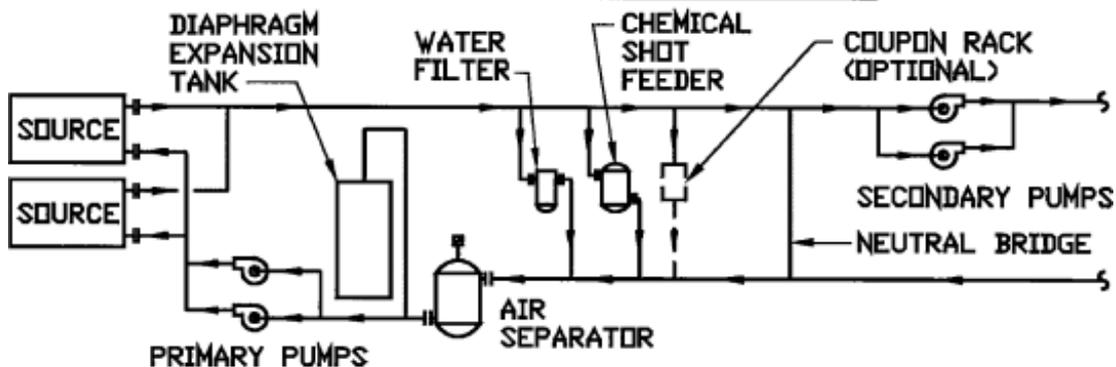
Figure 19.10. COUPLED CONSTANT VS. VARIABLE FLOW SYSTEMS.



CONSTANT FLOW AT SOURCE & TERMINAL EQUIPMENT
(3-WAY CONTROL VALVES)



CONSTANT OR VARIABLE FLOW AT SOURCE
VARIABLE FLOW AT TERMINAL EQUIPMENT
(2-WAY CONTROL VALVES)



CONSTANT OR VARIABLE FLOW PRIMARY,
VARIABLE FLOW SECONDARY
(2-WAY CONTROL VALVES)

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Figure 19.11. HEADERED CONSTANT VS. VARIABLE FLOW SYSTEMS.

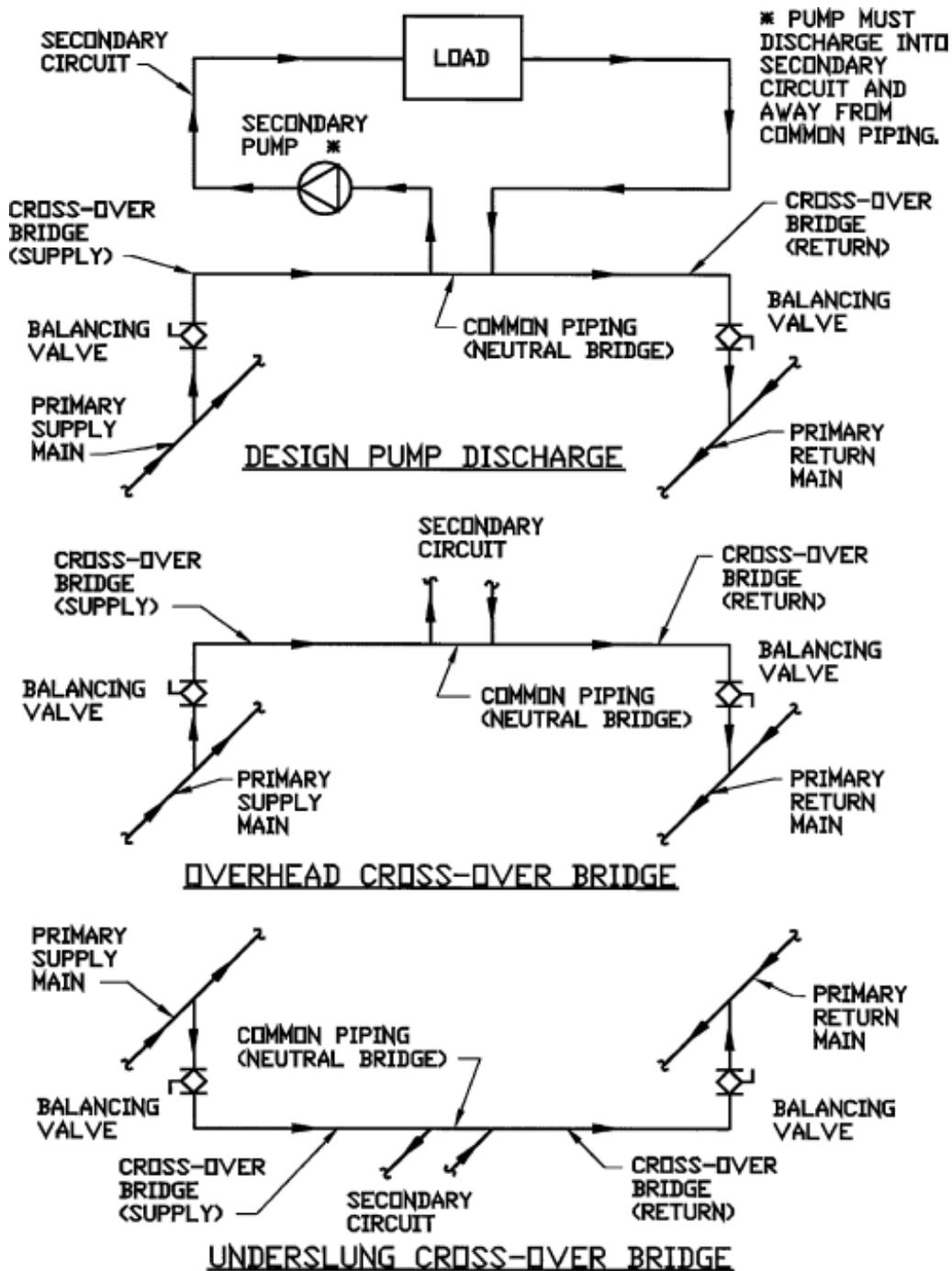
- Small systems with a single boiler or chiller.
- More than one boiler system if boilers are firetube or firebox boilers.
- Two chiller systems if chillers are connected in series.
- Small low-temperature heating water systems with 10-20°F delta T.
- Small chilled water systems with 7-10°F delta T.

- f. Condenser water systems.
 - g. Large chilled water and heating water systems with primary/secondary pumping systems, constant flow primary circuits.
4. Constant volume flow systems are not suited to (see Figs. 19.10 and 19.11):
- a. Multiple watertube boiler systems.
 - b. Parallel chiller systems.
 - c. Parallel boiler systems.
5. Constant volume flow systems are generally energy inefficient.

K. Variable Volume Flow Systems (See Figs. 19.10 and 19.11)

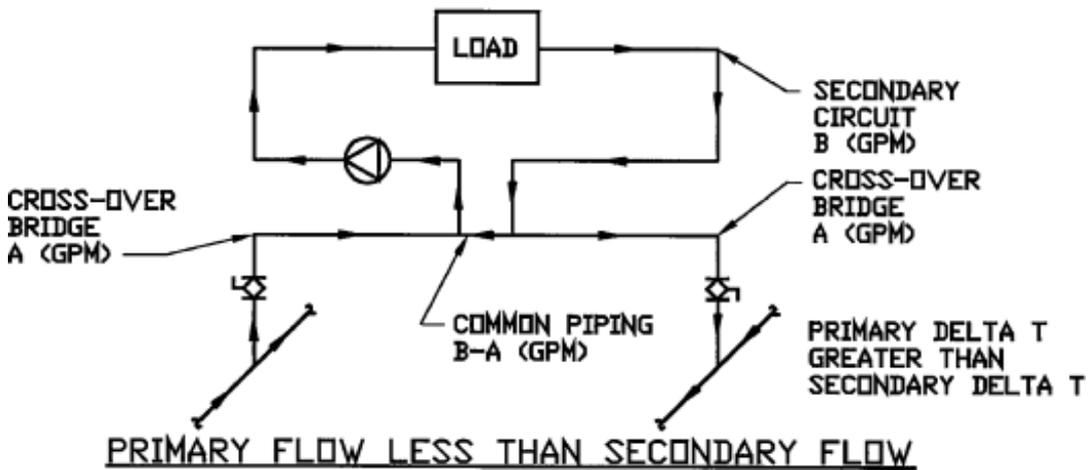
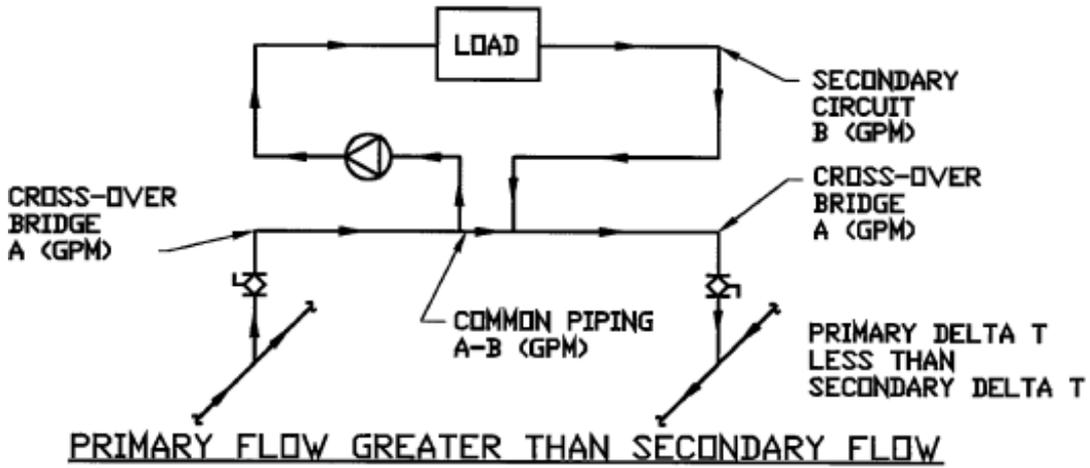
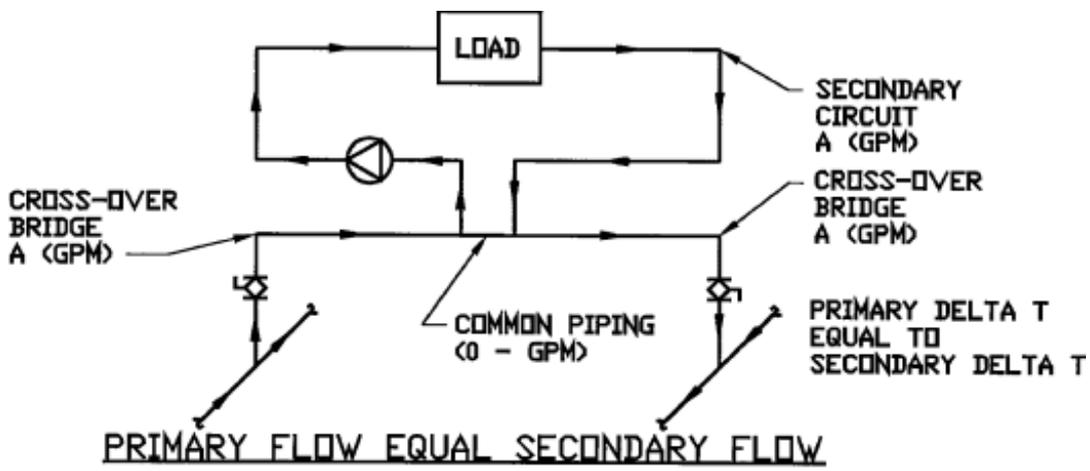
- 1. At partial load, the variable volume flow system return temperatures approach the temperature in the secondary medium.
- 2. Significantly higher pressure differentials occur at part load and must be considered during design unless variable speed pumps are provided.

L. Primary/Secondary/Tertiary Systems (PST Systems; See Figs. 19.12 through 19.21)



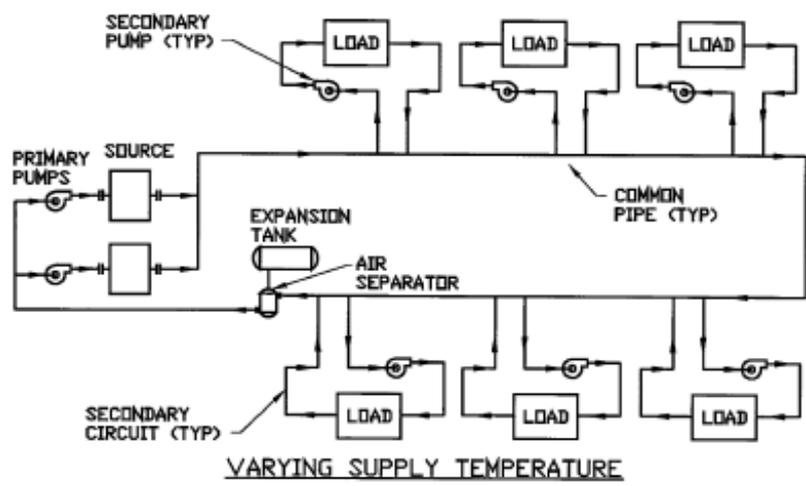
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Figure 19.12. PRIMARY-SECONDARY TERMINOLOGY.

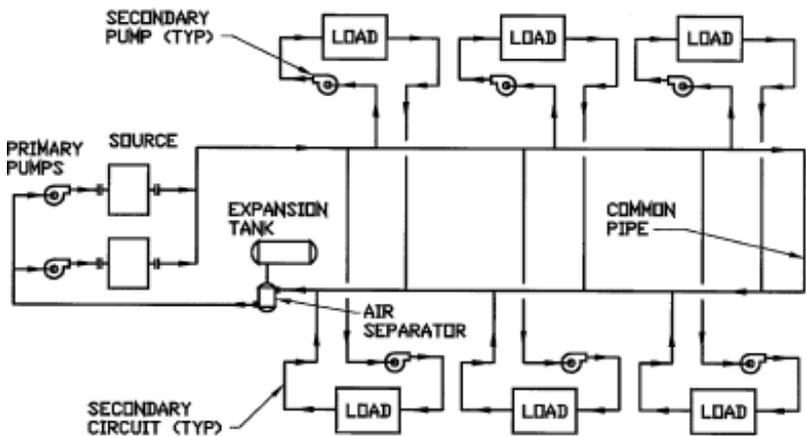


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Figure 19.13. PRIMARY-SECONDARY FLOW ANALYSIS.



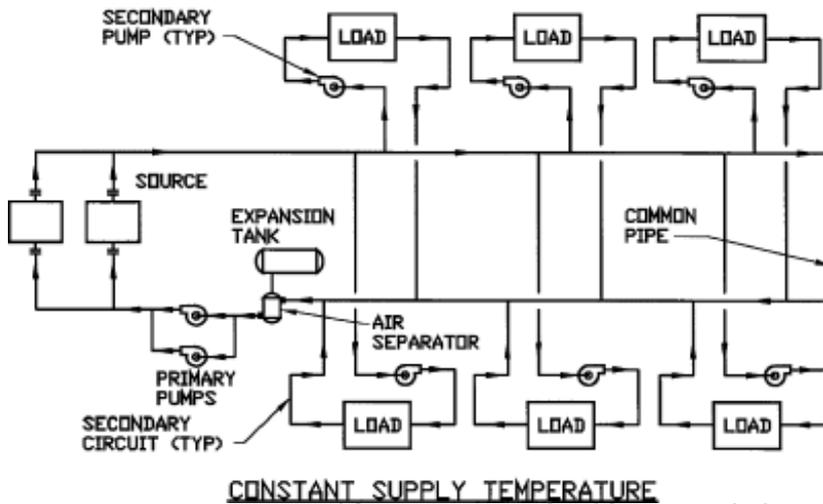
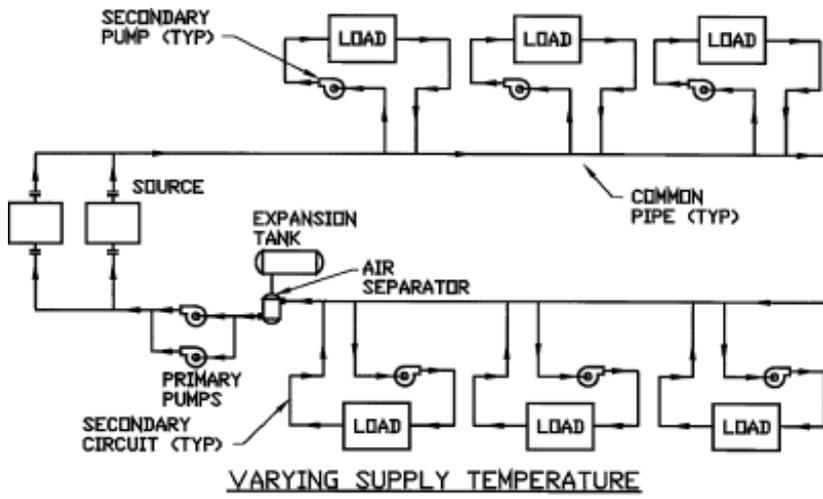
VARYING SUPPLY TEMPERATURE



CONSTANT SUPPLY TEMPERATURE

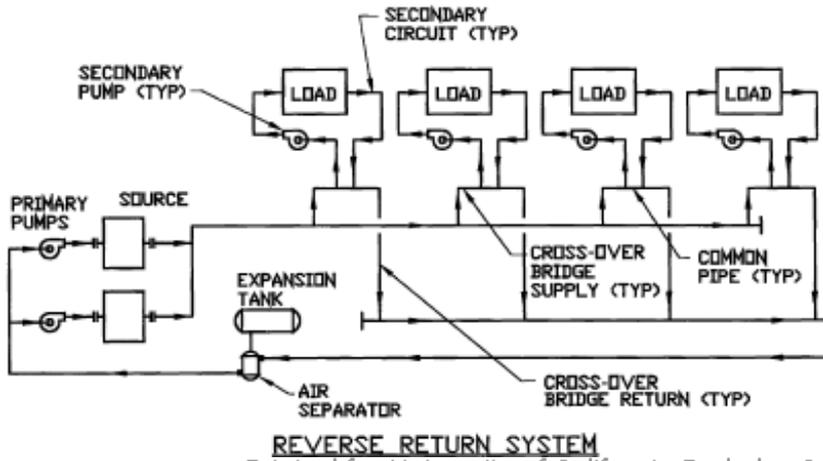
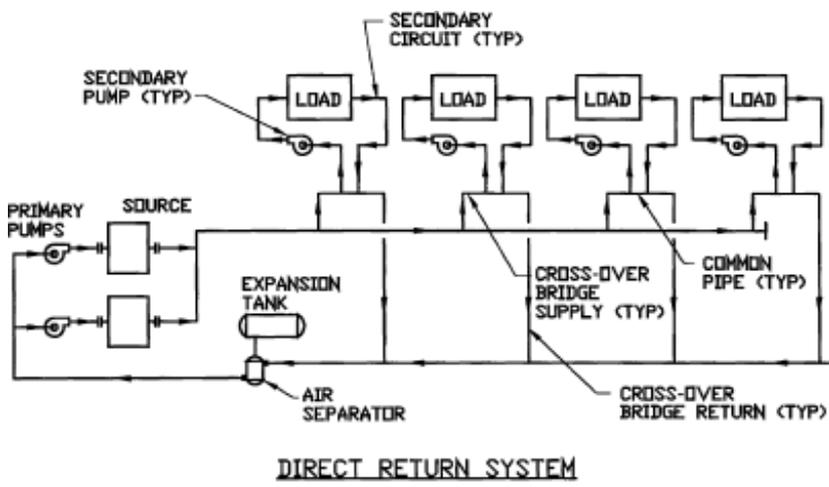
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Figure 19.14. COUPLED ONE-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.



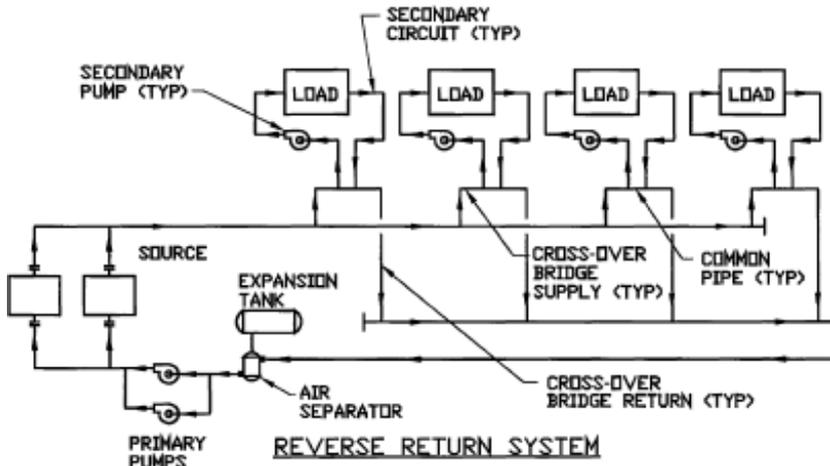
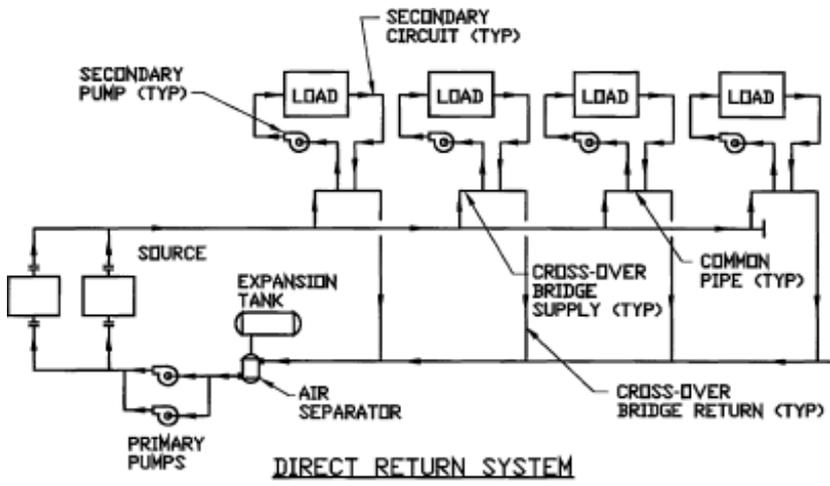
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Figure 19.15. HEADERED ONE-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.



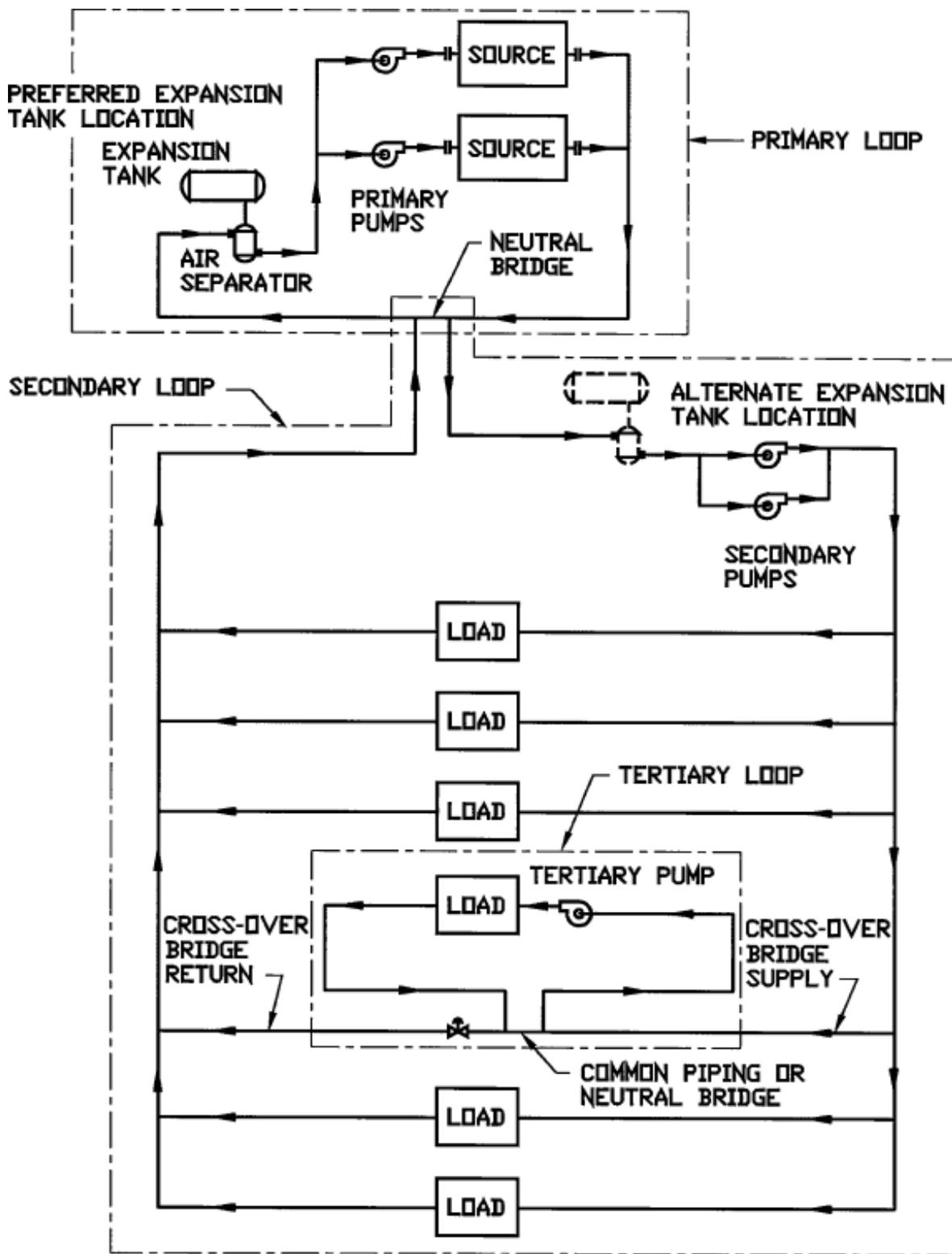
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Figure 19.16. COUPLED TWO-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.



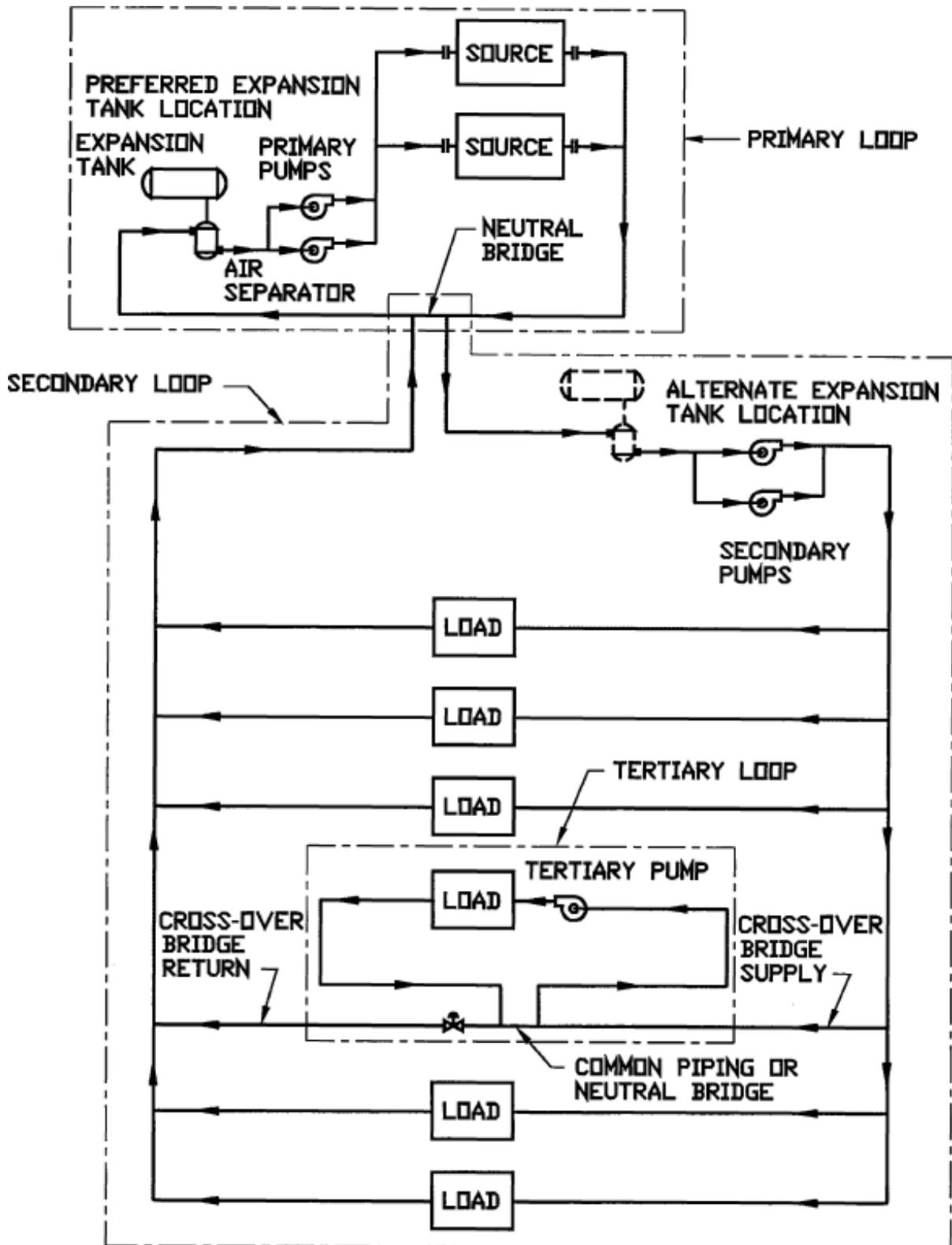
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Figure 19.17. HEADERED TWO-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.



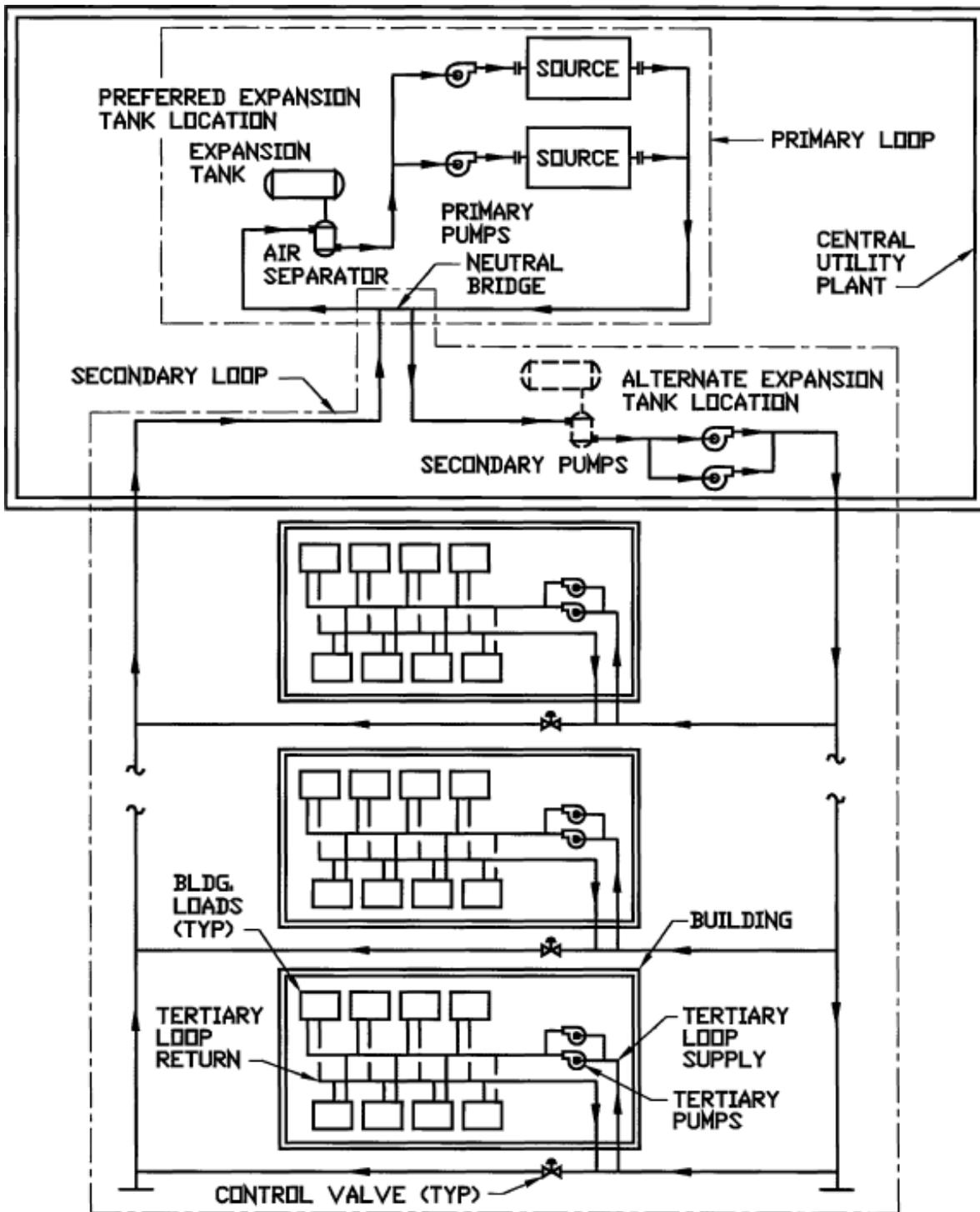
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Figure 19.18. COUPLED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.



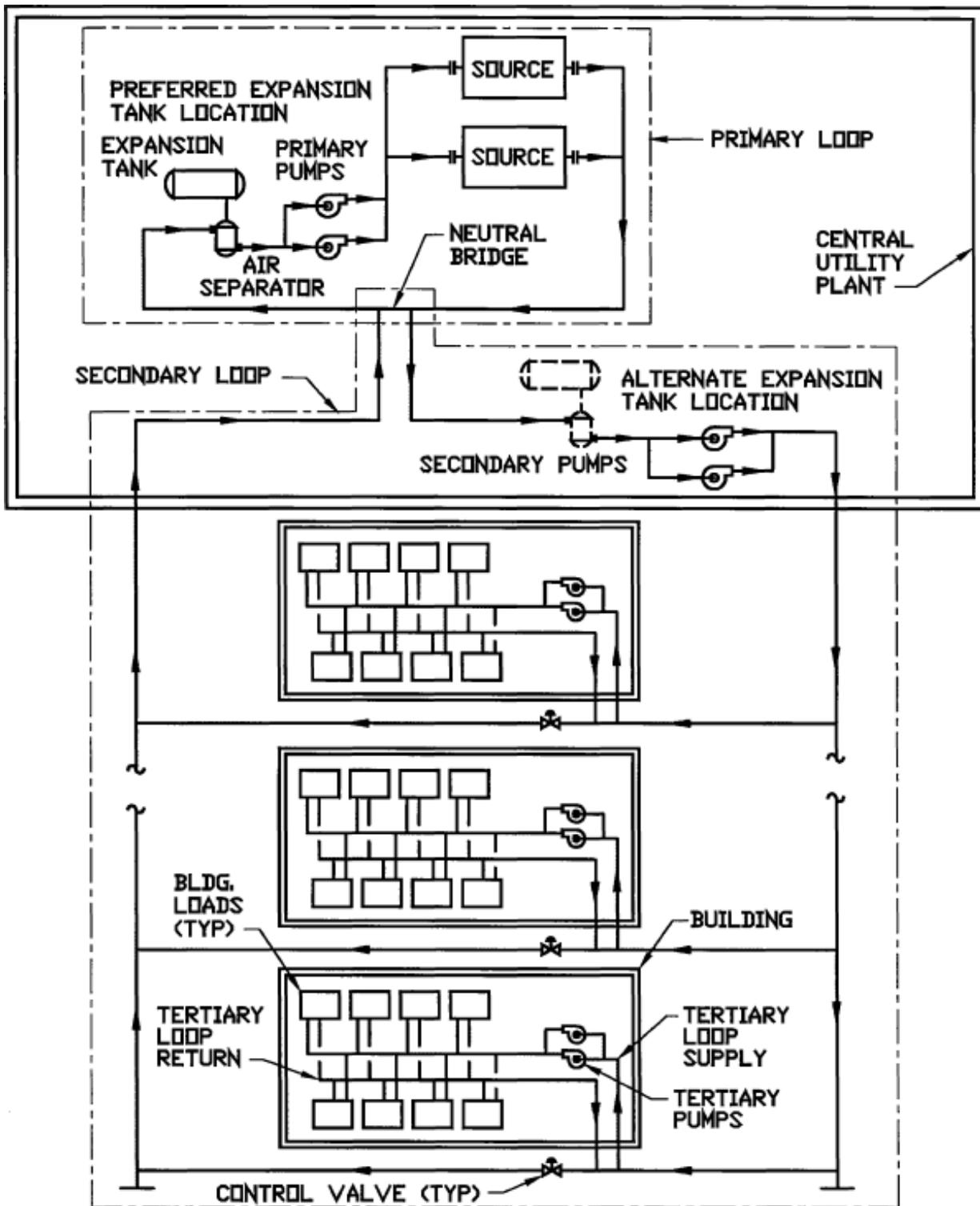
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Figure 19.19. HEADERED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.



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Figure 19.20. COUPLED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.



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Figure 19.21. HEADERED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

1. PST systems decouple system circuits hydraulically, thereby making control, operation, and analysis of large systems less complex.
2. Secondary (tertiary) pumps should always discharge into secondary (tertiary) circuits away from the common piping.
3. *Cross-Over Bridge*. Cross-over bridge is the connection between the primary (secondary) supply main and the primary (secondary) return main. Size

cross-over bridge at a pressure drop of 1–4 ft./100 ft.

4. *Common Piping*. Common piping (sometimes called bypass piping) is the length of piping common to both the primary and secondary circuit flow paths and the secondary and tertiary circuit flow paths. Common piping is the interconnection between the primary and secondary circuits and the secondary and tertiary circuits. The common piping is purposely designed to an extremely low or negligible pressure drop and is generally only 6" to 24" long maximum. By designing for an extremely low pressure drop, the common piping ensures hydraulic isolation of the secondary circuit from the primary circuit, and the tertiary circuit from the secondary circuit.
5. Extend common pipe size a minimum of 8 diameters upstream and a minimum of 4 diameters downstream when primary flow rate is considerably less than secondary flow rate (e.g., primary pipe size is smaller than secondary pipe size—use larger pipe size) to prevent any possibility of "jet flow." Common piping (bypass piping) in primary/secondary systems or secondary/tertiary systems should be a minimum of 10 pipe diameters in length and the same size as the larger of the two piping circuits.
6. A one-pipe primary system uses one pipe for supply and return. The secondary circuits are in series. Therefore, this system supplies a different supply water temperature to each secondary circuit, and the secondary circuits must be designed for this temperature change.
7. A two-pipe primary system uses two pipes, one for supply and one for return with a cross-over bridge connecting the two. The secondary circuits are in parallel. Therefore, this system supplies the same supply water temperature to each secondary circuit.

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19.06. Hydronic System Design and Piping Installation

Guidelines

A. Hydronic systems design principle and goal is to provide the correct water flow at the correct water temperature to the terminal users.

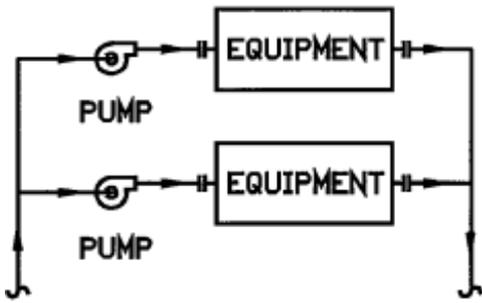
B. Common Design Errors

1. Differential pressure control valves are installed in pump discharge bypasses.

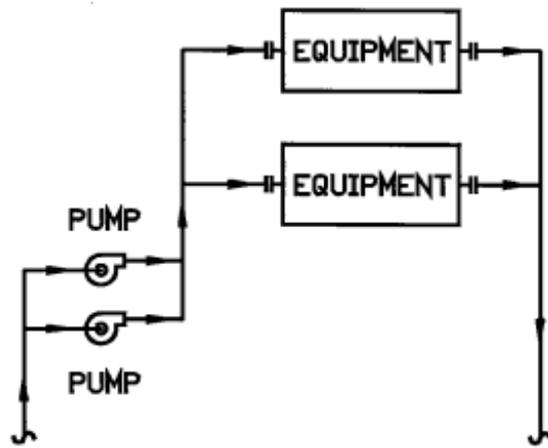
2. Control valves are not selected to provide control with system design pressure differentials at maximum and minimum flows.
3. Control valves are selected with improper pressure drop.
4. Incorrect primary/secondary/tertiary system design.
5. Constant flow secondary or tertiary systems are connected to variable flow primary or secondary systems, respectively.
6. Check valves are not provided in pump discharges when pumps are operating in parallel.
7. Automatic relief valves are oversized, which results in quick, sudden, and sometimes violent system pressure fluctuations.

C. Piping System Arrangements

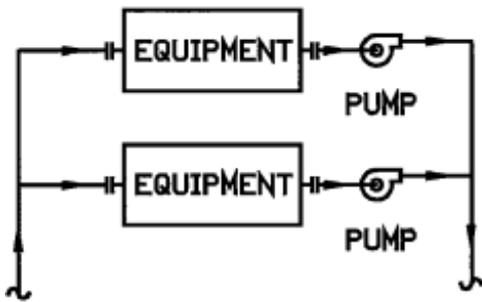
1. When designing pumping systems for chillers, boilers, and cooling towers, provide either a coupled pumping arrangement (each pump piped directly to each piece of central plant equipment) or provide a headered system (see [Fig. 19.22](#)). Hydronic systems should be designed with standby pumps (see [Figs. 19.23](#) and [19.24](#)).



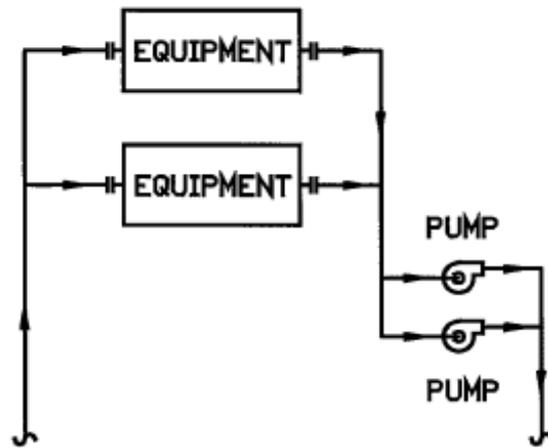
COUPLED PUMPING



HEADERED PUMPING



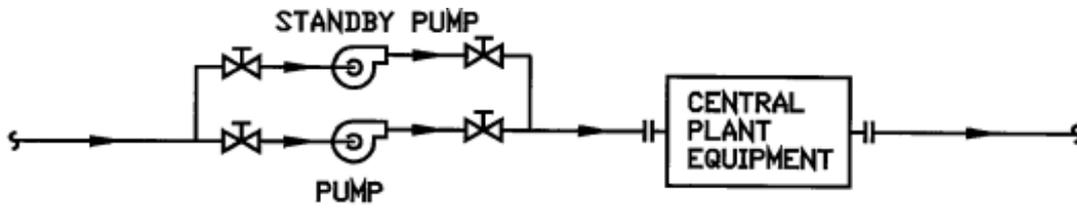
COUPLED PUMPING



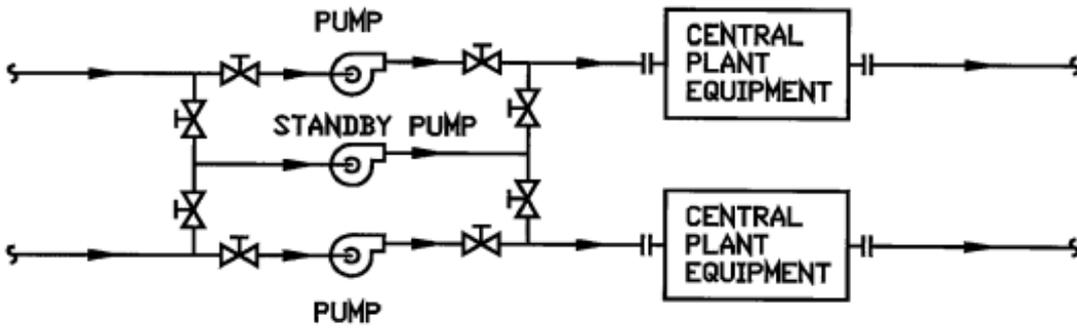
HEADERED PUMPING

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Figure 19.22. COUPLED-HEADERED PUMPING ARRANGEMENTS.

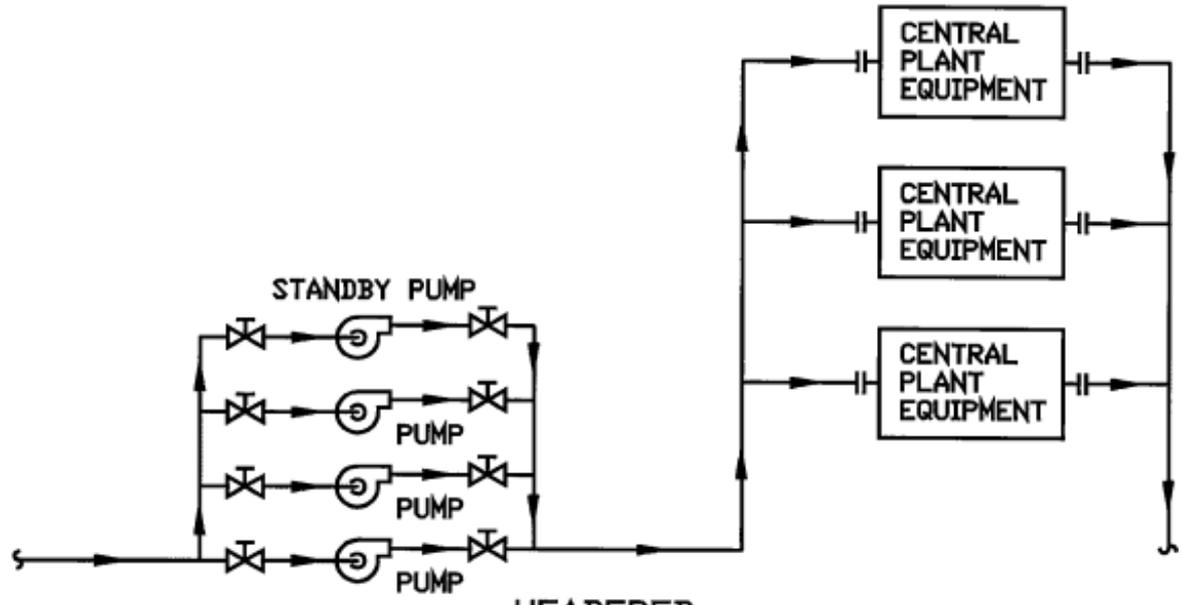


INDIVIDUAL



COUPLED

NOTE: STANDBY PUMP MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.

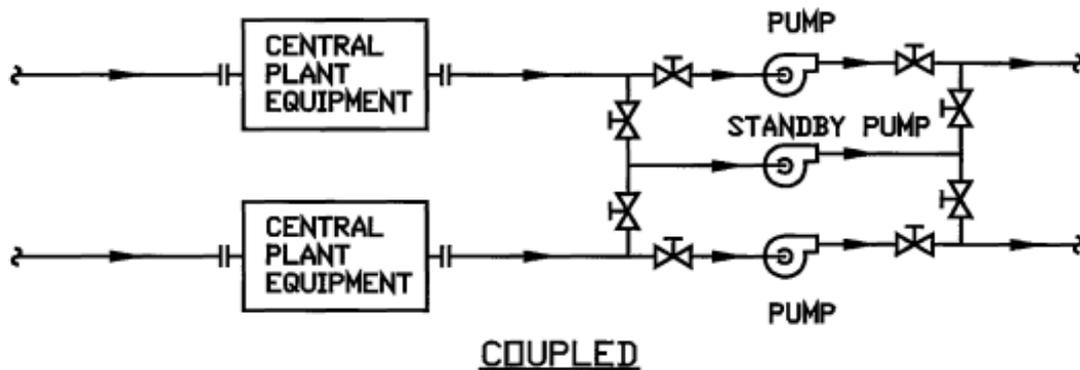
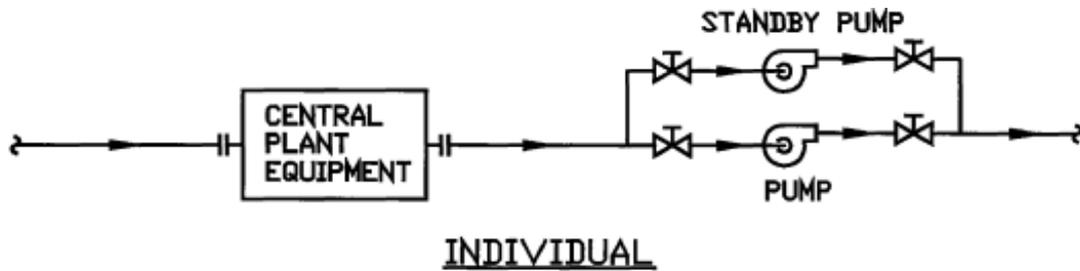


HEADERED

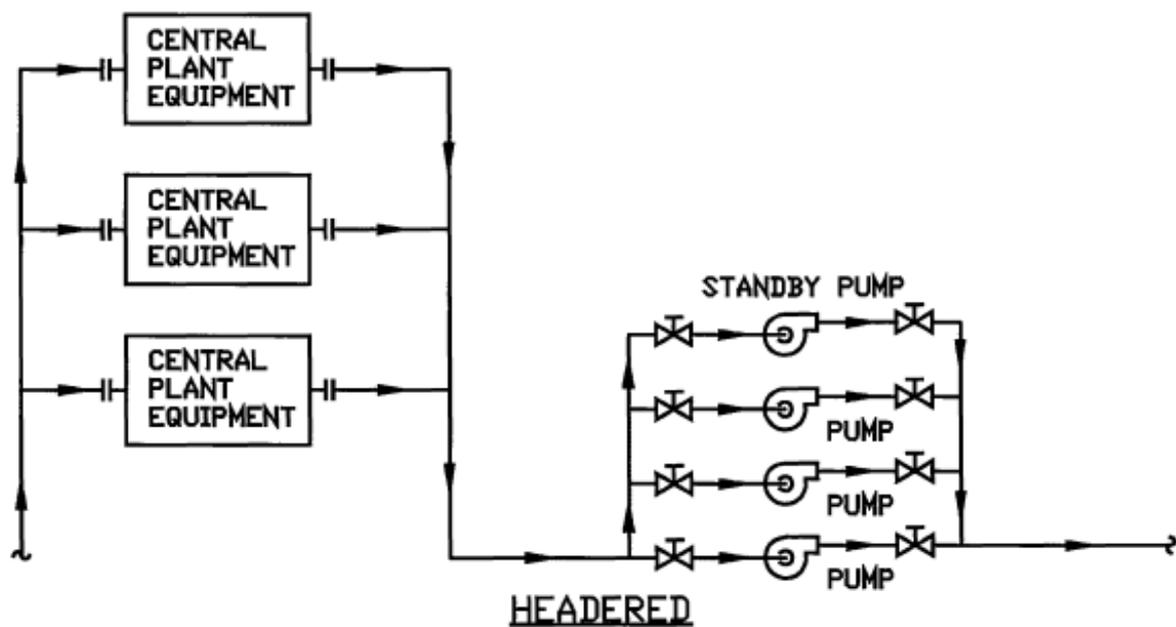
NOTE: STANDBY PUMP MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

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Figure 19.23. STANDBY PUMPS.



NOTE: STANDBY PUMP MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.



NOTE: STANDBY PUMP MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

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Figure 19.24. STANDBY PUMPS.

2. Coupled system:
 - a. A coupled system should only be used when all the equipment in the system is the same capacity (chillers, boilers, cooling towers, and associated pumps).
3. Headered system:

- a. A headered system is preferred especially when chillers, cooling towers, boilers, and associated pumps are of unequal capacity. Although, the system is easier to design and operate if the equipment is of equal capacity.
- b. When designing a headered system, Griswold valves (flow control devices) must be installed in the supply piping to each piece of equipment to obtain the proper flow through that piece of equipment. In addition to Griswold valves, control valves must be installed to isolate equipment not in service if the system is to be fully automatic. These control valves should be provided with a manual means of opening and closing in case of control system malfunction or failure.
- c. Provide adequate provisions for the expansion and contraction of piping in the boiler, chiller, cooling tower, and pump-headered systems. Provide U-shaped header connections for all equipment to accommodate expansion and contraction (first route piping away from the header, then route parallel to the header, and finally route back toward the header; the size of the U-shape will depend on the temperature of the system).

D. The minimum recommended hydronic system pipe size should be 3/4 inch.

E. In general, noise generation in hydronic systems indicates erosion is occurring.

F. Large System Diversities

1. Campus heating: 80 percent.
2. Campus cooling: 65 percent.
3. Constant flow: Load is diversified only; flow is not diversified, resulting in temperature changes.
4. Variable flow: Load and flow are both diversified.

G. When designing a campus or district type heating or cooling system, the controls at the interface between the central system and the building system should be secured so that access is limited to the personnel responsible for operating the central plant and not accessible to the building operators. Building operators may not fully understand the central plant operation and may unknowingly disrupt the central plant operation with system interface tinkering.

H. Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or at the end of each of the subsystems regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.

I. Central plant equipment (chillers, boilers, cooling towers, and associated pumps) should be of equal size units; however, the system design may include 1/2-sized units or 1/3-sized units with full-sized equipment. For example, a chiller system may be made up of 1,200-ton, 600-ton, and 400-ton chillers. However, 1/3-sized units have limited application. This permits providing multiple units to achieve the capacity of a single unit and having two or three pumps operate to replace the one larger pump.

J. Pump Discharge Check Valves

1. Pump discharge check valves should be center-guided, spring-loaded, disc-type check valves.
2. Pump discharge check valves should be sized so that the check valve is full open at the design flow rate. Generally, this will require the check valve to be one pipe size smaller than the connecting piping.
3. Condenser water system and other open piping system check valves should have globe style bodies to prevent flow reversal and slamming.
4. Installing check valves with 4 to 5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.

K. Install air vents at all high points in water systems. Install drains at all low points in water systems. All automatic air vents, manual air vents, and drains in hydronic systems should be piped to a safe location within 6 inches of the floor, preferably over a floor drain, especially with heating water systems.

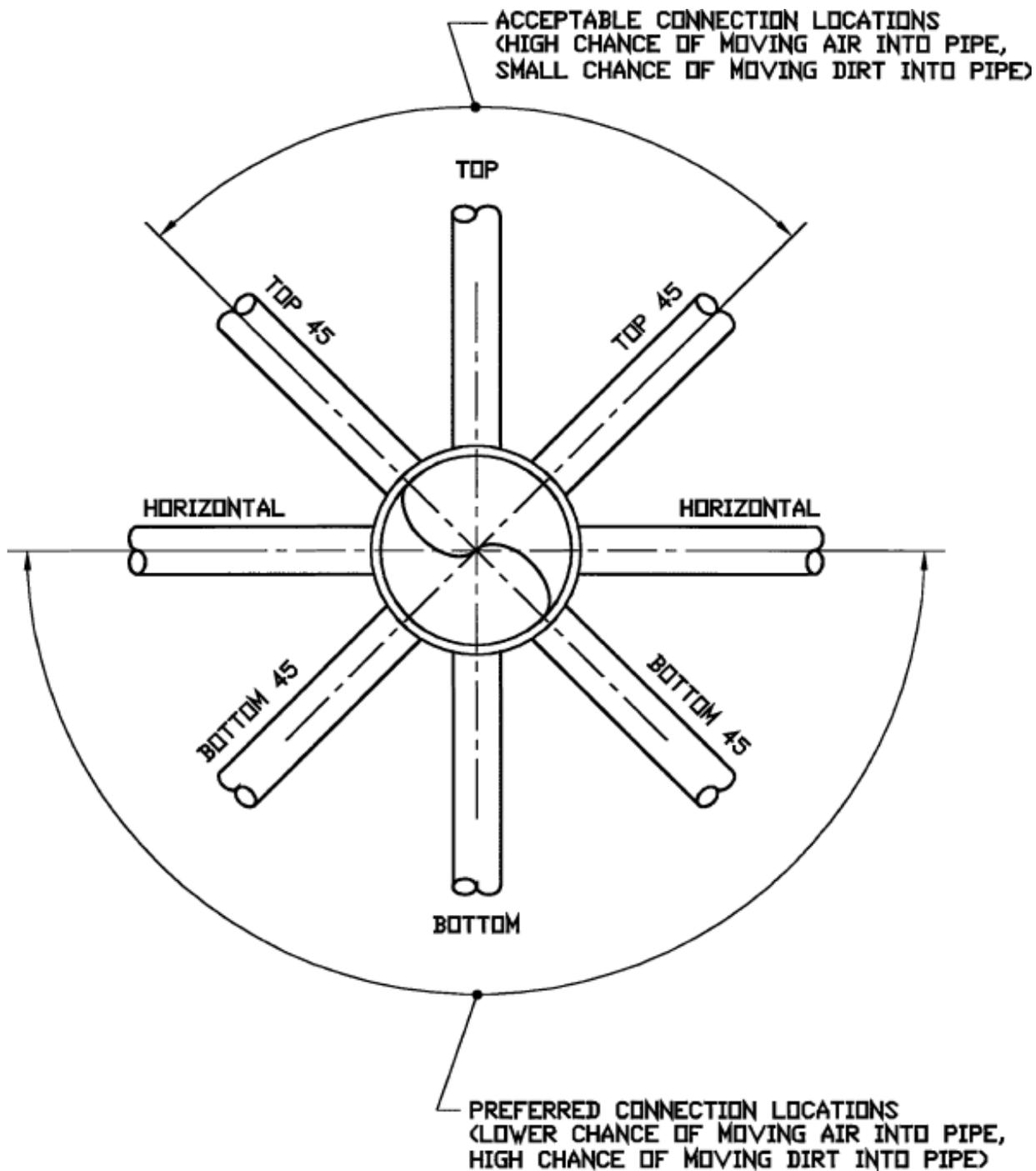
L. Thermometers should be installed in both the supply and return piping to all water coils, chillers, boilers, heat exchangers, and other similar equipment. Thermometers should also be installed at each location where major return streams mix at a location approximately 10 pipe diameters downstream of the mixing point. Placing thermometers

upstream of this point is not required, but often desirable, because the other return thermometers located upstream will provide the water temperatures coming into this junction point. Placing thermometers in these locations will provide assistance in troubleshooting system problems. Liquid-filled-type thermometers are more accurate than the dial-type thermometers.

M. Select water coils with tube velocities high enough at design flow so that tube velocities do not end up in the laminar flow region when the flow is reduced in response to low load conditions. Tube velocities become critical with units designed for 100 percent outside air at low loads near 32°F. Higher tube velocity selection results in a higher water pressure drop for the water coil. Sometimes a trade-off between pressure drop and low load flows must be evaluated.

N. Install the manual air vent and drain on a coupon rack to relieve pressure from the coupon rack to facilitate removing coupons. Pipe drain to the floor drain.

O. Make piping connections to mains and branches from piping using the following guidelines (see Fig. 19.25):



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Figure 19.25. HYDRONIC PIPING CONNECTIONS.

1. Top of piping: To prevent dirt from entering the main or branch piping.
2. Bottom or side of piping: To prevent air from entering the main or branch piping.

P. Do not use bull head tees (see Fig. 19.26).

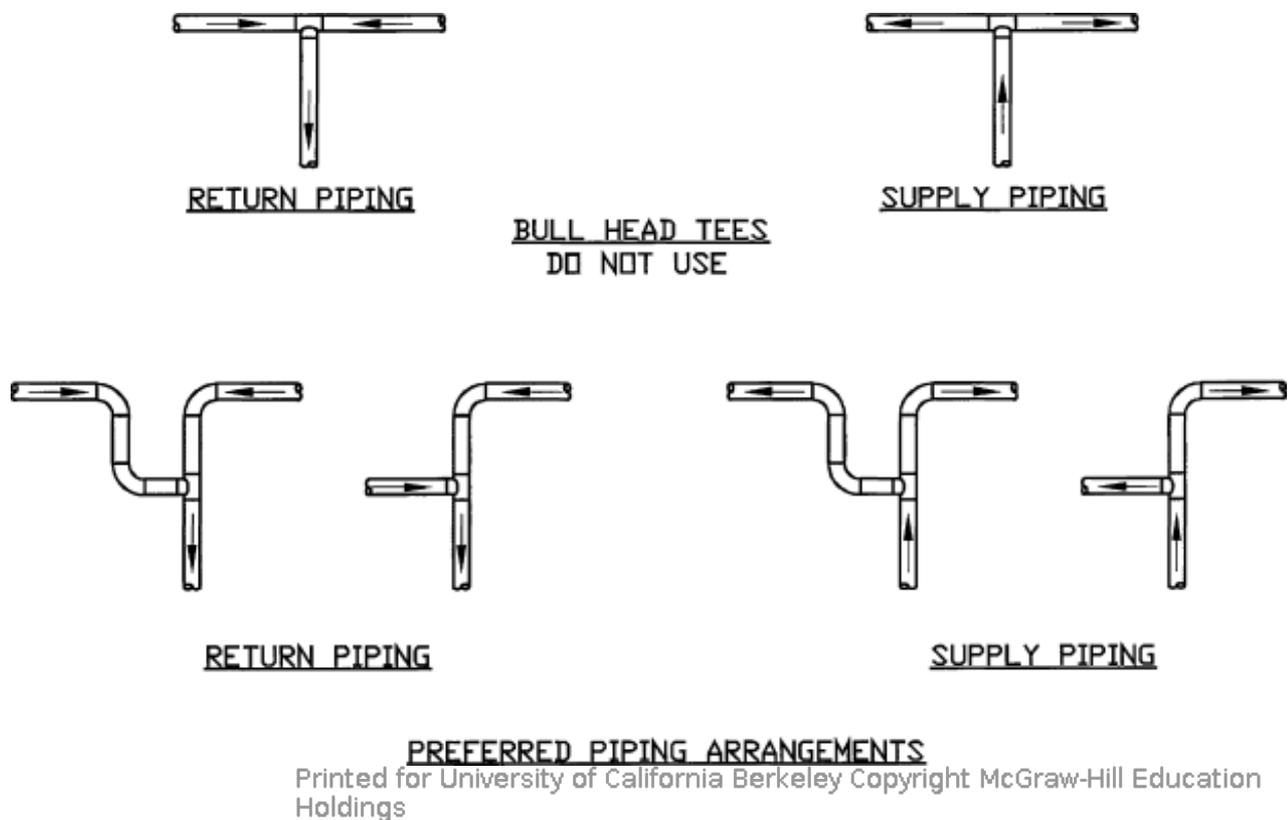


Figure 19.26. PIPING DESIGN—BULL HEAD TEES.

Q. Install the manual air vent on a chemical feed tank and also pipe drain to the floor drain.

R. Provide water meters on all makeup water and all blowdown water connections to hydronic systems (heating water, chilled water, condenser water, and steam systems). System water usage is critical in operating the systems, maintaining chemical levels, and troubleshooting the systems. If the project budget permits, these meter readings should be logged and recorded at the building facilities management and control system.

S. Locate all valves, strainers, unions, and flanges so they are accessible. All valves (except control valves) and strainers should be the full size of the pipe before reducing the size to make connections to the equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 feet or more) to permit disassembly for alteration and repairs.

T. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above the floor level. The chain should extend to 5'0" to 7'0" above the floor level.

U. All balancing valves should be provided with position indicators and maximum adjustable stops (memory stops).

V. All valves should be installed so the valve remains in service when equipment or piping on the equipment side of the valve is removed.

W. Locate all flow measuring devices in accessible locations with a straight section of pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of the device or as recommended by the manufacturer.

X. Provide a bypass around water filters and water softeners. Show water filters and water softener feeding hydronic or steam systems on schematic drawings and plans.

Y. Provide vibration isolators for all piping supports connected to, and within 50 feet of, isolated equipment and throughout mechanical equipment rooms, except at base elbow supports and anchor points.

Z. Do not use malleable iron fittings for glycol systems.

AA. Water in a system should be maintained at a pH of approximately 8 to 9. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline. Closed system water treatment should be 1,600 to 2,000 ppm Borax-Nitrite additive.

BB. Terminal Systems

1. Design for the largest possible system delta T.
2. Better to have terminal coils *slightly* oversized than undersized. Increasing flow rates in terminal coils to twice the design flow rate only increases coil capacity 5 to 16 percent, and tripling the flow rate only increases coil capacity 7 to 22 percent. Grossly oversized terminal unit coils can lead to serious control problems, so care must be taken in properly sizing coils.

CC. Terminal Unit Control Methods

1. Constant supply temperature, variable flow.
2. Variable supply temperature, constant flow.
3. Flow modulation to a minimum value at constant supply temperature. At minimum flow a pump or fan is started to maintain a constant minimum flow at a variable supply temperature.

4. No primary system control, secondary system control is accomplished by blending supply water with return water, or by utilizing face and bypass damper control.

DD. Terminal Unit Design

1. Terminal unit design should be designed for the largest possible system delta T.
2. Terminal unit design should be designed for the closest approach of primary return water temperature and secondary return temperature.
3. Terminals must be selected for full-load and partial-load performance.
4. Select coils with high water velocities at full load, larger pressure drop. This will result in increased performance at partial loads.

EE. Thermal Storage

1. Peak shaving. Constant supply with variable demand.
2. Space heating/cooling. Variable supply with constant-demand waste heat recovery.
3. Variable supply with variable demand.

FF. Provide stop check valves (located closest to the boiler) and isolation valves with a drain between them on both the supply and return connections to all heating water boilers.

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19.07. Chilled Water Systems

- A. **Leaving Water Temperature (LWT): 40-48 °F (60 °F Maximum)**
- B. **ΔT Range 10-20 °F.**
- C. **Chiller Start-up and Shutdown Bypass: When starting a chiller, it takes 5 to 15 minutes from the time the chiller start sequence is initiated until the time the chiller starts to provide chilled water at the design temperature. During this time, the chilled water supply temperature rises above the desired set point. If chilled water temperature is critical and this deviation is unacceptable, the method to correct this problem is to provide the chillers with a bypass that**

runs from the chiller discharge to the primary pump suction header return. The common pipe only needs to be sized for the flow of one chiller because it is unlikely that more than one chiller will be started at the same time. Chiller system operation with a bypass should be as follows:

1. In the chiller start sequence, the primary chilled water pump is started, the bypass valve is opened, and the supply header valve is closed. When the chilled water supply temperature is reached, as sensed in the bypass, the supply header valve is slowly opened. When the supply header valve is fully opened, the bypass valve is slowly closed.
 2. In the chiller stop sequence, the bypass valve is slowly opened. When the bypass valve is fully opened, the supply header valve is slowly closed. When the primary chilled water pump stops, the bypass valve is closed.
- D. Large- and campus-chilled water systems should be designed for large delta Ts and for variable flow secondary and tertiary systems.**
- E. Chilled water pump energy must be accounted for in the chiller capacity because they add heat load to the system (motor out, driven equipment in, see Part 12—Motor Heat Gain).**
- F. Methods of Maintaining Constant Chilled Water Flow**
1. Primary/secondary systems.
 2. Bypassing-control.
 3. Constant volume flow is only applicable to two chillers in series-flow or single chiller applications.
- G. It is best to design chilled water and condenser water systems to pump through the chiller.**
- H. When combining independent chilled water systems into a central plant ...**
1. Create a central system concept, control scheme, and flow schematics.
 2. The system shall only have a single expansion tank connection point sized to handle entire system expansion and contraction.
 3. All systems must be altered, if necessary, to be compatible with the central system concept (temperatures, pressures, flow concepts, variable or constant, control concepts).

4. For constant flow and variable flow systems, the secondary chillers are tied into the main chiller plant return main. Chilled water is pumped from the return main through the chiller and back to the return main.
 5. District chilled water systems, due to their size, extensiveness, or both, may require that independent plants feed into the supply main at different points. If this is required, design and layout must enable isolating the plant; provide start-up and shutdown bypasses; and provide adequate flow, temperature, pressure, and other control parameter readings and indicators for proper plant operation, as well as other design issues that affect plant operation and optimization.
- I. In large systems, it may be beneficial to install a steam-to-water or water-to-water heat exchanger to place an artificial load on the chilled water system to test individual chillers or groups of chillers during plant start-up, after repairs, or for troubleshooting chiller or system problems.**

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19.08. Low-Temperature Chilled Water Systems (Glycol or Ice Water Systems)

- A. Leaving Water Temperature (LWT): 20-40 °F (0 °F Minimum)**
- B. ΔT Range 20-40 °F**
- C. The design of low-temperature chilled-water systems is the same as chilled-water systems.**

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19.09. Heating Water Systems General

- A. From a design and practical standpoint, low-temperature heating water systems are often defined as systems with water temperatures of 210 °F and less, and high-temperature heating water systems are defined as systems with water temperatures of 211 °F and higher.**
- B. Provide a manual vent on top of a heating water boiler to vent air from the top of the boiler during filling and system operation. Pipe the manual vent discharge to the floor drain.**

- C. **Blowdown separators are not required for hot water boilers, but desirable for maintenance purposes. Install the blowdown separator so the inlet to the separator is at or below the boiler drain to enable the use of the blowdown separator during boiler draining for emergency repairs.**
- D. **Safety: High temperature hydronic systems when operated at higher system temperatures and higher system pressures will result in a lower chance of water hammer and the damaging effects of pipe leaks. These high-temperature heating water systems are also safer than lower-temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.**
- E. **Outside air temperature reset of low temperature heating water systems is recommended for energy savings and controllability of terminal units at low load conditions. However, care must be taken with boiler design to prevent thermal shock by low return water temperature or to prevent condensation in the boiler due to low supply water temperature and, therefore, lower combustion stack discharge temperature.**
- F. **Circulating hot water through a boiler that is not operating, in order to keep it hot for standby purposes, creates a natural draft of heated air through the boiler and up the stack, especially in natural draft boilers. Forced draft or induced draft boilers have combustion dampers that close when not firing and therefore reduce, but don't eliminate, this heat loss. Although this heat loss is undesirable for standby boilers, circulating hot water through the boiler is more energy efficient than firing the boiler. Operating a standby boiler may be in violation of air permit regulations in many jurisdictions today.**

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19.10. Low-Temperature Heating Water Systems

- A. **Leaving Water Temperature (LWT): 160-200°F (Recommend 180°F, Range: 140-200°F)**
- B. **ΔT Range 20-40°F**
- C. **Low Temperature Water 250°F and Less; 160 psig Maximum**

D. The system ΔT is generally limited by the boiler and the maximum temperature difference the boiler can withstand without thermal shock. The following are some common boiler types and the maximum recommended system temperature difference (consult the boiler manufacturer).

1. Steel boilers (fire tube, water tube): 40°F.
2. Cast-iron boilers: 40°F.
3. Modular or copper tube boilers: 100°F (some even higher)

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19.11. Medium- and High-Temperature Heating Water Systems

A. Leaving Water Temperature (LWT): 350-450 °F

B. ΔT Range 20-100 °F

C. Medium Temperature Water 251-350 °F, 160 psig Maximum

D. High Temperature Water 351-450 °F, 300 psig Maximum

E. The submergence or antiflash margin is the difference between the actual system operating pressure and the vapor pressure of water at the system operating temperature. However, submergence or antiflash margin is often expressed in degrees Fahrenheit—the difference between the temperature corresponding to the vapor pressure equal to the actual system pressure and the system operating temperature.

F. Provide operators on valves on the discharge of the feedwater pumps for medium- and high-temperature systems to provide positive shutoff because the check valves sometimes leak with the large pressure differential. Interlock the valves to open when the pumps operate. Verify that the valve is open with an end switch or a valve positioner.

G. Provide space and racks for spare nitrogen bottles in mechanically pressurized medium- and high-temperature heating water systems.

H. Medium- and High-Temperature Heating Water System Design Principles

1. System pressure must exceed the vapor pressure at the design temperature in all locations in the system. Verify this pressure requirement at the highest location in the system, at the pump suction, and at the control valve when at minimum flow or part load conditions. The greater the elevation difference, above the pressure source (in most cases, the expansion tank), the higher the selected operating temperature should be in the medium- and high-temperature heating water system.
2. Medium- and high-temperature water systems are unforgiving to system design errors in capacity or flow rates.
3. Conversion factors in standard HVAC equations must be adjusted for specific gravity and specific heat at the design temperatures.
4. Thermal expansion and contraction of piping must be considered and are critical in system design.
5. Medium- and high-temperature heating water systems can be transported over essentially unlimited distances.
6. The greater the system ΔT , the more economical the system becomes.
7. Use medium- and high-temperature heating water systems when required for process applications because it produces precise temperature control and more uniform surface temperatures in heat transfer devices.
8. The net positive suction head requirements of the medium- and high-temperature system pumps are critical and must be checked for adequate pressure. It is best to locate and design the pumps as follows so cavitation does not occur:
 - a. Oversize the pump suction line to reduce resistance.
 - b. Locate the pump at a lower level than the expansion tank to take advantage of the static pressure gain.
 - c. Elevate the expansion tank above the pumps.
 - d. Locate the pumps in the return piping circuit and pump through the boilers, thus reducing the system temperature at the pumps, which reduces the vapor pressure requirements.
9. Either blending fittings or properly designed pipe fittings must be used when blending return water with supply water in large ΔT systems or injecting

medium- and high-temperature primary supply water into low-temperature secondary circuits. When connecting piping to create a blending tee, the hotter water must always flow downward and the colder water must always flow upward. The blending pipe must remain vertical for a short length equal to a few pipe diameters on either side of the tee. Since turbulence is required for mixing action, it is not desirable to have straight piping for any great distance (a minimum of 10 pipe diameters is adequate).

- I. **Above approximately 300°F, the bearings and gland seals of a pump must be cooled. Consult factory representatives for all pumps for systems above 250°F to determine specification requirements. Cooling water leaving the pump cooling jacket should not fall below 100°F. The best method for cooling seals is to provide a separate heat exchanger (one at each pump or one for a group of pumps) and circulate the water through the seal chamber. The heat exchanger should be constructed of stainless steel. Another method to cool the seals is to take a side stream flow off of the pump discharge, cool the flow, and inject it into the end face. This is not recommended because the amount of energy wasted is quite substantial.**
- J. **Medium- and high-temperature heating water systems work well for radiant heating systems.**
- K. **Control valves should be placed in the supply to heat exchangers with a check valve in the return. This practice provides a safety shutoff in case of a major leak in the heat exchanger. By placing the control valve in the supply when a leak occurs, the temperature or pressure increases on the secondary side causing the control valve to close while the check valve prevents back flow or pressure from the return. Flashing may occur with the control valve in the supply when a large pressure differential exists or when the system is operated without an antflash margin. To correct this flashing, control must be split with one control valve in the supply and one control valve in the return.**
- L. **If using medium- or high-temperature heating water systems to produce steam, the steam pressure dictates the delta T and thus the return water temperature.**
- M. **Medium- and High-Temperature Heating Water Systems in Frequent Use**
 1. Cascade systems with integral expansion space:

- a. Type 1. Feedwater pump piped to steam boiler.
 - b. Type 2. Feedwater pump piped to medium- or high-temperature heating water system with steam boiler feedwater provided by medium- and high-temperature heating water system.
2. Flooded generators with external expansion/pressurization provisions.

N. Medium- and High-Temperature Water System Boiler Types

1. Natural circulators, fire tube, and water tube boilers.
2. Controlled (forced) circulation.
3. Combustion (natural and forced), corner tube boilers.

O. Design Requirements

1. Settling chamber to remove any foreign matter, dirt, and debris; oversized header with flanged openings for cleanout.
2. Generator must never be blown down. Blowdown should only be done at the expansion tank or piping system.
3. Boiler safety relief valves should only be tested when water content is cold; otherwise, flashing water-to-steam mixture will erode the valve seat and after opening once or twice the safety relief valves will leak constantly.
4. Boiler safety relief valves must only be considered protection for the boilers. Another safety relief valve must be provided on the expansion tank.
5. Relief valves should be piped to a blowdown tank.

P. Medium- and high-temperature heating water systems may be pressurized by steam systems on the generator discharge or by pump or mechanical means on the suction side of the primary pumps pumping through the boilers.

Q. Steam Pressurized System Characteristics

1. Steam pressurized systems are generally continuously operated with rare shutdowns.
2. A system expansion tank is pressurized with steam and contains a large volume of water at a high temperature, resulting in a considerable ability to absorb load fluctuations.

3. Steam pressurized systems improve the operation of combustion control.
4. A steam pressurized system reduces the need to anticipate load changes.
5. The system is closed and the entry of air or gas is prevented, thus reducing or eliminating corrosion or flow restricting accumulations.
6. Generally, these systems can operate at a lower pressure than pump or mechanically pressurized systems.
7. Steam pressurized systems have a higher first cost.
8. These systems require greater space requirements.
9. The large pressurization tank must be located above and over generators.
10. Pipe discharges into a steam pressurized expansion tank should be vertically upward or should not exceed an angle greater than 45 degrees with respect to the vertical.

R. Mechanically Pressurized System Characteristics

1. Mechanically pressurized systems have flexibility in their expansion tank location.
 2. Mechanically pressurized systems should be designed to pump through the generator. Place the expansion and pressurization means at the pump suction inlet.
 3. Mechanically pressurized systems are best suited for intermittently operated systems.
 4. A submergence or antiflash margin must be provided.
 5. A nitrogen supply must be kept on hand. The system cannot operate without nitrogen.
 6. Mechanically pressurized systems have a lower first cost.
 7. Mechanically pressurized systems require less expansion tank space.
 8. Startup and shutdown of these systems is simplified.
- S. Pumps in medium- and high-temperature heating water systems should be provided with 1/2 to 3/4 inch bypasses around the check valve and shutoff valves on the pump discharge in order to ...**

1. Refill the pump piping after repairs have been made.
2. Allow for opening the system shutoff valve (often the gate valve), which becomes difficult to open against the pressure differentials experienced.
3. Allow for a slow warming of the pump and pump seals, and for letting sealing surfaces seat properly.

T. Double valves should be installed on both the supply and return side of the equipment for isolation on heating water systems above 250°F with a drain between these valves to visually confirm isolation. The double valving of systems ensures isolation because of the large pressure differentials that occur when the system is opened for repairs. Double valve all of the following.

1. Equipment.
2. Drains.
3. Vents.
4. Gauges.
5. Instrumentation.
6. Double drain and vent valve operation: Fully open the valve closest to the system piping first. Then, open the second valve, modulating the second valve to control flow to the desired discharge rate. Close the second valve first when finished draining or venting. Operating in this fashion keeps the valve closest to the system from being eroded and thus allowing the valve to provide tight shutoff when needed. In addition, this operation allows for the replacement of the second valve with the system in operation since this valve receives most of the wear and tear during operation.

U. Do not use screw fittings because high- and medium-temperature water is very penetrating. Use welded or flanged fittings in lieu of screwed fittings. Do not use union joints.

V. Use of dissimilar metals must be avoided. Use only steel pipe, fittings, valves, flanges, and other devices.

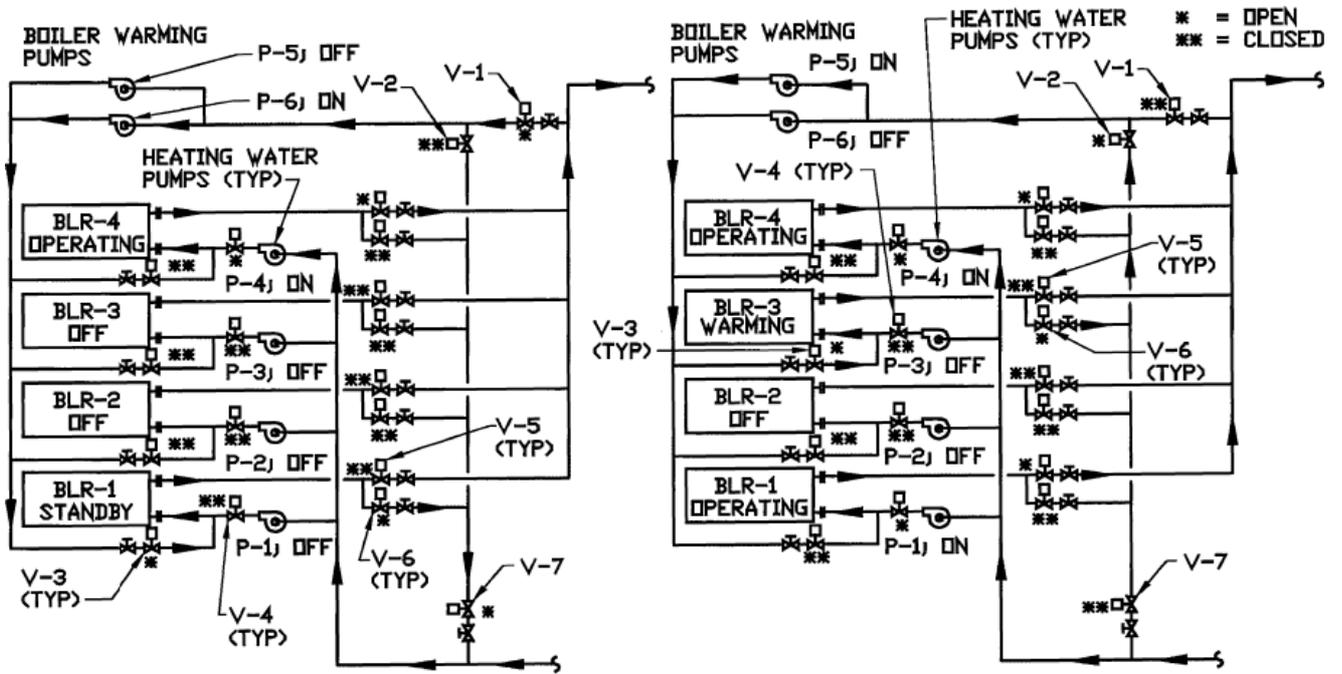
W. Do not use cast-iron or bronze body valves.

X. Use valves with metal-to-metal seats.

Y. Do not use lubricated plug valves.

19.12. Boiler Warming Techniques

- A. To provide fully automatic heating water system controls, the controls must look at and evaluate the boiler metal temperature (water temperature) and the refractory temperature prior to starting the primary pumps or enabling the boiler to fire.**
- B. First, the boiler system design must circulate system water through the boilers to keep the boiler water temperature at system temperature when the boiler is in standby mode, as discussed for boiler warming pump arrangements in the following.**
- C. Second, the design must look at the water temperature prior to starting the primary pumps to verify the boiler is ready for service.**
- D. Third, the design must look at refractory temperature to prevent the boiler from going to high fire if the refractory is not at the appropriate temperature. However, the refractory temperature is usually handled by the boiler control package.**
- E. Boiler warming pumps should be piped to both the system header and the boiler supply piping, thus allowing the boiler to be kept warm (in standby mode) from the system water flow or to warm the boiler when it has been out of service for repairs without the risk of shocking the boiler with system water temperature (see Figs. 19.27 and 19.28).**

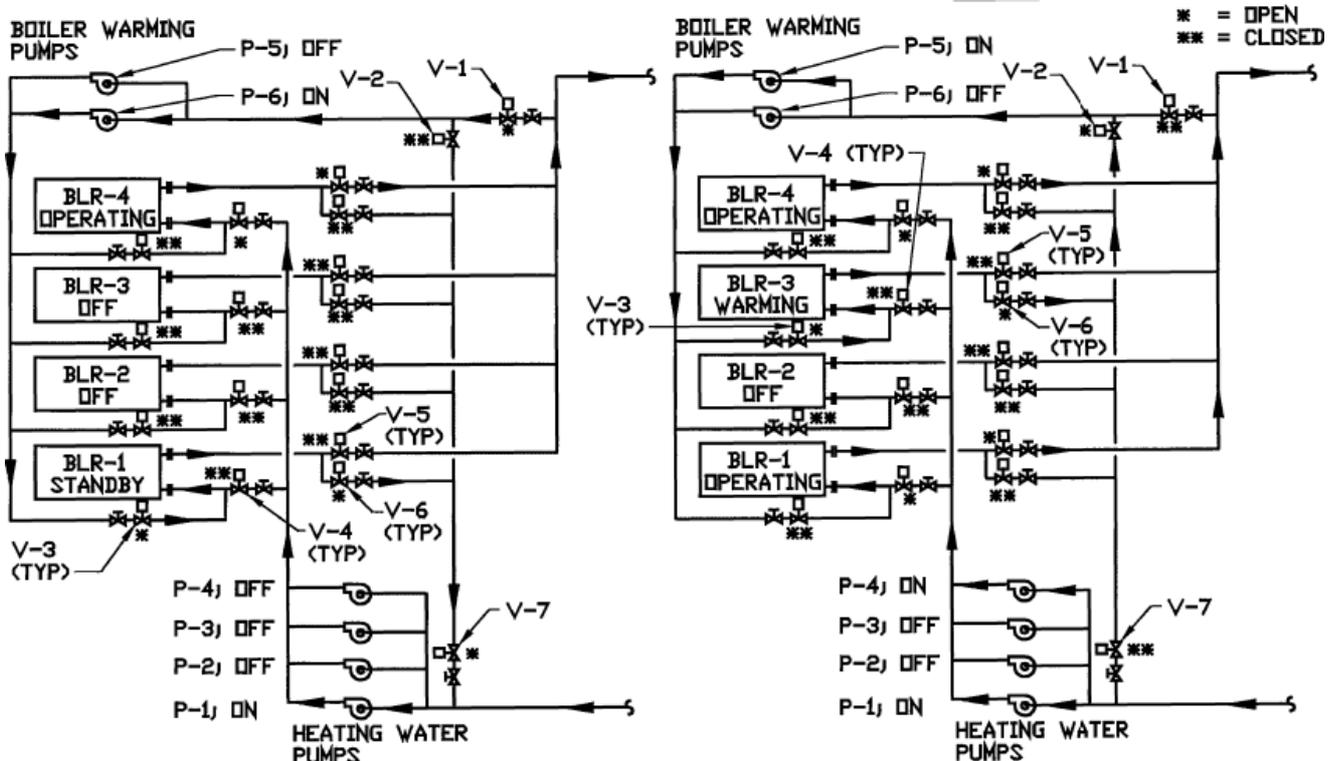


**BOILER STANDBY OPERATION
COUPLED PUMPS**

**BOILER WARMING OPERATION
COUPLED PUMPS**

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Figure 19.27. BOILER STANDBY AND WARMING DIAGRAM—COUPLED PUMPS.



**BOILER STANDBY OPERATION
HEADERED PUMPS**

**BOILER WARMING OPERATION
HEADERED PUMPS**

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Figure 19.28. BOILER STANDBY AND WARMING DIAGRAM—HEADERED PUMPS.

F. Boiler warming pumps should be selected for 0.1 GPM/BHP (range 0.05 to 0.1 GPM/BHP). At 0.1 GPM/BHP, it takes 45 to 75 minutes to completely exchange the water in the boiler. This flow rate is sufficient to offset the heat loss by radiation and stack losses on boilers when in standby mode of operation. In addition, this flow rate allows the system to keep the boiler warm without firing the boiler, thus allowing for more efficient system operation. For example, it takes 8 to 16 hours to bring a boiler online from a cold start. Therefore, the standby boiler must be kept warm to enable immediate startup of the boiler upon failure of an operating boiler.

G. Heating Water System Warm-Up Procedure

1. Heating water system startup should not exceed a 120°F temperature rise per hour, but boiler or heat exchanger manufacturer limitations should be consulted.
2. It is recommended that no more than a 25°F temperature rise per hour be used when warming heating water systems. Slow warming of the heating water system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
3. Low-temperature heating water systems (250°F and less) should be warmed slowly at a 25°F temperature rise per hour until the system design temperature is reached.
4. Medium- and high-temperature heating water systems (above 250°F) should be warmed slowly at a 25°F temperature rise per hour until a 250°F system temperature is reached. At this temperature, the system should be permitted to settle for at least eight hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 350°F or the system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment. When the system reaches 350°F and the design temperature is above 350°F, the system should be allowed to settle for at least eight hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the

system can be warmed up to 455°F or the system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment.

H. Provide heating water systems with warm-up valves for in-service startup as shown in the following table. This will allow operators to warm these systems slowly and prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when they are only opened a small amount in an attempt to control system warm-up speed.

I. Heating Water System Warming Valve Procedure

1. First, open the warming return valve slowly to pressurize the equipment without flow.
2. Once the system pressure has stabilized, slowly open the warming supply valve to establish flow and warm the system.
3. When the system pressure and temperature have stabilized, proceed with the following listed items one at a time:
 - a. Slowly open the main return valve.
 - b. Close the warming return valve.
 - c. Slowly open the main supply valve.
 - d. Close the warming supply valve.

Bypass and Warming Valves

Nominal Pipe Size

Main Valve Nominal Pipe Size

Series A Warming Valves

Series B Bypass Valves

4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
Notes:	3/4	1-1/2
10	1	1-1/2
Series A valve sizes are utilized in steam service for warming up		

Bypass and Warming Valves		
Main Valve Nominal Pipe Size	Series A Warming Valves	Series B Bypass Valves
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

- 1. Series A valve sizes are utilized in steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**
- 2. Series B valve sizes are utilized in pipe lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

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19.13. Dual Temperature Water Systems

- A. Leaving Cooling Water Temperature: 40-48 °F (60 °F Maximum)**
- B. Cooling ΔT Range: 10-20 °F**
- C. Leaving Heating Water Temperature: 160-200 °F (Recommend 180 °F, Range: 140-200 °F)**
- D. ΔT Range: 20-40 °F.**

- E. **Two-pipe switch-over systems provide heating or cooling but not both.**
- F. **Three-pipe systems provide heating and cooling at the same time with a blended return water temperature causing energy waste.**
- G. **Four-Pipe Systems**
 1. Hydraulically joined at the terminal user (most common with fan coil systems with a single coil). Must design the heating and cooling systems with a common and single expansion tank connected at the generating end. At the terminal units, the heating and cooling supplies should be connected and the heating and cooling returns should be connected.
 2. Hydraulically joined at the generator end (most common with condenser water heat recovery systems).
 3. Hydraulically joined at both ends.
- H. **Design of dual temperature water systems is the same as chilled water and heating water systems.**

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19.14. Condenser Water Systems

- A. **Entering Water Temperature (EWT): 85°F**
- B. **ΔT Range: 10-20°F**
- C. **Normal ΔT : 10°F**
- D. **Design of condenser water systems is the same as chilled water systems.**
- E. **When using condenser water systems in a waterside economizer operation to produce chilled water, remember to insulate the condenser water piping with the same insulation thickness as the chilled water system.**

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19.15. Water Source Heat Pump Loop

- A. **Range: 60-90°F**
- B. **ΔT Range: 10-20°F**

19.16. Hydronic System Equation Factors

A. $H = 500 \times \text{GPM} \times \Delta T$

B. Substitute the equation factors in the following table for the number 500 in the previous equation for the design water temperatures indicated. Generally, it is acceptable to use 500 for hydronic systems up to 200°F water.

Water Equation Factors

System Type	System Temperature Range °F	Equation Factor
Low-Temperature (Glycol) Chilled Water	0-40	See Note 2
Chilled Water	40-60	500
Condenser Water Heat Pump Loop	60-110	500
Low-Temperature Heating Water	110-150	490
	151-200	485
	201-250	480
Medium-Temperature Heating Water	251-300	475
	301-350	470
High-Temperature Heating Water	351-400	470
	401-450	470

Notes:

1. **Water equation corrections for temperature, density, and specific heat.**
2. **For glycol system equation factors, see Part 20.**

C. Water Equation Factor Derivations

1. Standard water conditions:
 - a. Temperature: 60°F.

b. Pressure: 14.7 psia (sea level).

c. Density: 62.4 lbs./ft.³

2. Water equation examples:

$$H = m \times c_w \times \Delta T$$

Water @ 250°F

$$\begin{aligned} c_w &= 1.02 \text{ Btu/Lb H}_2\text{O}^\circ\text{F} \times 62.4 \text{ Lbs.H}_2\text{O/ft}^3 \times 1.0 \text{ ft}^3/7.48052 \text{ gal.} \\ &\quad \times 60 \text{ min./h} \times 0.94 \text{ (SG)} \\ &\times 60 \text{ min./h} \times 0.94 \text{ (SG)} \\ &= 480 \text{ Btu min./h }^\circ\text{F gal.} \end{aligned}$$

$$H_{250^\circ\text{F}} = 480 \text{ Btu min./h }^\circ\text{F gal.} \times \text{GPM (gal./min.)} \times \Delta T (^\circ\text{F})$$

$$H_{250^\circ\text{F}} = 480 \times \text{GPM} \times \Delta T (^\circ\text{F})$$

Water @ 450°F

$$\begin{aligned} c_w &= 1.13 \text{ Btu/Lb H}_2\text{O}^\circ\text{F} \times 62.4 \text{ Lbs.H}_2\text{O/ft}^3 \times 1.0 \text{ ft}^3/7.48052 \text{ gal.} \\ &\quad \times 60 \text{ min./h} \times 0.83 \text{ (SG)} \\ &\times 60 \text{ min./h} \times 0.83 \text{ (SG)} \\ &= 470 \text{ Btu min./h }^\circ\text{F gal.} \end{aligned}$$

$$H_{450^\circ\text{F}} = 470 \text{ Btu min./h }^\circ\text{F gal.} \times \text{GPM (gal./min.)} \times \Delta T (^\circ\text{F})$$

$$H_{450^\circ\text{F}} = 470 \times \text{GPM} \times \Delta T (^\circ\text{F})$$

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19.17. Hydronic System Design Temperatures and Pressures

- A. **When designing medium- and high-temperature heating water systems, the appropriate system operating pressure or antiflash margin must be maintained to prevent water from becoming steam and creating water hammer.**
- B. **Antiflash margin is the difference between the actual system operating pressure and the vapor pressure of water at the system operating temperature. However, antiflash margin is often expressed in degrees Fahrenheit—the difference between the temperature corresponding to the vapor pressure equal to the actual system pressure and the system operating temperature.**

Hydronic System Design Temperatures and Pressures

Hydronic System Design Temperatures and Pressures

Water Temperature °F	Vapor Pressure psig	System Operating Pressure Antiflash Margin						
		10°F	20°F	30°F	40°F	50°F	60°F	70°F
200	-3.2	-0.6	2.5	6	10	15	21	27
210	-0.6	2.5	6	10	15	21	27	35
212	0.0	3	7	11	16	22	29	36
215	0.9	4	8	13	18	24	31	39
220	2.5	6	10	15	21	27	35	43
225	4.2	8	13	18	24	30	39	48
230	6.1	10	15	21	27	35	43	52
240	10.3	15	21	27	34	43	52	63
250	15.1	21	27	34	43	52	63	75
260	20.7	27	34	43	52	63	75	88
270	27.2	34	43	52	63	75	88	103
275	30.7	39	47	58	69	81	96	111
280	34.5	43	52	63	75	88	103	120
290	42.8	52	63	75	88	103	120	138
300	52.3	63	75	88	103	120	138	159
310	62.9	75	88	103	120	138	159	181
320	74.9	88	103	120	138	159	181	206
325	81.4	96	111	129	148	170	193	219
330	88.3	103	120	138	159	181	206	232
340	103.2	120	138	159	181	206	232	262
350	119.8	138	159	181	206	232	262	294
360	138.2	159	181	206	232	262	294	329
370	158.5	181	206	232	262	294	329	367
375	169.5	193	219	247	277	311	347	387
380	180.9	206	232	262	294	329	367	407
390	205.5	232	262	294	329	367	407	452
400	232.4	262	294	329	367	407	452	500
410	261.8	294	329	367	407	452	500	551
420	293.8	329	367	407	452	500	551	606
425	310.9	347	387	429	475	524	578	635
Notes:	328.6	367	407	452	500	551	606	665
440	366.5	407	452	500	551	606	665	729
450	407.4	452	500	551	606	665	729	797

1. Safety: High-temperature hydronic systems when operated at

- Notes:** Water Vapor System Operating Pressure Antiflash Margin Temperature Pressure
1. **Safety:** High-temperature hydronic systems when operated at 70°F higher system temperatures and higher system pressures will result in a lower chance of water hammer and the damaging effects of pipe leaks. These high-temperature heating water systems are also safer than lower-temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.
 2. The antiflash margin of 40°F minimum is recommended for nitrogen or mechanically pressurized systems.

19.18. Piping Materials

A. 125 Psi (289 ft.) and Less

1. 2" and smaller:
 - a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B
Fittings: black malleable iron screw fittings, 150 lbs. ANSI/ASME B16.3
Joints: pipe threads, general purpose (American) ANSI/ASME B1.20.1.
 - b. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B
Fittings: cast-iron threaded fittings, 150 lbs. ANSI/ASME B16.4 Joints: pipe threads, general purpose (American) ANSI/ASME B1.20.1.
 - c. Pipe: type "L" copper tubing, ASTM B88, Hard Drawn Fittings: wrought copper solder joint fittings, ANSI/ASME B16.22 Joints: solder joint with 95-5 tin antimony solder, 96-4 tin silver solder, or 94-6 tin silver solder, ASTM B32.
2. 2-1/2" through 10":
 - a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B
Fittings: steel butt-welding fittings ANSI/ASME B16.9
Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.
 - b. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B

Fittings: factory-grooved end fittings equal to Victaulic full-flow. Tees shall be equal to Victaulic Style 20, 25, 27, or 29.

Joints: Mechanical couplings equal to Victaulic couplings Style 75 or 77 with Grade E gaskets, lubricated per the manufacturer's recommendation.

3. 12" and larger:

a. Pipe: black steel pipe, ASTM A53, 3/8" wall, Type E or S, Grade B

Fittings: steel butt-welding fittings ANSI/ASME B16.9

Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

b. Pipe: black steel pipe, ASTM A53, 3/8" wall, Type E or S, Grade B

Fittings: Factory-grooved end fittings equal to Victaulic full-flow. Tees shall be equal to Victaulic Style 20, 25, 27, or 29.

Joints: mechanical couplings equal to Victaulic couplings Style 75 or 77 with Grade E gaskets, lubricated per manufacturer's recommendation.

4. Mechanical joint manufacturers:

a. Victaulic.

b. Anvil Gruvlok.

c. Grinnell.

B. 126-250 Psig (290-578 ft.)

1. 1-1/2" and smaller:

a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B

Fittings: forged steel socket-weld, 300 lbs., ANSI B16.11

Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

b. Pipe: carbon steel pipe, ASTM A106, Schedule 80, Grade B

Fittings: forged steel socket-weld, 300 lbs., ANSI B16.11

Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

2. 2" and larger:

a. Pipe: black steel pipe, ASTM A53, Schedule 40, Type E or S, Grade B

Fittings: steel butt-welding fittings, 300 lbs., ANSI/ASME B16.9

Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

b. Pipe: carbon steel pipe, ASTM A106, Schedule 80, Grade B

Fittings: steel butt-welding fittings, 300 lbs., ANSI/ASME B16.9

Joints: welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec 9.

19.19. Expansion Tanks and Air Separators

A. Minimum (Fill) Pressure

1. Height of system + 5 to 10 psi or 5–10 psi, whichever is greater.

B. Maximum (System) Pressure

1. 150-lbs. systems: 45–125 psi.
2. 250-lbs. systems: 125–225 psi.

C. System Volume Estimate

1. 12 gal./ton.
2. 35 gal./BHP.

D. Connection Location

1. Suction side of pump(s).
2. Suction side of primary pumps when used in primary/secondary/tertiary systems. An alternate location in primary/secondary/tertiary systems with a single secondary circuit may be the suction side of the secondary pumps.

E. Expansion Tank Design Considerations

1. Solubility of air in water. The amount of air that water can absorb and hold in solution is temperature- and pressure-dependent. As temperature increases, maximum solubility decreases, and as pressure increases, maximum solubility increases. Therefore, expansion tanks are generally connected to the suction side of the pump (the lowest pressure point).
2. Expansion tank sizing. If due to space or structural limitations, the expansion tank must be undersized, the minimum expansion tank size should be capable of handling at least 1/2 of the system expansion volume. With less than this capacity, system startup becomes a tedious and extremely sensitive process. If the expansion tank is undersized, an automatic drain should be provided and operated by the control system in addition to the manual drain. Size both the manual and automatic drains to enable a quick dump of a waterlogged tank (especially critical with undersized tanks) within the limits of the nitrogen fill speed and system pressure requirements.
3. System volume changes:
 - a. System startup and shutdown result in the largest change in system volume.

- b. System volume expansion and contraction must be evaluated at full load and partial load. Variations caused by load changes are described in the following:
1. In constant flow systems, heating water return temperatures rise and chilled water temperatures drop as load decreases until at no load the return temperature is equal to the supply temperature. Heating systems expand and cooling systems contract at part load.
 2. In variable flow systems, heating water return temperatures drop and chilled water return temperatures rise as load decreases until at no load the return temperature equals the temperature in the secondary medium. Heating systems contract, and cooling systems expand at part load.
4. Expansion tanks are used to accept system volume changes, and a gas cushion (usually air or nitrogen) pressure is maintained by releasing the gas from the tank and readmitting the gas into the tank as the system water expands and contracts, respectively. Expansion tanks are used where constant pressurization in the system must be maintained.
 5. Cushion tanks are used in conjunction with expansion tanks and are limited in size. As system water expands, pressure increases in the cushion tank until reaching the relief point, at which time it discharges to a lower-pressure expansion tank. As the system water contracts, pressure decreases in the cushion tank until reaching a low limit, at which time the pump starts and pumps the water from the low pressure expansion tank to the cushion tank, thus increasing the pressure. Cushion tank relief and makeup flow rates are based on the initial expansion of a heating system, or the initial contraction of a cooling system during start-up, because this will be the largest change in system volume for either system.
 6. Compression tanks build their own pressure through the thermal expansion of the system contents. Compression tanks are not recommended on medium- or high-temperature heating water systems.
 7. When expansion tank level transmitters are provided for building automation control systems, the expansion tank level should be provided from the level transmitter with local readout at the expansion tank, compression tank, or cushion tank. Also provide a sight glass or some other means of visually verifying the level in the tank and the accuracy of transmitter.

8. When expansion tank pressure transmitters are provided for building automation control systems, the expansion tank pressure should be provided from the pressure transmitter with local readout at the expansion tank, compression tank, or cushion tank. Also provide a pressure gauge at the tank to verify the transmitter.
9. Nitrogen relief from the expansion, cushion, or compression tank must be vented to outside (the noise when discharging is quite deafening). The vent can be tied into the vent off of the blowdown separator. Also need to provide nitrogen pressure monitoring and alarms and manual nitrogen relief valves.
10. Expansion tank sizing can be simplified using the following tables and their respective correction factors. These tables can be especially helpful for preliminary sizing.
 - a. Low-temperature systems. Tables on pages 253 through 256.
 - b. Medium-temperature systems. Tables on pages 257 through 260.
 - c. High-temperature systems. Tables on pages 260 through 264.
11. Figure 19.29 is a photograph of an expansion tank in its installed condition.



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Figure 19.29. PHOTOGRAPH OF AN EXPANSION TANK.

F. Air Separators

1. Air separators shall be full line size.
2. Figure 19.30 is a photograph of an air separator in its installed condition.



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Figure 19.30. PHOTOGRAPH OF AN AIR SEPARATOR.

EXPANSION TANK SIZING—LOW TEMPERATURE SYSTEMS

Tank Size Expressed as a Percentage of System Volume

Maximum System Temperature °F	Expansion Tank Type			
	Closed Tank	Open Tank	Diaphragm Tank	
Tank Volume			Acceptance Volume	
100	2.21	1.37	1.32	0.59
Notes:	3.08	1.87	1.83	0.82

Tank Size Expressed as a Percentage of System Volume				
120	3.71	2.24	2.21	0.99
130	4.81	2.87	2.86	1.28
140	5.67	3.37	3.37	1.51
150	6.77	3.99	4.03	1.80
160	7.87	4.61	4.68	2.10
170	9.20	5.36	5.48	2.45
180	10.53	6.11	6.27	2.81
190	11.87	6.86	7.06	3.16
200	13.20	7.61	7.86	3.52
210	14.77	-	8.79	3.93
220	16.34	-	9.72	4.35
230	17.90	-	10.66	4.77
240	19.71	-	11.73	5.25
250	21.51	-	12.80	5.73

Notes:

- 1. Table based on initial temperature: 50°F.**
- 2. Table based on initial pressure: 10 psig.**
- 3. Table based on maximum operating pressure: 30 psig.**
- 4. For initial and maximum pressures different than those listed above, multiply the tank size only (not the Acceptance Volume) by correction factors contained in the Low Temperature System Correction Factor tables that follow.**

CLOSED EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure	Pressure Increase—psig Initial Pressure + Pressure Increase									
	Maximum Operating Pressure									
psig	5	10	15	20	25	30	35	40	45	

Initial Pressure psig	Pressure Increase - psig				Maximum Operating Pressure	Pressure + Pressure Increase			
	1.75	2.00	2.25	2.50		0.75	0.80	0.85	0.90
5	2.66	1.55	1.18	1.00	0.89	0.82	0.76	0.72	0.69
10	3.73	2.14	1.60	1.34	1.18	1.07	0.99	0.94	0.89
15	4.99	2.81	2.08	1.72	1.50	1.36	1.25	1.17	1.11
20	6.43	3.57	2.62	2.15	1.86	1.67	1.53	1.43	1.35
25	8.05	4.43	3.22	2.62	2.26	2.02	1.84	1.71	1.61
30	9.85	5.37	3.88	3.14	2.69	2.39	2.18	2.02	1.89
35	11.83	6.41	4.60	3.70	3.16	2.80	2.54	2.35	2.20
40	13.99	7.54	5.39	4.31	3.66	3.23	2.93	2.70	2.52
45	16.34	8.75	6.23	4.96	4.21	3.70	3.34	3.07	2.86
50	18.86	10.06	7.13	5.66	4.78	4.20	3.78	3.46	3.22
55	21.57	11.46	8.09	6.41	5.40	4.72	4.24	3.88	3.60
60	24.46	12.95	9.11	7.20	6.05	5.28	4.73	4.32	4.00
65	27.53	14.53	10.20	8.03	6.73	5.87	5.25	4.78	4.42
70	30.77	16.20	11.34	8.91	7.45	6.48	5.79	5.27	4.86
75	34.21	17.96	12.55	9.84	8.21	7.13	6.36	5.78	5.33
80	37.82	19.81	13.81	10.81	9.01	7.81	6.95	6.31	5.81
85	41.61	21.75	15.13	11.83	9.84	8.52	7.57	6.86	6.31
90	45.59	23.79	16.52	12.89	10.71	9.25	8.22	7.44	6.83
95	49.74	25.91	17.97	13.99	11.61	10.02	8.89	8.04	7.37

Notes:

- 1. Table based on initial temperature: 50°F.**
- 2. Table based on initial pressure: 200 psig.**
- 3. Table based on maximum operating pressure: 300 psig.**



**CLOSED EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM
CORRECTION FACTORS**

Initial Pressure + Pressure Increase = Maximum Operating Pressure

Initial Pressure psig	55	60	65	70	75	80	85	90	95	100
5	0.48	0.47	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.43
10	0.65	0.63	0.62	0.61	0.59	0.59	0.58	0.57	0.56	0.56
15	0.83	0.80	0.78	0.77	0.75	0.74	0.73	0.72	0.71	0.70
20	1.03	0.99	0.96	0.94	0.92	0.90	0.89	0.87	0.86	0.85
25	1.24	1.19	1.16	1.13	1.10	1.08	1.06	1.04	1.02	1.00
30	1.47	1.41	1.37	1.33	1.29	1.26	1.24	1.21	1.19	1.17
35	1.71	1.65	1.59	1.54	1.50	1.46	1.43	1.40	1.37	1.35
40	1.98	1.89	1.82	1.77	1.71	1.67	1.63	1.59	1.56	1.53
45	2.26	2.16	2.07	2.00	1.94	1.89	1.84	1.80	1.76	1.73
50	2.55	2.44	2.34	2.26	2.18	2.12	2.06	2.01	1.97	1.93
55	2.86	2.73	2.62	2.52	2.44	2.36	2.30	2.24	2.19	2.14
60	3.19	3.04	2.91	2.80	2.70	2.62	2.54	2.48	2.42	2.36
65	3.54	3.36	3.21	3.09	2.98	2.88	2.80	2.72	2.65	2.59
70	3.90	3.70	3.53	3.39	3.27	3.16	3.06	2.98	2.90	2.83
75	4.27	4.05	3.87	3.71	3.57	3.45	3.34	3.24	3.16	3.08
80	4.67	4.42	4.21	4.04	3.88	3.75	3.63	3.52	3.43	3.34
85	5.08	4.81	4.58	4.38	4.21	4.06	3.92	3.81	3.70	3.61
90	5.51	5.21	4.95	4.73	4.54	4.38	4.23	4.10	3.99	3.88
95	5.95	5.62	5.34	5.10	4.89	4.71	4.55	4.41	4.28	4.17
100	6.41	6.05	5.74	5.48	5.26	5.06	4.88	4.73	4.59	4.46

Notes:

- 1. Table based on initial temperature: 50°F.**
- 2. Table based on initial pressure: 10 psig.**
- 3. Table based on maximum operating pressure: 30 psig.**

**DIAPHRAGM EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM
CORRECTION FACTORS**

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	5	10	15	20	25	30	35	40	45	50
5	2.21	1.33	1.04	0.89	0.80	0.74	0.70	0.67	0.64	0.6
10	2.66	1.55	1.18	1.00	0.89	0.82	0.76	0.72	0.69	0.6
15	3.11	1.78	1.33	1.11	0.98	0.89	0.83	0.78	0.74	0.7
20	3.55	2.00	1.48	1.22	1.07	0.96	0.89	0.84	0.79	0.7
25	4.00	2.22	1.63	1.34	1.16	1.04	0.95	0.89	0.84	0.8
30	4.45	2.45	1.78	1.45	1.25	1.11	1.02	0.95	0.89	0.8
35	4.89	2.67	1.93	1.56	1.34	1.19	1.08	1.00	0.94	0.8
40	5.34	2.89	2.08	1.67	1.43	1.26	1.15	1.06	0.99	0.9
45	5.79	3.12	2.23	1.78	1.52	1.34	1.21	1.12	1.04	0.9
50	6.24	3.34	2.38	1.89	1.61	1.41	1.27	1.17	1.09	1.0
55	6.68	3.57	2.53	2.01	1.69	1.49	1.34	1.23	1.14	1.0
60	7.13	3.79	2.68	2.12	1.78	1.56	1.40	1.28	1.19	1.1
65	7.58	4.01	2.82	2.23	1.87	1.64	1.47	1.34	1.24	1.1
70	8.03	4.24	2.97	2.34	1.96	1.71	1.53	1.39	1.29	1.2
75	8.47	4.46	3.12	2.45	2.05	1.79	1.59	1.45	1.34	1.2
80	8.92	4.68	3.27	2.57	2.14	1.86	1.66	1.51	1.39	1.2
85	9.37	4.91	3.42	2.68	2.23	1.93	1.72	1.56	1.44	1.3
90	9.82	5.13	3.57	2.79	2.32	2.01	1.79	1.62	1.49	1.3
95	10.26	5.36	3.72	2.90	2.41	2.08	1.85	1.67	1.54	1.4
100	10.71	5.58	3.87	3.01	2.50	2.16	1.91	1.73	1.59	1.4

Notes:

1. Table based on initial temperature: 50°F.

2. **Table based on initial pressure: 10 psig.**
Initial Pressure + Pressure Increase = Maximum Operating Pressure

3. **Table based on maximum operating pressure: 30 psig.**



**DIAPHRAGM EXPANSION TANK SIZING LOW TEMPERATURE SYSTEM
CORRECTION FACTORS**

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	55	60	65	70	75	80	85	90	95	100
5	0.61	0.59	0.58	0.57	0.56	0.56	0.55	0.55	0.54	0.54
10	0.65	0.63	0.62	0.61	0.59	0.59	0.58	0.57	0.56	0.56
15	0.69	0.67	0.65	0.64	0.62	0.61	0.60	0.60	0.59	0.58
20	0.73	0.71	0.69	0.67	0.65	0.64	0.63	0.62	0.61	0.60
25	0.77	0.74	0.72	0.70	0.68	0.67	0.66	0.64	0.63	0.63
30	0.81	0.78	0.76	0.73	0.71	0.70	0.68	0.67	0.66	0.65
35	0.85	0.82	0.79	0.77	0.74	0.73	0.71	0.69	0.68	0.67
40	0.89	0.86	0.82	0.80	0.77	0.75	0.74	0.72	0.71	0.69
45	0.93	0.89	0.86	0.83	0.80	0.78	0.76	0.74	0.73	0.71
50	0.97	0.93	0.89	0.86	0.83	0.81	0.79	0.77	0.75	0.74
55	1.01	0.97	0.93	0.89	0.86	0.84	0.81	0.79	0.78	0.76
60	1.06	1.00	0.96	0.92	0.89	0.87	0.84	0.82	0.80	0.78
65	1.10	1.04	1.00	0.96	0.92	0.89	0.87	0.84	0.82	0.80
70	1.14	1.08	1.03	0.99	0.95	0.92	0.89	0.87	0.85	0.83
75	1.18	1.12	1.06	1.02	0.98	0.95	0.92	0.89	0.87	0.85
80	1.22	1.15	1.10	1.05	1.01	0.98	0.95	0.92	0.89	0.87
85	1.26	1.19	1.13	1.08	1.04	1.01	0.97	0.94	0.92	0.89
90	1.30	1.23	1.17	1.12	1.07	1.03	1.00	0.97	0.94	0.92
95	1.34	1.27	1.20	1.15	1.10	1.06	1.02	0.99	0.96	0.94

Tank Size Expressed as a Percentage of System Volume

Expansion Tank Type

Diaphragm Tank

Maximum System Temperature °F	Expansion Tank Type		Diaphragm Tank	
	Closed Tank	Open Tank	Tank Volume	Acceptance Volume
250	263.25	-	18.02	5.73
260	285.30	-	19.53	6.21
270	310.23	-	21.24	6.75
280	335.16	-	22.95	7.29
290	360.08	-	24.65	7.83
300	387.88	-	26.56	8.44
310	415.67	-	28.46	9.04
320	443.47	-	30.36	9.65
330	474.13	-	32.46	10.32
340	504.80	-	34.56	10.98
350	538.33	-	36.86	11.71

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 200 psig.
3. Table based on maximum operating pressure: 300 psig.
4. For initial and maximum pressures different than those listed above, multiply the tank size only (not the Acceptance Volume) by correction factors contained in the Medium Temperature System Correction Factor tables that follow.

CLOSED EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

$$\text{Initial Pressure} + \text{Pressure Increase—psig} = \text{Maximum Operating Pressure}$$

Initial Pressure psig	Pressure Increase—psig									
	10	20	30	40	50	60	70	80	90	100
Pressure psig	= Maximum Operating Pressure									
30	0.36	0.21	0.16	0.14	0.13	0.12	0.11	0.10	0.10	0.10
40	0.52	0.30	0.23	0.19	0.17	0.15	0.14	0.14	0.13	0.13
50	0.72	0.41	0.30	0.25	0.22	0.20	0.18	0.17	0.16	0.16
60	0.94	0.52	0.39	0.32	0.28	0.25	0.23	0.21	0.20	0.19
70	1.19	0.66	0.48	0.39	0.34	0.30	0.28	0.26	0.24	0.23
80	1.47	0.80	0.58	0.47	0.41	0.36	0.33	0.31	0.29	0.28
90	1.78	0.97	0.70	0.56	0.48	0.43	0.39	0.36	0.34	0.33
100	2.12	1.14	0.82	0.66	0.56	0.49	0.45	0.41	0.39	0.38
110	2.49	1.34	0.95	0.76	0.64	0.57	0.51	0.47	0.44	0.43
120	2.88	1.54	1.09	0.87	0.74	0.65	0.58	0.54	0.50	0.49
130	3.31	1.76	1.25	0.99	0.83	0.73	0.66	0.60	0.56	0.55
140	3.77	2.00	1.41	1.11	0.94	0.82	0.73	0.67	0.62	0.61
150	4.26	2.25	1.58	1.25	1.05	0.91	0.82	0.75	0.69	0.68
160	4.78	2.52	1.76	1.39	1.16	1.01	0.90	0.82	0.76	0.75
170	5.32	2.80	1.96	1.54	1.28	1.11	0.99	0.90	0.83	0.82
180	5.90	3.09	2.16	1.69	1.41	1.22	1.09	0.99	0.91	0.89
190	6.50	3.40	2.37	1.85	1.54	1.34	1.19	1.08	0.99	0.97
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	1.06
210	7.81	4.07	2.82	2.20	1.83	1.58	1.40	1.27	1.16	1.14
220	8.50	4.42	3.06	2.39	1.98	1.71	1.51	1.37	1.25	1.23
230	9.22	4.79	3.32	2.58	2.13	1.84	1.63	1.47	1.35	1.33
240	9.98	5.18	3.58	2.78	2.30	1.98	1.75	1.58	1.44	1.42
250	10.76	5.58	3.85	2.98	2.47	2.12	1.87	1.69	1.54	1.52
260	11.57	5.99	4.13	3.20	2.64	2.27	2.00	1.80	1.65	1.63

Notes:

1. Table based on initial temperature: 50°F.

2. Table based on initial pressure: 200 psig
Initial Pressure + Pressure Increase = Maximum Operating Pressure
 3. Table based on maximum operating pressure: 300 psig.



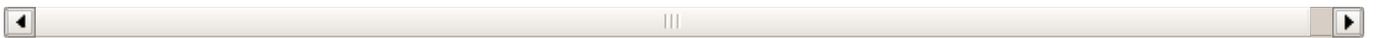
**CLOSED EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM
 CORRECTION FACTORS**

Initial Pressure psig	Pressure Increase—psig									
	Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
30	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08
40	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.10
50	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13
60	0.19	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15
70	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
80	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.21
90	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24
100	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.27
110	0.39	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30
120	0.44	0.42	0.41	0.39	0.38	0.37	0.36	0.35	0.34	0.33
130	0.50	0.47	0.45	0.44	0.42	0.41	0.40	0.39	0.38	0.37
140	0.55	0.52	0.50	0.48	0.47	0.45	0.44	0.43	0.42	0.41
150	0.61	0.58	0.55	0.53	0.51	0.49	0.48	0.47	0.46	0.44
160	0.67	0.63	0.61	0.58	0.56	0.54	0.52	0.51	0.50	0.48
170	0.73	0.69	0.66	0.63	0.61	0.59	0.57	0.55	0.54	0.53
180	0.80	0.76	0.72	0.69	0.66	0.64	0.62	0.60	0.58	0.57
190	0.87	0.82	0.78	0.75	0.72	0.69	0.67	0.65	0.63	0.61
200	0.94	0.89	0.84	0.81	0.77	0.74	0.72	0.70	0.68	0.66
210	1.01	0.96	0.91	0.87	0.83	0.80	0.77	0.75	0.73	0.71
220	1.08	1.03	0.97	0.93	0.89	0.86	0.83	0.81	0.79	0.77

220	1.09	1.03	0.97	0.93	0.89	0.86	0.83	0.80	0.78	0.75
Initial Pressure	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
230	1.17	1.10	1.04	1.00	0.95	0.92	0.88	0.85	0.83	0.81
240	1.26	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
250	1.33	1.26	1.19	1.13	1.08	1.04	1.00	0.97	0.94	0.91
260	1.42	1.34	1.27	1.20	1.15	1.10	1.06	1.03	0.99	0.96

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 200 psig.
3. Table based on maximum operating pressure: 300 psig.



DIAPHRAGM EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	10	20	30	40	50	60	70	80	90	100
30	1.74	1.03	0.79	0.67	0.60	0.55	0.52	0.50	0.48	0.46
40	2.06	1.19	0.90	0.75	0.67	0.61	0.57	0.54	0.51	0.49
50	2.37	1.35	1.00	0.83	0.73	0.66	0.61	0.57	0.55	0.52
60	2.69	1.50	1.11	0.91	0.79	0.71	0.66	0.61	0.58	0.56
70	3.01	1.66	1.21	0.99	0.86	0.77	0.70	0.65	0.62	0.59
80	3.33	1.82	1.32	1.07	0.92	0.82	0.75	0.69	0.65	0.62
90	3.64	1.98	1.43	1.15	0.98	0.87	0.79	0.73	0.69	0.65
100	3.96	2.14	1.53	1.23	1.05	0.93	0.84	0.77	0.72	0.68
110	4.28	2.30	1.64	1.31	1.11	0.98	0.88	0.81	0.76	0.71
120	4.60	2.46	1.74	1.39	1.17	1.03	0.93	0.85	0.79	0.75
130	4.92	2.62	1.85	1.47	1.24	1.08	0.97	0.89	0.83	0.78
140	5.23	2.78	1.96	1.55	1.30	1.14	1.02	0.93	0.86	0.81
150	5.55	2.93	2.06	1.63	1.36	1.19	1.07	0.97	0.90	0.84

Initial Pressure psig	150	160	170	180	190	200	210	220	230	240	250	260
	5.55	5.87	6.19	6.50	6.82	7.14	7.46	7.78	8.09	8.41	8.73	9.05
	2.95	3.09	3.25	3.41	3.57	3.73	3.89	4.05	4.21	4.36	4.52	4.68
	2.00	2.17	2.27	2.38	2.49	2.59	2.70	2.80	2.91	3.02	3.12	3.23
	1.05	1.71	1.79	1.86	1.94	2.02	2.10	2.18	2.26	2.34	2.42	2.50
	1.50	1.43	1.49	1.56	1.62	1.68	1.75	1.81	1.87	1.94	2.00	2.06
	1.19	1.24	1.30	1.35	1.40	1.45	1.51	1.56	1.61	1.67	1.72	1.77
	1.07	1.11	1.16	1.20	1.25	1.29	1.34	1.38	1.43	1.47	1.52	1.56
	0.97	1.01	1.05	1.09	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.41
	0.90	0.93	0.97	1.01	1.04	1.08	1.11	1.15	1.18	1.22	1.25	1.29
	0.84	0.87	0.90	0.94	0.97	1.00	1.03	1.06	1.10	1.13	1.16	1.19

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 200 psig.
3. Table based on maximum operating pressure: 300 psig.



DIAPHRAGM EXPANSION TANK SIZING MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
30	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.40	0.39	0.39
40	0.48	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40
50	0.50	0.49	0.48	0.46	0.45	0.45	0.44	0.43	0.43	0.42
60	0.53	0.52	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.44
70	0.56	0.54	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45
Notes:	0.59	0.57	0.55	0.53	0.52	0.51	0.49	0.48	0.48	0.47

Initial Pressure psig	0.59	0.57	0.55	0.53	0.52	0.51	0.49	0.48	0.48	0.47
	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
90	0.62	0.60	0.57	0.56	0.54	0.53	0.51	0.50	0.49	0.48
100	0.65	0.62	0.60	0.58	0.56	0.55	0.53	0.52	0.51	0.50
110	0.68	0.65	0.62	0.60	0.58	0.57	0.55	0.54	0.53	0.52
120	0.71	0.67	0.65	0.62	0.60	0.59	0.57	0.56	0.54	0.53
130	0.74	0.70	0.67	0.65	0.62	0.61	0.59	0.57	0.56	0.55
140	0.76	0.73	0.70	0.67	0.65	0.63	0.61	0.59	0.58	0.56
150	0.79	0.75	0.72	0.69	0.67	0.64	0.63	0.61	0.59	0.58
160	0.82	0.78	0.74	0.71	0.69	0.66	0.64	0.63	0.61	0.60
170	0.85	0.81	0.77	0.74	0.71	0.68	0.66	0.64	0.63	0.61
180	0.88	0.83	0.79	0.76	0.73	0.70	0.68	0.66	0.64	0.63
190	0.91	0.86	0.82	0.78	0.75	0.72	0.70	0.68	0.66	0.64
200	0.94	0.89	0.84	0.81	0.77	0.74	0.72	0.70	0.68	0.66
210	0.97	0.91	0.87	0.83	0.79	0.76	0.74	0.71	0.69	0.67
220	1.00	0.94	0.89	0.85	0.81	0.78	0.76	0.73	0.71	0.69
230	1.02	0.97	0.92	0.87	0.84	0.80	0.78	0.75	0.73	0.71
240	1.05	0.99	0.94	0.90	0.86	0.82	0.79	0.77	0.74	0.72
250	1.08	1.02	0.96	0.92	0.88	0.84	0.81	0.79	0.76	0.74
260	1.11	1.05	0.99	0.94	0.90	0.86	0.83	0.80	0.78	0.75

Notes:

- 1. Table based on initial temperature: 50°F.**
- 2. Table based on initial pressure: 200 psig.**
- 3. Table based on maximum operating pressure: 300 psig.**



EXPANSION TANK SIZING—HIGH TEMPERATURE SYSTEMS

Tank Sized Expressed as a Percentage of System Volume

Expansion Tank Type

Diaphragm Tank

Maximum System Temperature °F	Expansion Tank Type		Diaphragm Tank	
	Closed Tank	Open Tank	Tank Volume	Acceptance Volume
350	1,995.03	-	47.71	11.71
360	2,119.30	-	50.68	12.44
370	2,243.58	-	53.65	13.17
380	2,378.48	-	56.88	13.96
390	2,524.02	-	60.36	14.82
400	2,669.56	-	63.84	15.67
410	2,815.10	-	67.32	16.53
420	2,981.90	-	71.31	17.51
430	3,138.07	-	75.04	18.42
440	3,315.51	-	79.29	19.46
450	3,492.95	-	83.53	20.51

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 psig.
3. Table based on maximum operating pressure: 800 psig.
4. For initial and maximum pressures different than those listed above, multiply the tank size (the Acceptance Volume) by correction factors contained in the High Temperature System Correction Factor tables that follow.

CLOSED EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS

$$\text{Initial Pressure} + \text{Pressure Increase—psig} = \text{Maximum Operating Pressure}$$

Initial Pressure psig	9.91	5.10	3.49	2.69	2.20	1.88	1.65	1.48	1.35	1.24
Pressure Increase—psig	20	40	60	80	100	120	140	160	180	200
680	10.49	5.39	3.69	2.99	2.50	2.18	1.95	1.78	1.65	1.54
700										

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 psig.
3. Table based on maximum operating pressure: 800 psig.



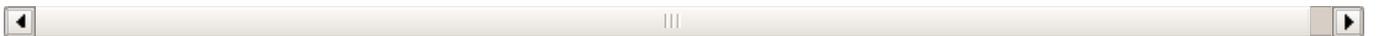
**CLOSED EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM
CORRECTION FACTORS**

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
160	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10
180	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12
200	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13
220	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.15
240	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
260	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.19
280	0.28	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20
300	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22
320	0.34	0.32	0.31	0.29	0.28	0.27	0.27	0.26	0.25	0.25
340	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27
360	0.40	0.38	0.37	0.35	0.34	0.32	0.31	0.31	0.30	0.29
380	0.44	0.42	0.40	0.38	0.37	0.35	0.34	0.33	0.32	0.31
400	0.48	0.45	0.43	0.41	0.39	0.38	0.37	0.36	0.35	0.34
420	0.52	0.49	0.46	0.44	0.43	0.41	0.40	0.38	0.37	0.36
440	0.56	0.53	0.50	0.48	0.46	0.44	0.42	0.41	0.40	0.39
460	0.60	0.57	0.54	0.51	0.49	0.47	0.45	0.44	0.43	0.42

Initial Pressure psig	20	40	60	80	100	120	140	160	180	200
460	0.60	0.56	0.54	0.51	0.49	0.47	0.45	0.44	0.43	0.41
480	0.64	0.60	0.57	0.55	0.52	0.50	0.49	0.47	0.45	0.44
500	0.69	0.66	0.63	0.61	0.58	0.56	0.54	0.53	0.51	0.50
520	0.73	0.69	0.65	0.62	0.59	0.57	0.55	0.53	0.51	0.50
540	0.78	0.73	0.69	0.66	0.63	0.61	0.58	0.56	0.54	0.53
560	0.83	0.78	0.74	0.70	0.67	0.64	0.62	0.60	0.58	0.56
580	0.88	0.83	0.78	0.74	0.71	0.68	0.65	0.63	0.61	0.59
600	0.93	0.87	0.83	0.78	0.75	0.72	0.69	0.66	0.64	0.62
620	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.70	0.68	0.66
640	1.04	0.97	0.92	0.87	0.83	0.80	0.76	0.74	0.71	0.69
660	1.10	1.03	0.97	0.92	0.88	0.84	0.80	0.77	0.75	0.72
680	1.15	1.08	1.02	0.97	0.92	0.88	0.84	0.81	0.78	0.76
700	1.21	1.14	1.07	1.01	0.87	0.92	0.89	0.85	0.82	0.80

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 psig.
3. Table based on maximum operating pressure: 800 psig.



DIAPHRAGM EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	20	40	60	80	100	120	140	160	180	200
160	2.39	1.32	0.96	0.78	0.67	0.60	0.55	0.51	0.48	0.46
180	2.64	1.44	1.04	0.84	0.72	0.64	0.59	0.54	0.51	0.48
200	2.88	1.56	1.12	0.90	0.77	0.68	0.62	0.57	0.54	0.51
220	3.13	1.69	1.21	0.97	0.82	0.73	0.66	0.61	0.57	0.53
240	3.37	1.81	1.30	1.03	0.87	0.77	0.69	0.64	0.59	0.56

Initial Pressure	Pressure Increase	Initial Pressure + Pressure Increase	Initial Pressure - Pressure Increase	Maximum Operating Pressure	Initial Pressure + Pressure Increase	Initial Pressure - Pressure Increase	Initial Pressure + Pressure Increase	Initial Pressure - Pressure Increase	Initial Pressure + Pressure Increase	Initial Pressure - Pressure Increase
240	3.57	1.81	1.29	1.05	0.87	0.77	0.69	0.64	0.59	0.56
260	3.62	1.93	1.37	1.09	0.87	0.81	0.73	0.67	0.62	0.58
280	3.86	2.05	1.45	1.15	0.90	0.85	0.76	0.70	0.65	0.60
300	4.11	2.18	1.53	1.21	1.02	0.89	0.80	0.73	0.67	0.63
320	4.35	2.30	1.61	1.27	1.07	0.93	0.83	0.76	0.70	0.66
340	4.60	2.42	1.70	1.33	1.12	0.97	0.87	0.79	0.73	0.68
360	4.84	2.55	1.78	1.40	1.17	1.01	0.90	0.82	0.76	0.71
380	5.09	2.67	1.86	1.46	1.21	1.05	0.94	0.85	0.78	0.73
400	5.34	2.79	1.94	1.52	1.26	1.09	0.97	0.88	0.81	0.75
420	5.58	2.91	2.02	1.58	1.31	1.13	1.01	0.91	0.84	0.78
440	5.83	3.04	2.11	1.64	1.36	1.18	1.04	0.94	0.87	0.80
460	6.07	3.16	2.19	1.70	1.41	1.22	1.08	0.97	0.89	0.83
480	6.32	3.28	2.27	1.76	1.46	1.26	1.11	1.00	0.92	0.85
500	6.56	3.40	2.35	1.82	1.51	1.30	1.15	1.04	0.95	0.88
520	6.81	3.53	2.43	1.89	1.56	1.34	1.18	1.07	0.97	0.90
540	7.05	3.65	2.52	1.95	1.61	1.38	1.22	1.10	1.00	0.93
560	7.30	3.77	2.60	2.01	1.66	1.42	1.25	1.13	1.03	0.95
580	7.55	3.90	2.68	2.07	1.71	1.46	1.29	1.16	1.06	0.98
600	7.79	4.02	2.76	2.13	1.75	1.50	1.32	1.19	1.08	1.00
620	8.04	4.14	2.84	2.19	1.80	1.54	1.36	1.22	1.11	1.02
640	8.28	4.26	2.92	2.25	1.85	1.58	1.39	1.25	1.14	1.05
660	8.53	4.39	3.01	2.32	1.90	1.63	1.43	1.28	1.17	1.07
680	8.77	4.51	3.09	2.38	1.95	1.67	1.46	1.31	1.19	1.10
700	9.02	4.63	3.17	2.44	2.00	1.71	1.50	1.34	1.22	1.12

Notes:

- 1. Table based on initial temperature: 50°F.**
- 2. Table based on initial pressure: 600 psig.**
- 3. Table based on maximum operating pressure: 800 psig.**

Initial Pressure Increase—psig Initial Pressure + Pressure Increase

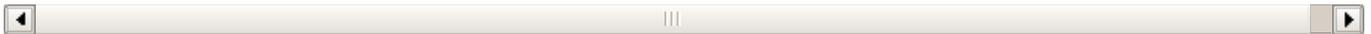
**DIAPHRAGM EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM
CORRECTION FACTORS**

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
160	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.35
180	0.46	0.44	0.43	0.42	0.40	0.39	0.39	0.38	0.37	0.36
200	0.49	0.47	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.38
220	0.51	0.49	0.47	0.45	0.44	0.43	0.41	0.41	0.40	0.39
240	0.53	0.51	0.49	0.47	0.45	0.44	0.43	0.42	0.41	0.40
260	0.55	0.53	0.50	0.49	0.47	0.46	0.44	0.43	0.42	0.41
280	0.57	0.55	0.52	0.50	0.49	0.47	0.46	0.45	0.44	0.43
300	0.60	0.57	0.54	0.52	0.50	0.49	0.47	0.46	0.45	0.44
320	0.62	0.59	0.56	0.54	0.52	0.50	0.49	0.47	0.46	0.45
340	0.64	0.61	0.58	0.56	0.54	0.52	0.50	0.49	0.47	0.46
360	0.66	0.63	0.60	0.57	0.55	0.53	0.52	0.50	0.49	0.48
380	0.69	0.65	0.62	0.59	0.57	0.55	0.53	0.51	0.50	0.49
400	0.71	0.67	0.64	0.61	0.58	0.56	0.54	0.53	0.51	0.50
420	0.73	0.69	0.66	0.63	0.60	0.58	0.56	0.54	0.53	0.51
440	0.75	0.71	0.67	0.64	0.62	0.59	0.57	0.56	0.54	0.52
460	0.78	0.73	0.69	0.66	0.63	0.61	0.59	0.57	0.55	0.54
480	0.80	0.75	0.71	0.68	0.65	0.63	0.60	0.58	0.57	0.55
500	0.82	0.77	0.73	0.70	0.67	0.64	0.62	0.60	0.58	0.56
520	0.84	0.79	0.75	0.71	0.68	0.66	0.63	0.61	0.59	0.57
540	0.86	0.81	0.77	0.73	0.70	0.67	0.65	0.62	0.60	0.59
560	0.89	0.83	0.79	0.75	0.72	0.69	0.66	0.64	0.62	0.60

Initial Pressure (psig)	0.91	0.85	0.81	0.77	0.73	0.70	0.67	0.65	0.63	0.61
580	0.93	0.87	0.73	0.78	0.75	0.72	0.69	0.66	0.64	0.62
600	0.95	0.89	0.84	0.80	0.78	0.75	0.70	0.68	0.66	0.64
620	0.97	0.91	0.86	0.82	0.79	0.76	0.72	0.69	0.67	0.65
640	0.98	0.92	0.86	0.82	0.78	0.75	0.72	0.69	0.67	0.65
660	1.00	0.94	0.88	0.84	0.80	0.76	0.73	0.71	0.68	0.66
680	1.02	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.69	0.67
700	1.04	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.71	0.68

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 psig.
3. Table based on maximum operating pressure: 800 psig.



Citation

EXPORT
 Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 19: Hydronic (Water) Piping Systems, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 20: Glycol Piping Systems

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20.01. Glycol System Piping

- A. **Glycol piping is a special type of hydronic piping.**
- B. **Design and sizing of glycol piping systems are identical to chilled water or heating water piping systems, except that the flows are increased to account for the differences in the thermal properties of glycol versus water.**

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20.02. Glycol System Design Considerations

- A. **HVAC system glycol applications should use an industrial-grade ethylene glycol (phosphate-based) or propylene glycol (phosphate-based) with corrosion inhibitors without fouling. Specify glycol to have *zero* silicate content.**
- B. **Automobile antifreeze solutions should *not* be used for HVAC systems because they contain silicates to protect aluminum engine parts. These silicates can cause fouling in HVAC systems.**
- C. **Consider having the antifreeze dyed to facilitate leak detection.**
- D. **Glycol systems should be filled with a high-quality water, preferably distilled or deionized (deionized is recommended) water, or filled with prediluted solutions of industrial-grade glycol. Water should have less**

than 25 ppm of chloride and sulfate, and less than 50 ppm of hard-water ions (Ca⁺⁺, Mg⁺⁺). City water is treated with chlorine, which is corrosive.

- E. **Automatic makeup water systems should be avoided to prevent system contamination or system dilution. A low-level liquid alarm should be used in lieu of an automatic fill line.**
- F. **Systems should be clean with little or no corrosion.**
- G. **Industrial-grade glycol will last up to 20 years in a system if properly maintained.**
- H. **Propylene glycol should be used where low oral toxicity is important or where incidental contact with drinking water is possible.**
- I. **Expansion tank sizing is critical to the design of glycol systems. The design should allow for a glycol level of about two-thirds full during operation. Glycol will expand about 6 percent.**
- J. **Water quality should be analyzed at each site for careful evaluation of the level of corrosion protection required.**
- K. **Foaming of a glycol system is usually caused by air entrainment, improper expansion tank design, contamination by organics (oil, gas) or solids, or improper system operation. Foaming will reduce heat transfer and aggravate cavitation corrosion.**
- L. **A buffering agent should be added to maintain fluid alkalinity, minimize acidic corrosive attack, and counteract fluid degradation. Proper buffering agents will reduce fluid maintenance, extend fluid life, and be less sensitive to contamination.**
- M. **A nonabsorbent bypass filter, of the sock or cartridge variety, should be installed in each glycol system.**
- N. **An annual chemical analysis should be conducted to determine the glycol content, oxidative degradation, foaming agent concentration, inhibitor concentration, buffer concentration, freezing point, and pH, reserve alkalinity.**

Ethylene Glycol Characteristics	Propylene Glycol Characteristics
More effective freeze point depression	Less effective freeze point depression
Better heat transfer efficiency	Lower heat transfer efficiency
Lower viscosity	Higher viscosity
Low flammability	Low flammability
Low chemical oxygen demand (more friendly to the environment)	High chemical oxygen demand (less friendly to the environment)
Biodegrades in a reasonable period of time—10–20 days completely	Greater resistance to complete biodegradation—more than 20 days
Noncarcinogenic	Noncarcinogenic
Higher level of acute (short-term) and chronic (long-term) toxicity to humans and animals when taken orally—targets the kidney	Lower level of acute (short-term) and chronic (long-term) toxicity to humans and animals when taken orally
Mild eye irritant	Mild eye irritant
Less irritating to the skin	More irritating to the skin
No adverse reproductive effects in lifetime or three-generation studies	No adverse reproductive effects in lifetime or three-generation studies
At high concentrations during pregnancy will cause birth defects and is toxic to the fetus	At the same concentrations during pregnancy will not cause birth defects
Relatively nontoxic to both sewage microorganisms needed for biodegradation and to aquatic life	Relatively nontoxic to both sewage microorganisms needed for biodegradation and to aquatic life

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20.03. Glycol System Equation Factors and Derivations

A. **$H = 500 \times GPM \times \Delta T$**

B. Substitute the equation factors in the following tables for the number 500 in the preceding equation for the ethylene or propylene glycol indicated.

Ethylene Glycol

% Glycol Solution	Temperature °F		Specific Heat	Specific Gravity (1)	Equation Factor
	Freeze Point	Boiling Point			
0	+32	212	1.00	1.000	500
10	+26	214	0.97	1.012	491
20	+16	216	0.94	1.027	483
30	+4	220	0.89	1.040	463
40	-12	222	0.83	1.055	438
50	-34	225	0.78	1.067	416
60	-60	232	0.73	1.079	394
70	<-60	244	0.69	1.091	376
80	-49	258	0.64	1.101	352
90	-20	287	0.60	1.109	333
100	+10	287+	0.55	1.116	307

Notes:

1. Specific gravity with respect to water at 60 °F.

Propylene Glycol

% Glycol Solution	Temperature °F		Specific Heat	Specific Gravity (1)	Equation Factor
	Freeze Point	Boiling Point			
0	+32	212	1.000	1.000	500
10	+26	212	0.980	1.008	494
20	+19	213	0.960	1.017	488
30	+8	216	0.935	1.026	480
40	-7	219	0.895	1.034	463
50	-28	222	0.850	1.041	442
60	<-60	225	0.805	1.046	421
70	<-60	230	0.750	1.048	393
80	<-60	230+	0.690	1.048	362
90	<-60	230+	0.645	1.045	337
100	<-60	230+	0.570	1.040	296

Notes:

1. Specific gravity with respect to water at 60°F.

A. Glycol Equation Factor Derivations

1. Standard water conditions:

a. Temperature:	60°F.
b. Pressure:	14.7 psia (sea level).
c. Density:	62.4 lbs./ft. ³

2. Water equation examples:

$$H = m \times c_g \times \Delta T.$$

30 percent ethylene glycol.

$$c_g = 0.89 \text{ Btu/Lb-H}_2\text{O [AC1]}^\circ\text{F} \times 62.4 \text{ Lbs-H}_2\text{O/Ft}^3 \times 1.0 \text{ Ft}^3/7.48052 \text{ gal.} \times 60 \text{ min./h} \times 1.040 \text{ (SG)}$$
$$= 463 \text{ Btu min./h }^\circ\text{F gal.}$$

$$H_{30\%EG} = 463 \text{ Btu min./h }^\circ\text{F gal.} \times \text{GPM (gal/min.)} \times \Delta T (^\circ\text{F}).$$

$$H_{30\%EG} = 463 \times \text{GPM} \times \Delta T (^\circ\text{F}).$$

50 percent propylene glycol.

$$c_g = 0.85 \text{ Btu/Lb-H}_2\text{O }^\circ\text{F} \times 62.4 \text{ Lbs-H}_2\text{O/Ft}^3 \times 1.0 \text{ Ft}^3 / 7.48052 \text{ gal.} \times 60 \text{ min./h} \times 1.041 \text{ (SG)}$$
$$= 442 \text{ Btu min./h }^\circ\text{F gal.}$$

$$H_{50\%PG} = 442 \text{ Btu min./h }^\circ\text{F gal.} \times \text{GPM (gal/min.)} \times \Delta T (^\circ\text{F}).$$

$$H_{50\%PG} = 442 \times \text{GPM} \times \Delta T (^\circ\text{F}).$$

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Part 21: Steam Piping Systems

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21.01. Steam Piping Systems

A. Steam Pipe -Sizing

1. Low-pressure steam systems:
 - a. Low-pressure steam: 0–15 psig.
 - b. 0.2–3 psi total system pressure drop max.
 - c. 1/8–1/2 psi/100 ft.
2. Medium-pressure steam systems:
 - a. Medium-pressure steam: 16–100 psig.
 - b. 3–10 psi total system pressure drop max.
 - c. 1/2–2 psi/100 ft.
3. High-pressure steam systems:
 - a. High-pressure steam: 101–300 psig.
 - b. 10–60 psi total system pressure drop max.
 - c. 2–5 psi/100 ft.
4. Steam velocity:
 - a. 15,000 FPM maximum.
 - b. 6,000–12,000 FPM recommended.
 - c. Low pressure systems: 4,000–6,000 FPM.

- d. Medium pressure systems: 6,000–8,000 FPM.
 - e. High pressure systems: 10,000–15,000 FPM.
5. Friction loss estimate:
- a. $2.0 \times \text{System Length (ft.)} \times \text{Friction Rate (ft./100 ft.)}$.
6. Standard steel pipe sizes—1/2", 3/4", 1", 1-1/4", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20", 24", 30", 36", 42", 48", 54", 60", 72", 84", 96".
7. Total pressure drop in the steam system should not exceed 20 percent of the total maximum steam pressure at the boiler.
8. Steam condensate liquid to steam volume ratio is 1:1600 at 0 psig.
9. Flash steam: Flash steam is formed when hot steam condensate under pressure is released to a lower pressure; the temperature drops to the boiling point of the lower pressure, causing some of the condensate to evaporate, forming steam. Flash steam occurs whenever steam condensate experiences a drop in pressure and thus produces steam at the lower pressure.
- a. Low-pressure steam systems flash steam is negligible and can generally be ignored.
 - b. Medium- and high-pressure steam systems flash steam is important to utilize and consider when sizing condensate piping.
- c. Flash steam recovery requirements:
- 1. To utilize flash steam recovery, the condensate must be at a reasonably high pressure (medium- and high-pressure steam systems) and the traps supplying the condensate must be capable of operating with the back pressure of the flash steam system.
 - 2. There must be a use or demand for the flash steam at the reduced pressure. Demand for steam at the lower pressure should be greater than the supply of flash steam. The demand for steam should occur at the same time as the flash steam supply.
 - 3. The steam equipment should be in close proximity to the flash steam source to minimize installation and radiation losses and to fully take advantage of the flash steam recovery system. Flash steam recovery

systems are especially advantageous when steam is utilized at multiple pressures within the facility and the distribution systems are already in place.

10. Saturated steam:

- a. Saturated steam: Saturated steam is steam that is in equilibrium with the liquid at a given pressure. One pound of steam has a volume of 26.8 cu.ft. at atmospheric pressure (0 psig).
- b. Dry saturated steam: Dry steam is steam which has been completely evaporated and contains no liquid water in the form of mist or small droplets. Steam systems that produce a dry steam supply are superior to systems that produce a wet steam supply.
- c. Wet saturated steam: Wet steam is steam that has not been completely evaporated and contains water in the form of mist or small droplets. Wet steam has a heat content substantially lower than dry steam.
- d. Superheated steam: Superheated steam is dry saturated steam that is heated, which increases the temperature without increasing the system pressure.

11. Steam types:

- a. Plant steam: Steam produced in a conventional boiler system using softened and chemically treated water.
- b. Filtered steam: Plant steam that has been filtered to remove solid particles (no chemical removal).
- c. Clean steam: Steam produced in a clean steam generator using distilled, de-ionized, reverse-osmosis, or ultra-pure water.
- d. Pure steam: Steam produced in a clean steam generator using distilled or de-ionized pyrogen-free water, normally defined uncondensed water for injection.

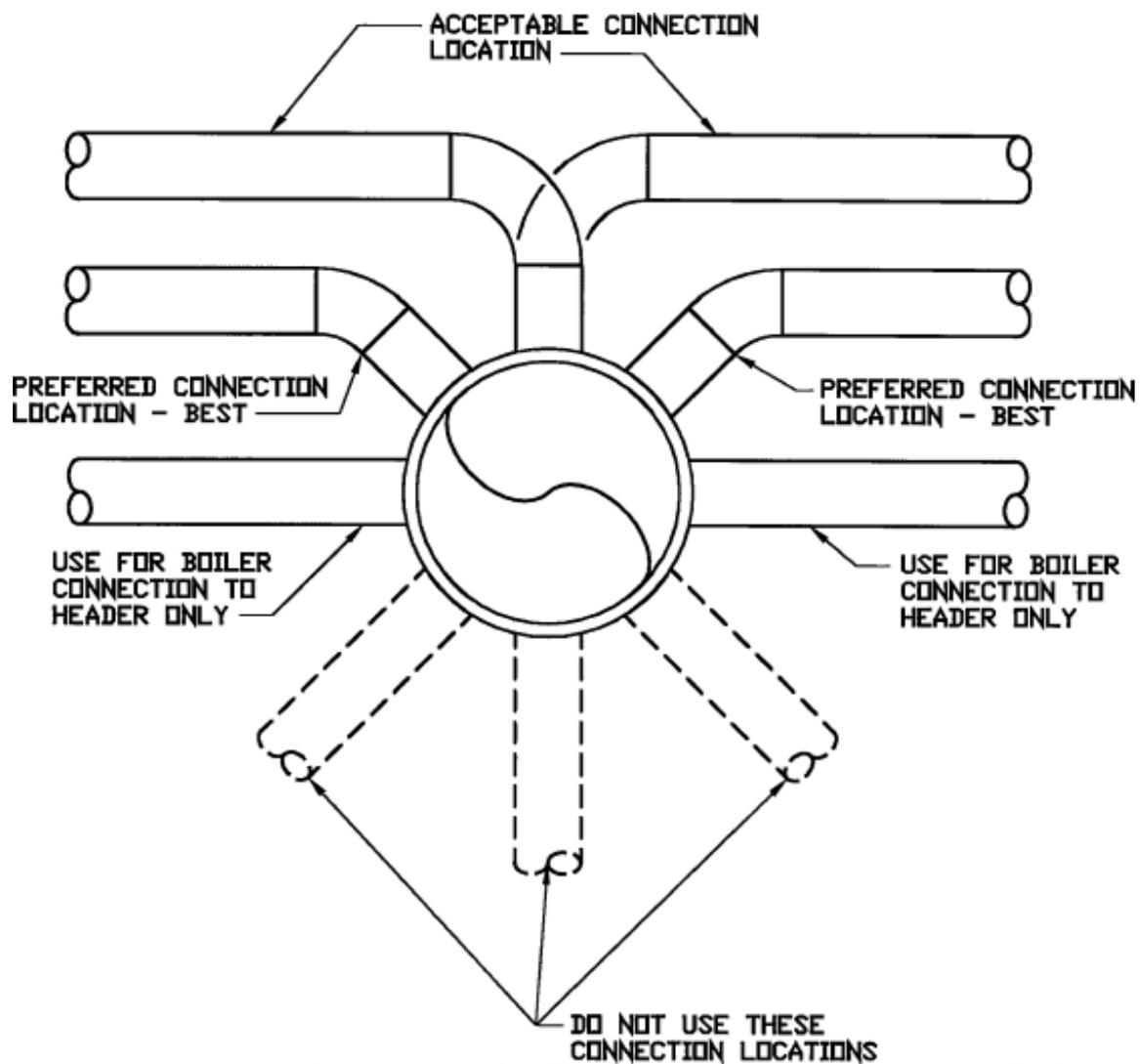
12. Steam purity versus steam quality:

- a. Steam purity: A qualitative measure of steam contamination caused by dissolved solids, volatiles, or particles in vapor, or by tiny water droplets that may remain in the steam following primary separation in the boiler.

- b. Steam quality: The ratio of the weight of dry steam to the weight of dry saturated steam and entrained water [Example: 0.95 quality refers to 95 parts steam (95 percent) and 5 parts water (5 percent)].

B. Steam System Design and Pipe Installation Guidelines

1. The minimum recommended steam pipe size is 3/4 inch.
2. Locate all valves, strainers, unions, and flanges so they are accessible. All valves (except control valves) and strainers should be the full size of the pipe before reducing the size to make connections to equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 feet or more), to permit disassembly for alteration and repairs.
3. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level. The chain should extend to 5'0"-7'0" above the floor level.
4. All valves should be installed so the valve remains in service when equipment or piping on the equipment side of the valve is removed.
5. Locate all flow measuring devices in accessible locations with the straight section of the pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of the device or as recommended by the manufacturer.
6. Provide vibration isolators for all piping supports connected to, and within 50 feet of, isolated equipment, except at base elbow supports and anchor points, throughout mechanical equipment rooms, and for supports of steam mains within 50 feet of boiler or pressure reducing valves.
7. Pitch steam piping downward in the direction of flow 1/4" per 10 ft. (1" per 40 ft.) minimum.
8. Where the length of steam branch lines are less than 8 feet, pitch branch lines downward toward mains 1/2" per foot minimum.
9. Connect all branch lines to the top of steam mains (45 degree preferred, 90 degree acceptable; see [Fig. 21.1](#)).



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Figure 21.1. STEAM PIPING CONNECTIONS

10. Steam piping should be installed with eccentric reducers (flat on the bottom) to prevent accumulation of condensate in the pipe and thus decreasing the risk of water hammer.
11. Drip leg collection points on steam piping should be the same size as the steam piping to prevent steam condensate from passing over the drip leg and thus decreasing the risk of water hammer. The drip leg collection point should be a minimum of 12 inches long including a minimum 6-inch-long dirt leg with the steam trap outlet above the dirt leg.
12. Drip legs must be installed at all low points, downfed runouts to all equipment, end of mains, bottom of risers, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.
13. On straight runs with no natural drainage points, install drip legs at intervals not exceeding 200 feet where the pipe is pitched downward in the direction of steam flow, and a maximum of 100 feet where the pipe is pitched up so

that condensate flow is opposite of steam flow.

14. Steam traps used on steam mains and branches shall be a minimum 3/4" size.
15. Control of steam systems with more than 2 million Btuh should be accomplished with two or more control valves (see steam PRVs).
16. Double valves should be installed on the supply side of equipment for isolating steam systems, above 100 psig, with a drain between these valves to visually confirm isolation. The reason for the double valving of systems is to ensure isolation because of the large pressure differentials that occur when the system is opened for repairs. Double valve all of the following:
 - a. Equipment.
 - b. Drains.
 - c. Vents.
 - d. Gauges.
 - e. Instrumentation.
17. Steam in a steam system should be maintained at a pH of approximately 8 to 9. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline.
18. Provide a stop check valve (located closest to the boiler) and an isolation valve with a drain between these valves on the steam supply connections to all steam boilers.
19. Provide steam systems with warm-up valves for in-service start-up as shown in the following table. This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when they are only opened a small amount in an attempt to control system warm-up speed.

BYPASS AND WARMING VALVES

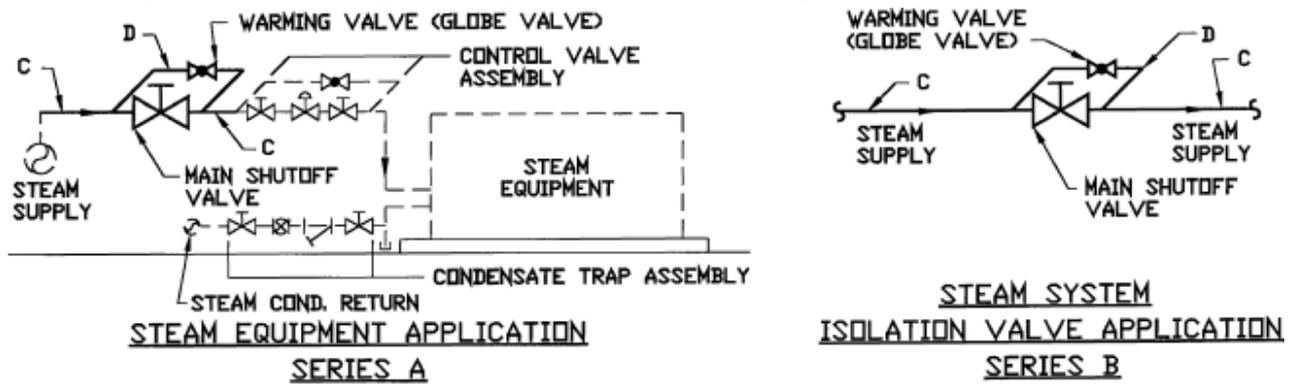
Main Valve Nominal Pipe Size	Nominal Pipe Size	
	Series A Warming Valves	Series B Bypass Valves

4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

- 1. Series A valve sizes are utilized in steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**
- 2. Series B valve sizes are utilized in pipe lines conveying gases or liquids where by-passing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted-on type.**

20. Steam system warming valve procedure (see Fig. 21.2):



NOTES:

1. SERIES A WARMING VALVES COVER STEAM OR MEDIUM/HIGH TEMPERATURE HEATING WATER SERVICE FOR SYSTEM OR EQUIPMENT WARM-UP BEFORE THE MAIN SHUTOFF VALVE TO THE SYSTEM OR DEVICE IS OPENED. WARMING VALVES ARE ALSO USED FOR BALANCING PRESSURES WHERE LINES ARE OF LIMITED VOLUME.
2. SERIES B WARMING VALVES COVER LINES CONVEYING GASES OR LIQUIDS WHERE BYPASSING MAY FACILITATE THE OPERATION OF THE MAIN VALVE BY BALANCING THE PRESSURES ON BOTH SIDES OF THE MAIN VALVE.

MAIN VALVE SIZE (C)	WARMING VALVE SIZE (D)	
	SERIES A WARMING VALVES	SERIES B WARMING VALVES
4"	1/2"	1"
5", 6"	3/4"	1-1/4"
8"	3/4"	1-1/2"
10"	1"	1-1/2"
12", 14"	1"	2"
16", 18", 20"	1"	3"
24", 30"	1"	4"
36", 42"	1"	6"
48", 54"	1"	8"
60", 72"	1"	10"
84", 96"	1"	12"

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Figure 21.2. STEAM SYSTEM WARMING VALVES.

- a. Slowly open the warming supply valve to establish flow and to warm the system.
- b. Once the system pressure and temperature have stabilized, proceed with the following items, one at a time:
 1. Slowly open the main supply valve.
 2. Close the warming supply valve.

21. Steam system warm-up procedure:

- a. Steam system start-up should not exceed 120°F temperature rise per hour, but the boiler or heat exchanger manufacture limitations should be consulted.
- b. It is recommended that no more than a 25°F temperature rise per hour be used when warming steam systems. Slow warming of the steam system allows for system piping, supports, hangers, and anchors to keep up with system expansion.

- c. Low-pressure steam systems (15 psig and less) should be warmed slowly at 25°F temperature rise per hour until system design pressure is reached.
- d. Medium- and high-pressure steam systems (above 15 psig) should be warmed slowly at 25°F temperature rise per hour until 250°F-15 psig system temperature-pressure is reached. At this temperature-pressure, the system should be permitted to settle for at least eight hours or more (preferably overnight). The temperature-pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 120 psig or the system design pressure in 25 psig pressure increments. Allow the system to settle for an hour before increasing the pressure to the next increment. When the system reaches 120 psig and the design pressure is above 120 psig, the system should be allowed to settle for at least eight hours or more (preferably overnight). The pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 300 psig or the system design pressure in 25 psig pressure increments; allow the system to settle for an hour before increasing the pressure to the next increment.

C. Low-Pressure Steam Pipe Materials (0-15 psig):

- 1. 2" and smaller:

a. Pipe:	Black Steel Pipe, <i>ASTM A53, Schedule 40</i> , Type E or S, Grade B
Fittings:	Black Cast Iron Screw Fittings, 125 lb., <i>ANSI/ASME B16.4</i>
Joints:	Pipe Threads, General Purpose (American) <i>ANSI/ASME B1.20.1.</i>

- 2. 2-1/2" through 10":

a. Pipe:	Black Steel Pipe, <i>ASTM A53, Schedule 40, Type E or S, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 125 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

3. 12" and larger:

a. Pipe:	Black Steel Pipe, <i>ASTM A53, 3/8" wall, Type E or S, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 125 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

D. Medium-Pressure Steam Pipe (16-100 psig):

1. 1-1/2" and Smaller:

a. Pipe:	Black Steel Pipe, <i>ASTM A53, Schedule 40, Type E or S, Grade B</i>
Fittings:	Forged Steel Socket-Weld, 150 lb., <i>ANSI B16.11</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>
b. Pipe:	Carbon Steel Pipe, <i>ASTM A106, Schedule 40, Grade B</i>
Fittings:	Forged Steel Socket-Weld, 150 lb., <i>ANSI B16.11</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

2. 2" through 10":

a. Pipe:	Black Steel Pipe, <i>ASTM A53, Schedule 40, Type E or S, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 150 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i>
b. Pipe:	Carbon Steel Pipe, <i>ASTM A106, Schedule 40, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 150 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

3. 12" and larger:

a. Pipe:	Black Steel Pipe, <i>ASTM A53, 3/8" wall, Type E or S, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 150 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>
b. Pipe:	Carbon Steel Pipe, <i>ASTM A106, 3/8" wall, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 150 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

E. High-Pressure Steam Pipe (100-300 psig):

1. 1-1/2" and smaller:

a. Pipe:	Black Steel Pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B</i>
Fittings:	Forged Steel Socket-Weld, 300 lb., <i>ANSI B16.11</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>
b. Pipe: Carbon Steel Pipe, <i>ASTM A106, Schedule 80, Grade B</i>	
Fittings:	Forged Steel Socket-Weld, 300 lb., <i>ANSI B16.11</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

2. 2" and larger:

a. Pipe:	Black Steel Pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 300 lb., <i>ANSI/ASME B16.9</i>
Joints: Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>	
b. Pipe:	Carbon Steel Pipe, <i>ASTM A106, Schedule 80, Grade B</i>
Fittings:	Steel Butt-Welding Fittings, 300 lb., <i>ANSI/ASME B16.9</i>
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

F. Pipe Testing

- 1.5 × System Working Pressure.
- 100 psi minimum.

G. Steam Pressure Reducing Valves (PRV)

- PRV types:

a. Direct acting:

1. Low cost.
2. Limited ability to respond to changing load and pressure.
3. Suitable for systems with low flow requirements.
4. Suitable for systems with constant loads.
5. Limited control of downstream pressure.

b. Pilot-operated:

1. Close control of downstream pressure over a wide range of upstream pressures.
2. Suitable for systems with varying loads.
3. Ability to respond to changing loads and pressures.
4. Types:
 - a. Pressure-operated-pilot.
 - b. Temperature-pressure-operated-pilot.

2. Use multiple stage reduction where greater than 100 psig reduction is required or where greater than 50 psig reduction is required to deliver a pressure less than 25 psig operating pressure or when intermediate steam pressure is required.
3. Use multiple PRVs where system steam capacity exceeds 2" PRV size, when normal operation calls for 10 percent of design load for sustained periods, or when there are two distinct load requirements (i.e., summer/winter). Provide the number of PRVs to suit the project.
 - a. If the system capacity for a single PRV exceeds the 2" PRV size but is not larger than the 4" PRV size, use two PRVs with 1/3 and 2/3 capacity split.
 - b. If system capacity for a single PRV exceeds the 4" PRV size, use three PRVs with 25 percent, 25 percent, and 50 percent, or 15 percent, 35 percent, and 50 percent capacity split to suit the project.
4. The smallest PRV should be no greater than 1/3 of the system capacity. The maximum size PRV should be 4" (6" when 4" PRV will require more than three valves per stage).

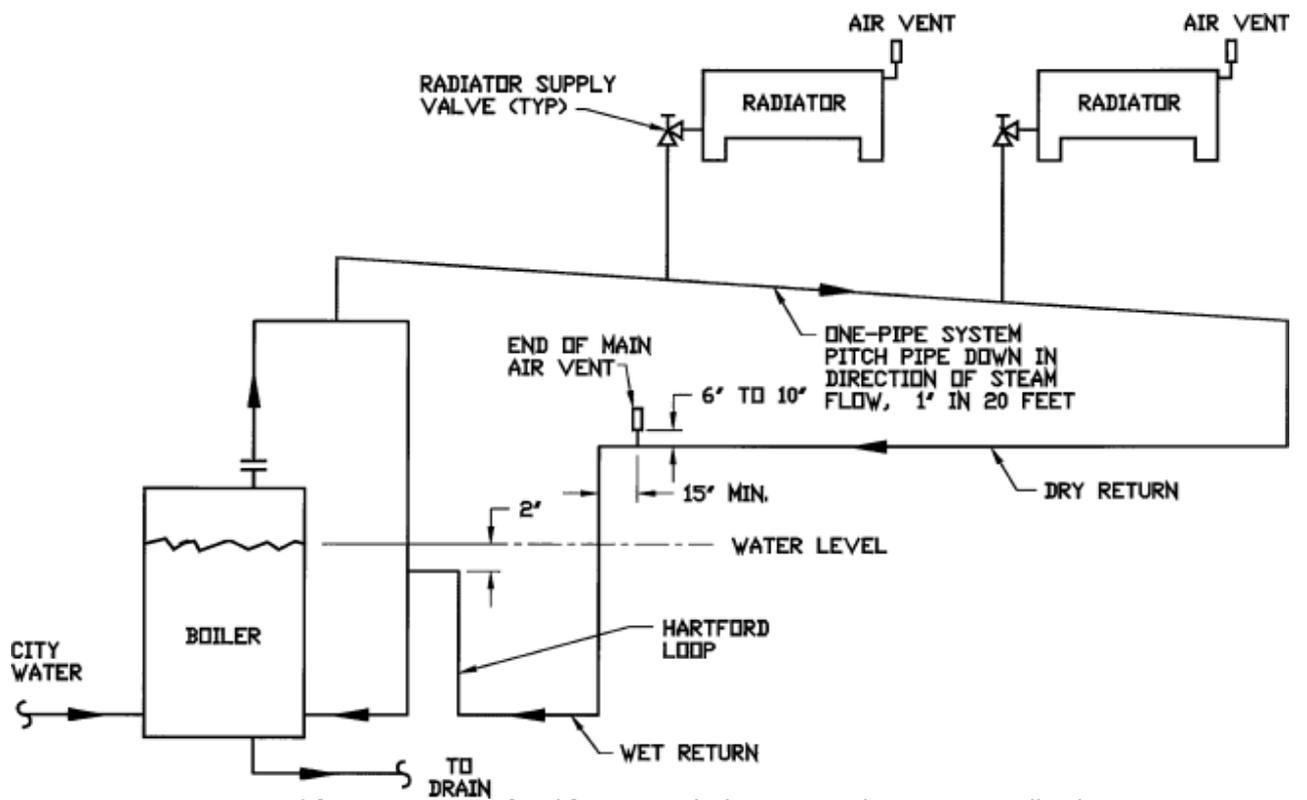
5. The PRV bypass should be two pipe sizes smaller than the largest PRV.
6. Provide 10 pipe diameters from the PRV inlet to the upstream header.
7. Provide 20 pipe diameters from the PRV outlet to the downstream header.
8. Maximum pipe velocity upstream and downstream of PRV:
 - a. 8" and smaller: 10,000 FPM.
 - b. 10" and larger: 8,000 FPM.
 - c. Where low sound levels are required, reduce velocities by 25–50 percent.
 - d. If the outlet velocity exceeds the preceding listings, use a noise suppressor.
9. Avoid abrupt changes in pipe size. Use concentric reducers.
10. Limit pipe diameter changes to two pipe sizes per stage of expansion.

H. **Safety Relief Valves**

1. The safety relief valve must be capable of handling the volume of steam as determined by the high pressure side of the largest PRV, or the bypass, whichever is greater.
2. Use multiple safety relief valves if the capacity of a 4" safety relief valve is exceeded. Each valve must have a separate connection to the pipeline.
3. Safety, relief, and safety relief valve testing is dictated by the insurance underwriter.

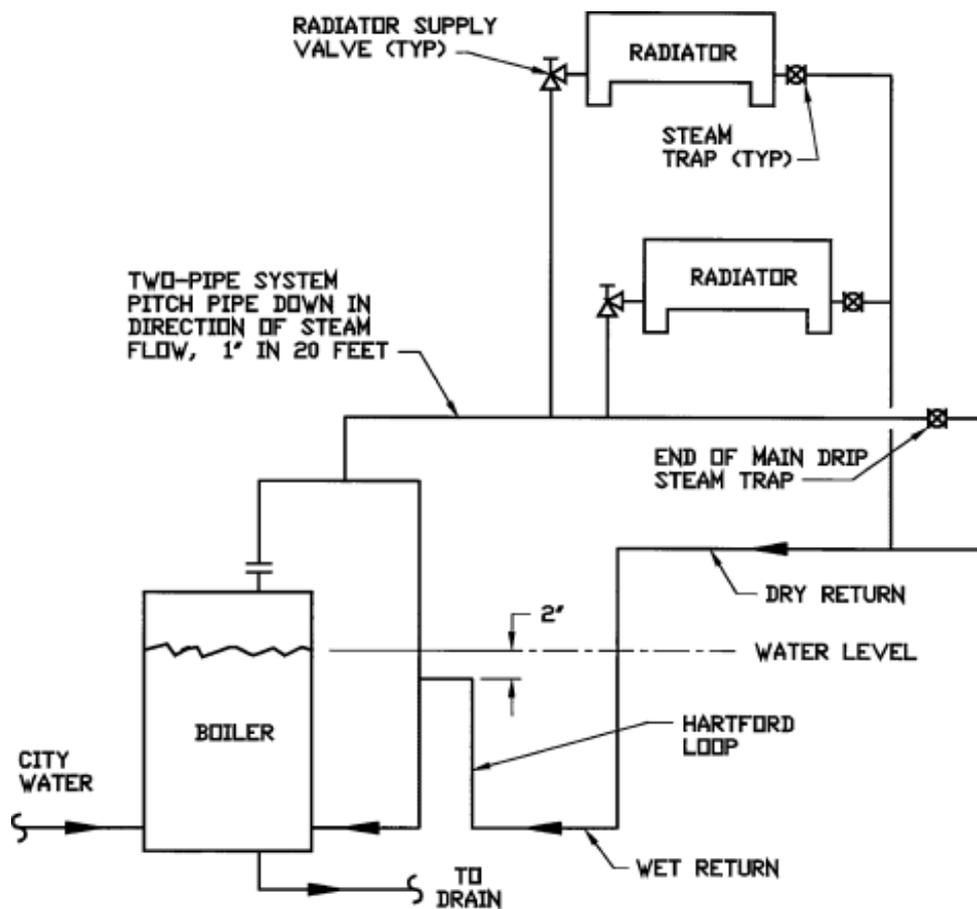
I. **Steam -Systems**

1. Residential steam systems are low-pressure steam systems normally with gravity return condensate systems (see [Figs. 21.3](#) through [21.5](#)).



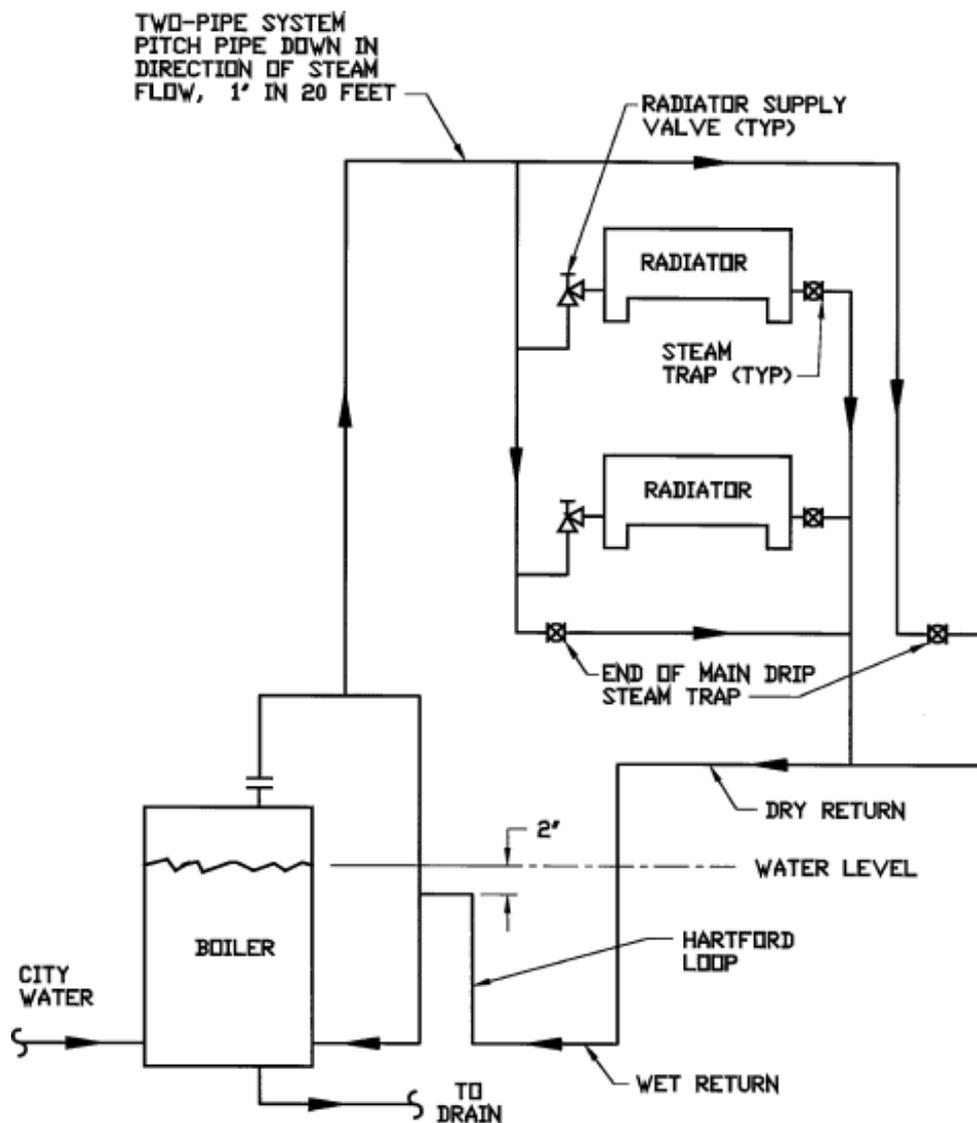
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Figure 21.3. RESIDENTIAL LP STEAM SYSTEMS 1.



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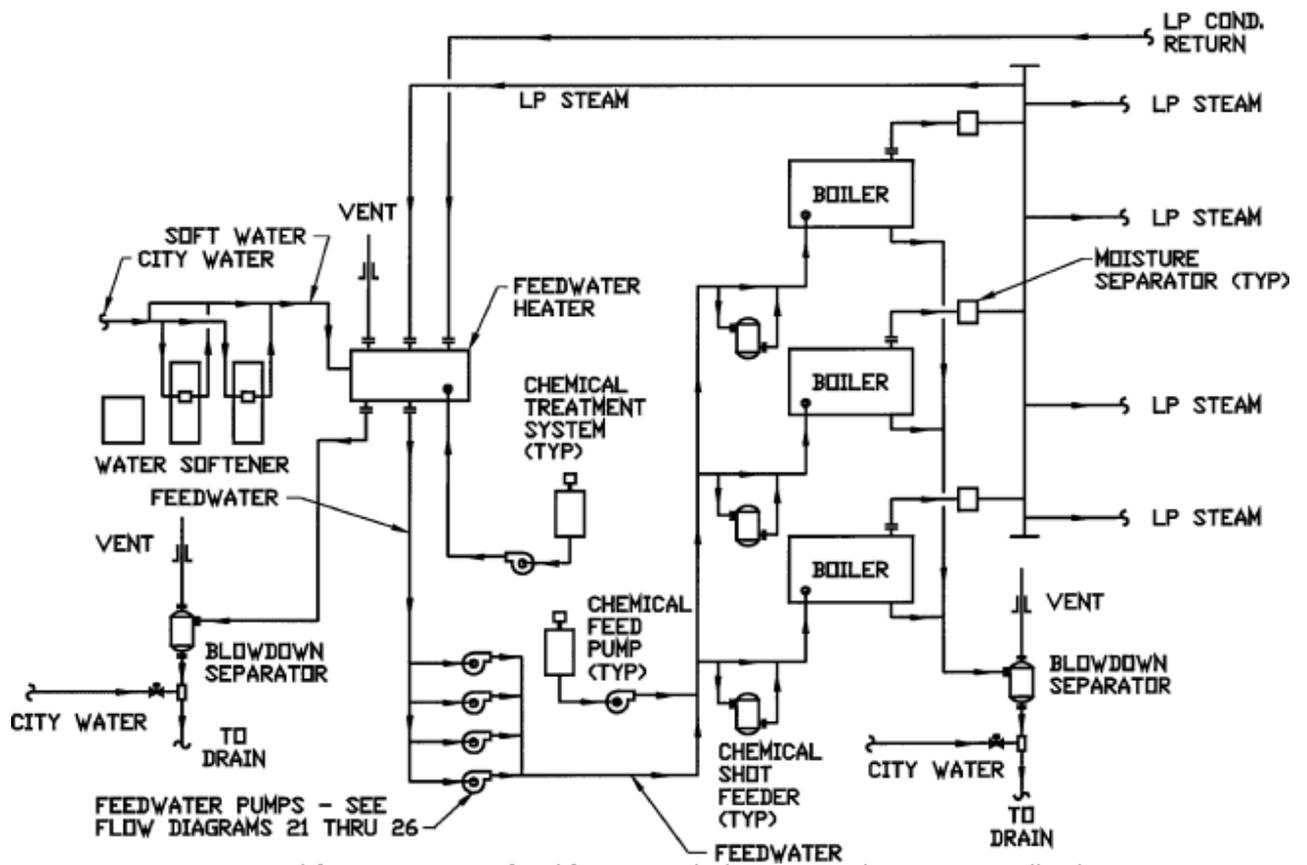
Figure 21.4. RESIDENTIAL LP STEAM SYSTEMS 2.



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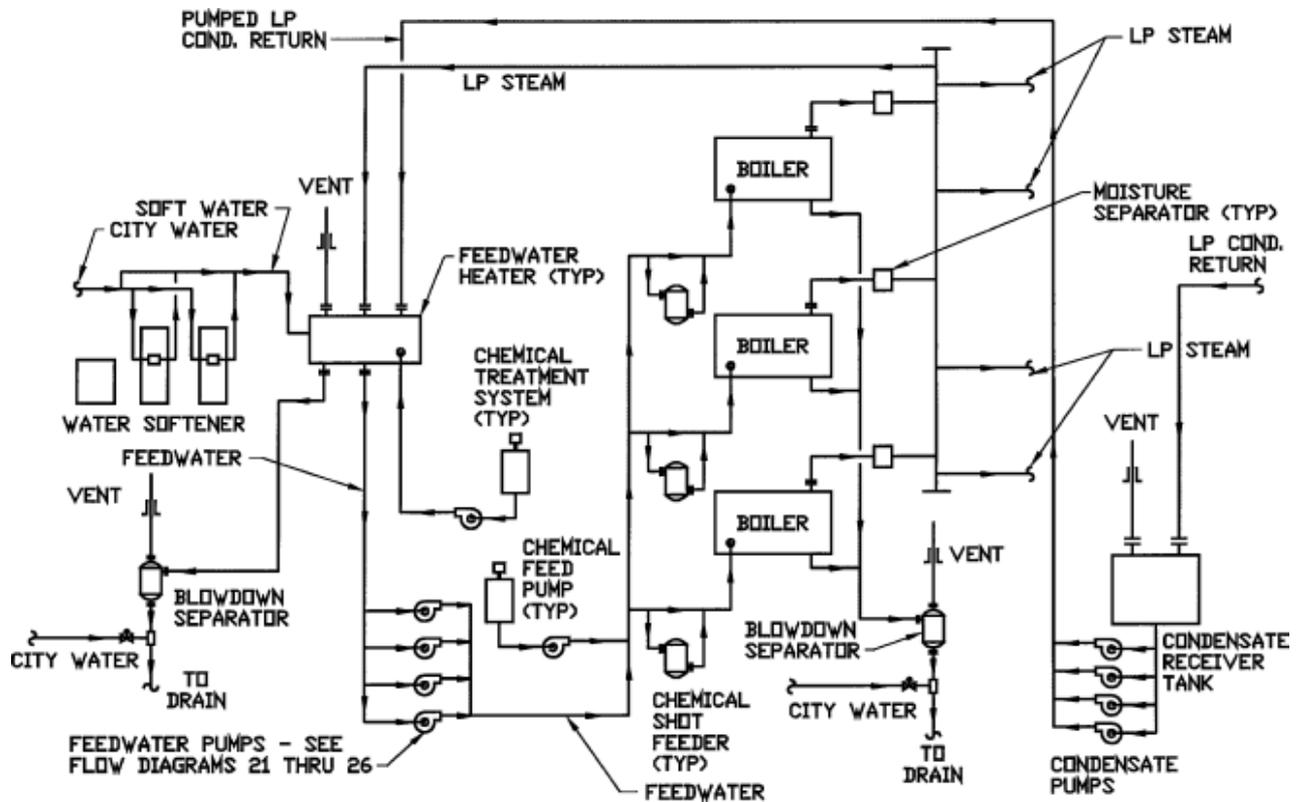
Figure 21.5. RESIDENTIAL LP STEAM SYSTEMS 3.

- Commercial low-pressure steam systems may be provided with either gravity or pumped condensate return systems (see [Figs. 21.6](#) and [21.7](#)).



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Figure 21.6. LOW-PRESSURE STEAM SYSTEMS-GRAVITY RETURN.



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Figure 21.7. LOW-PRESSURE STEAM SYSTEMS-PUMPED RETURN.

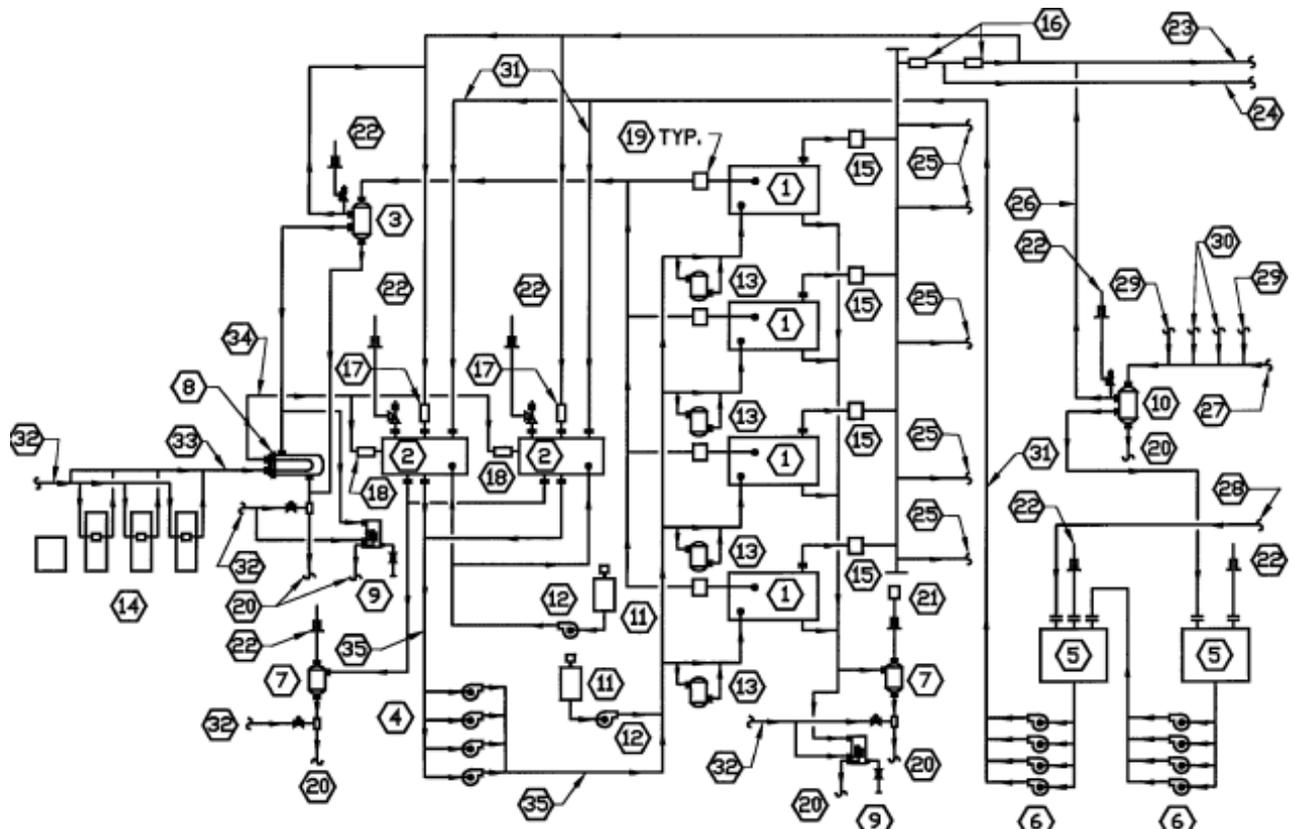
3. Commercial and industrial medium- and high-pressure steam systems are generally provided with pumped condensate return systems (see Figs. 21.8 and 21.9).

HIGH PRESSURE STEAM SYSTEM KEYED NOTES:

- | | |
|---|--|
| ① BOILER | ②⑥ FLASH STEAM TO LP STEAM SYSTEM |
| ② DEAERATOR OR FEEDWATER HEATER | ②⑦ COMBINED HIGH-PRESSURE & MEDIUM-PRESSURE CONDENSATE RETURNS |
| ③ BLOWDOWN FLASH TANK | ②⑧ LOW PRESSURE CONDENSATE RETURN |
| ④ FEEDWATER PUMPS - SEE FLOW DIAGRAMS 21 THROUGH 26 | ②⑨ MEDIUM-PRESSURE CONDENSATE RETURN |
| ⑤ CONDENSATE RECEIVER TANK | ③⑩ HIGH-PRESSURE CONDENSATE RETURN |
| ⑥ CONDENSATE PUMPS | ③① PUMPED CONDENSATE RETURN |
| ⑦ BLOWDOWN SEPARATOR | ③② CITY WATER |
| ⑧ BLOWDOWN HEAT EXCHANGER | ③③ TREATED WATER |
| ⑨ SAMPLE COOLER | ③④ HEATED SOFT WATER |
| ⑩ FLASH TANK | ③⑤ FEEDWATER |
| ⑪ CHEMICAL TREATMENT SYSTEMS | |
| ⑫ CHEMICAL FEED PUMPS | |
| ⑬ CHEMICAL SHOT FEEDER | |
| ⑭ WATER TREATMENT SYSTEM | |
| ⑮ MOISTURE SEPARATOR | |
| ⑯ PRV STATION | |
| ⑰ TEMPERATURE CONTROL | |
| ⑱ LEVEL CONTROL | |
| ⑲ TOP BLOWDOWN CONTROLLER | |
| ⑳ TO DRAIN | |
| ㉑ EXHAUST HEAD | |
| ㉒ VENT, TERMINATE A MINIMUM OF 7'-6" ABOVE ROOF | |
| ㉓ STEAM SYSTEM #1 (LOW PRESSURE STEAM) | |
| ㉔ STEAM SYSTEM #2 (MEDIUM PRESSURE STEAM) | |
| ㉕ STEAM SYSTEM #3 (HIGH PRESSURE STEAM) | |

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Figure 21.8. HP STEAM SYSTEM FLOW DIAGRAM NOTES.



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Figure 21.9. HIGH-PRESSURE STEAM SYSTEMS-PUMPED RETURN.

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21.02. Steam System Design Criteria

STEAM SYSTEM DESIGN CRITERIA

System Type	Initial Steam Pressure psig	Maximum Pressure Drop psig/100 ft.	Maximum Total System Pressure Drop psig	Maximum Velocity FPM
Low Pressure	1	1/8	0.2	4,000
	3	1/8	0.6	4,000
	5	1/4	1.0	6,000
	7	1/4	1.5	6,000
	10	1/2	2.0	6,000
Velocity Range	12	1/2	2.5	6,000
4,000-6,000	15	1/2	3	6,000

FPM				
Medium System	20	Initial Steam Pressure	1/2	Maximum Total System Pressure Drop
Pressure Type	25	psig	1/2-1	psig/100 ft. Drop psig
	30		1	
	40		1	
	50		1	
	60		1	
	75		1-2	
Velocity Range	85		1-2	
6,000-12,000 FPM	100		1-2	
High Pressure	120		2	
	125		2	
	150		2	
	175		2	
	200		2-5	
	225		2-5	
	250		2-5	
Velocity Range	275		2-5	
6,000-15,000 FPM	300		2-5	

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21.03. Steam Tables

STEAM TABLES

Steam Pressure psia	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32°F) Btu/lb.		
				Sensible	Latent	Total

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Sensible Heat Content (above 32° F) Btu/lb.	Latent Heat Btu/lb.	Total Heat Btu/lb.
0	14.7	212.0	26.800	180.2	970.4	1,150.6
1	15.7	215.3	25.212	183.5	968.2	1,151.7
2	16.7	218.5	23.798	186.7	966.2	1,152.9
3	17.7	221.5	22.536	189.7	964.3	1,154.0
4	18.7	224.4	21.407	192.6	962.4	1,155.0
5	19.7	227.1	20.387	195.4	960.6	1,156.0
6	20.7	229.8	19.467	198.1	958.9	1,157.0
7	21.7	232.3	18.626	200.7	957.3	1,158.0
8	22.7	234.8	17.855	203.1	955.7	1,158.8
9	23.7	237.1	17.147	205.5	954.2	1,159.5
10	24.7	239.4	16.496	207.8	952.7	1,160.2
11	25.7	241.6	15.895	210.1	951.2	1,160.9
12	26.7	243.7	15.337	212.2	949.8	1,161.7
13	27.7	245.8	14.817	214.4	948.4	1,162.4
14	28.7	247.8	14.334	216.4	947.1	1,163.1
15	29.7	249.8	13.881	218.3	945.8	1,163.8
16	30.7	251.7	13.458	220.3	944.5	1,164.5
17	31.7	253.5	13.059	222.2	943.3	1,165.2
18	32.7	255.3	12.685	224.0	942.1	1,165.9
19	33.7	257.1	12.332	225.8	940.9	1,166.6
20	34.7	258.8	11.998	227.5	939.7	1,167.3
21	35.7	260.5	11.684	229.2	938.5	1,168.0
22	36.7	262.1	11.385	230.9	937.4	1,168.7
23	37.7	263.7	11.102	232.5	936.3	1,169.4
24	38.7	265.3	10.833	234.1	935.2	1,170.1
25	39.7	266.8	10.577	235.7	934.1	1,170.8
26	40.7	268.3	10.333	237.3	933.1	1,171.5
27	41.7	269.8	10.101	238.7	932.1	1,172.2
28	42.7	271.2	9.879	240.2	931.1	1,172.9
29	43.7	272.6	9.666	241.7	930.1	1,173.6
30	44.7	274.0	9.463	243.1	929.1	1,174.3
31	45.7	275.4	9.269	244.5	928.2	1,175.0
32	46.7	276.8	9.082	245.9	927.2	1,175.7
33	47.7	278.1	8.904	247.2	926.3	1,176.4
34	48.7	279.4	8.732	248.5	925.4	1,177.1
35	49.7	280.6	8.567	249.8	924.5	1,177.8

35	49.7	280.0	8.507	249.9	924.5	1,174
36	50.7	281.9	8.498	251.1	923.6	1,174
37	51.7	283.1	8.255	252.4	922.7	1,175
38	52.7	284.4 °F	8.109	Sensible	Latent	Total
39	53.7	285.6	7.966	254.9	921.0	1,175
40	54.7	286.7	7.843	256.1	920.1	1,176
41	55.7	287.9	7.697	257.3	919.3	1,176
42	56.7	289.1	7.570	258.5	918.4	1,176
43	57.7	290.2	7.447	259.6	917.6	1,177
44	58.7	291.3	7.327	260.8	916.8	1,177
45	59.7	292.4	7.212	261.9	916.0	1,177
46	60.7	293.5	7.100	263.0	915.2	1,178
47	61.7	294.6	6.992	264.2	914.4	1,178
48	62.7	295.6	6.887	265.3	913.6	1,178
49	63.7	296.7	6.785	266.3	912.9	1,179
50	64.7	297.7	6.686	267.4	912.1	1,179
51	65.7	298.7	6.591	268.4	911.4	1,179
52	66.7	299.7	6.498	269.4	910.6	1,180
53	67.7	300.7	6.407	270.5	909.9	1,180
54	68.7	301.7	6.391	271.5	909.2	1,180
55	69.7	302.7	6.234	272.5	908.5	1,181
56	70.7	303.6	6.151	273.5	907.7	1,181
57	71.7	304.6	6.070	274.5	907.0	1,181
58	72.7	305.5	5.991	275.4	906.3	1,181
59	73.7	306.4	5.915	276.4	905.6	1,182
60	74.7	307.4	5.840	277.3	905.0	1,182
61	75.7	308.3	5.768	278.3	904.3	1,182
62	76.7	309.2	5.696	279.2	903.6	1,182
63	77.7	310.1	5.627	280.1	902.9	1,183
64	78.7	310.9	5.560	281.0	902.3	1,183
65	79.7	311.8	5.494	281.9	901.6	1,183
66	80.7	312.7	5.430	282.8	901.0	1,183
67	81.7	313.5	5.367	283.7	900.3	1,184
68	82.7	314.4	5.306	284.6	899.7	1,184
69	83.7	315.2	5.246	285.5	899.0	1,184
70	84.7	316.0	5.187	286.3	898.4	1,184
71	85.7	316.9	5.130	287.2	897.8	1,185

72 73 74	Steam Pressure psig	86.7 87.7 88.7	Steam Pressure psia	317.7 318.5 319.3	Saturation Temperature °F	5.075 5.020 4.966	Specific Volume cu.ft./lb.	288.9 288.9 289.7	Heat Content (above 32°F) Btu/lb.	1,185 1,185 1,185
								Sensible	Latent	Total
75		89.7		320.1		4.914		290.5	895.3	1,185
76		90.7		320.9		4.863		291.3	894.7	1,186
77		91.7		321.6		4.813		292.1	894.1	1,186
78		92.7		322.4		4.764		292.9	893.5	1,186
79		93.7		323.2		4.715		293.7	892.9	1,186
80		94.7		323.9		4.668		294.5	892.3	1,186
81		95.7		324.7		4.623		295.3	891.7	1,187
82		96.7		325.4		4.578		296.1	891.1	1,187
83		97.7		326.2		4.533		296.9	890.6	1,187
84		98.7		326.9		4.489		297.6	890.0	1,187
85		99.7		327.6		4.447		298.4	889.4	1,187
86		100.7		328.4		4.405		299.1	888.8	1,187
87		101.7		329.1		4.364		299.9	888.3	1,188
88		102.7		329.8		4.324		300.6	887.7	1,188
89		103.7		330.5		4.284		301.4	887.1	1,188
90		104.7		331.2		4.245		302.1	886.6	1,188
91		105.7		331.9		4.207		302.8	886.1	1,188
92		106.7		332.6		4.170		303.5	885.5	1,189
93		107.7		333.3		4.133		304.3	885.0	1,189
94		108.7		333.9		4.098		305.0	884.4	1,189
95		109.7		334.6		4.062		305.7	883.9	1,189
96		110.7		335.3		4.048		306.4	883.3	1,189
97		111.7		336.0		3.993		307.1	882.8	1,189
98		112.7		336.6		3.959		307.8	882.2	1,190
99		113.7		337.3		3.926		308.4	881.8	1,190
100		114.7		337.9		3.894		309.1	881.2	1,190
101		115.7		338.6		3.862		309.8	880.7	1,190
102		116.7		339.2		3.830		310.5	880.2	1,190
103		117.7		339.9		3.799		311.1	879.7	1,190
104		118.7		340.5		3.769		311.8	879.2	1,191
105		119.7		341.1		3.739		312.5	878.7	1,191
106		120.7		341.7		3.710		313.1	878.1	1,191
107		121.7		342.4		3.681		313.8	877.6	1,191

108 Steam 109 Pressure	122.7 Steam 123.7 Pressure	343.0 Saturation 343.6 Temperature	3.652 Specific 3.624 Volume	314.4 Heat Content (above 315.1 32°F)	877.1 Btu/lb.	1,191
110 psig	124.7 psia	344.2 °F	3.596 cu ft/lb.	Sensible	Latent	Total
111	125.7	344.8	3.569	316.3	875.6	1,191
112	126.7	345.4	3.543	317.0	875.1	1,192
113	127.7	346.0	3.516	317.6	874.6	1,192
114	128.7	346.6	3.490	318.2	874.2	1,192
115	129.7	347.2	3.465	318.9	873.7	1,192
116	130.7	347.8	3.440	319.5	873.2	1,192
117	131.7	348.4	3.415	320.1	872.7	1,192
118	132.7	348.9	3.390	320.7	872.2	1,192
119	133.7	349.5	3.366	321.3	871.7	1,193
120	134.7	350.1	3.342	321.9	871.3	1,193
121	135.7	350.7	3.319	322.5	870.8	1,193
122	136.7	351.2	3.296	323.1	870.3	1,193
123	137.7	351.8	3.273	323.7	869.8	1,193
124	138.7	352.4	3.251	324.3	869.4	1,193
125	139.7	352.9	3.228	324.9	868.9	1,193
126	140.7	353.5	3.206	325.5	868.4	1,193
127	141.7	354.0	3.185	326.0	868.0	1,194
128	142.7	354.6	3.163	326.6	867.5	1,194
129	143.7	355.1	3.142	327.2	867.0	1,194
130	144.7	355.7	3.121	327.8	866.6	1,194
131	145.7	356.2	3.101	328.4	866.1	1,194
132	146.7	356.7	3.081	328.9	865.7	1,194
133	147.7	357.3	3.061	329.5	865.2	1,194
134	148.7	357.8	3.042	330.0	864.8	1,194
135	149.7	358.3	3.022	330.6	864.3	1,194
136	150.7	358.8	3.003	331.1	863.9	1,195
137	151.7	359.4	2.984	331.7	863.4	1,195
138	152.7	359.9	2.965	332.2	863.0	1,195
139	153.7	360.4	2.947	332.8	862.5	1,195
140	154.7	360.9	2.928	333.3	862.1	1,195
141	155.7	361.4	2.910	333.9	861.6	1,195
142	156.7	361.9	2.893	334.4	861.2	1,195
143	157.7	362.4	2.875	334.9	860.8	1,195
144	158.7	362.9	2.858	335.5	860.4	1,195

144	158.7	362.9	2.850	335.0	858.4	1,195
145	159.7	363.4	2.841	336.0	858.9	1,195
146	160.7	363.9	2.824	336.5	859.5	1,196
147	161.7	364.4	2.807	337.1	859.0	1,196
148	162.7	364.9	2.791	337.6	858.6	1,196
149	163.7	365.4	2.775	338.1	858.2	1,196
150	164.7	365.9	2.759	338.6	857.8	1,196
151	165.7	366.4	2.743	339.1	857.3	1,196
152	166.7	366.9	2.727	339.7	856.9	1,196
153	167.7	367.4	2.712	340.2	856.5	1,196
154	168.7	367.9	2.696	340.7	856.1	1,196
155	169.7	368.3	2.681	341.2	855.7	1,196
156	170.7	368.8	2.666	341.7	855.3	1,197
157	171.7	369.3	2.651	342.2	854.8	1,197
158	172.7	369.7	2.636	342.7	854.4	1,197
159	173.7	370.2	2.621	343.2	854.0	1,197
160	174.7	370.7	2.607	343.7	853.6	1,197
161	175.7	371.1	2.593	344.2	853.2	1,197
162	176.7	371.6	2.579	344.7	852.8	1,197
163	177.7	372.1	2.565	345.2	852.4	1,197
164	178.7	372.5	2.551	345.7	852.0	1,197
165	179.7	373.0	2.537	346.1	851.6	1,197
166	180.7	373.4	2.524	346.6	851.2	1,197
167	181.7	373.9	2.511	347.1	850.8	1,197
168	182.7	374.4	2.498	347.6	850.4	1,198
169	183.7	374.8	2.484	348.1	850.0	1,198
170	184.7	375.2	2.471	348.5	849.6	1,198
171	185.7	375.7	2.459	349.0	849.2	1,198
172	186.7	376.1	2.446	349.5	848.8	1,198
173	187.7	376.6	2.434	350.0	848.4	1,198
174	188.7	377.0	2.421	350.4	848.1	1,198
175	189.7	377.4	2.409	350.9	847.7	1,198
176	190.7	377.9	2.397	351.4	847.2	1,198
177	191.7	378.3	2.385	351.8	846.9	1,198
178	192.7	378.8	2.373	352.3	846.5	1,198
179	193.7	379.2	2.361	352.8	846.1	1,198
180	194.7	379.6	2.349	353.2	845.7	1,198

180	194.7	379.6	2.349	353.2	845.7	1,198
181	195.7	380.0	2.337	353.7	845.3	1,199
182	196.7	380.5	2.326	354.1	844.9	1,199
183	197.7	380.9	2.315	354.6	844.4	1,199
184	198.7	381.3	2.304	355.1	844.1	1,199
185	199.7	381.7	2.292	355.5	843.8	1,199
186	200.7	382.2	2.281	355.9	843.4	1,199
187	201.7	382.6	2.271	356.3	843.1	1,199
188	202.7	383.0	2.260	356.8	842.7	1,199
189	203.7	383.4	2.249	357.2	842.3	1,199
190	204.7	383.8	2.238	357.7	841.9	1,199
191	205.7	384.2	2.228	358.1	841.6	1,199
192	206.7	384.6	2.218	358.5	841.2	1,199
193	207.7	385.0	2.207	359.0	840.8	1,199
194	208.7	385.4	2.197	359.4	840.5	1,199
195	209.7	385.8	2.187	359.9	840.1	1,200
196	210.7	386.3	2.177	360.3	839.7	1,200
197	211.7	386.7	2.167	360.7	839.4	1,200
198	212.7	387.1	2.158	361.2	838.9	1,200
199	213.7	387.5	2.148	361.6	838.6	1,200
200	214.7	387.9	2.138	362.1	838.2	1,200
201	215.7	388.2	2.128	362.5	837.8	1,200
202	216.7	388.6	2.119	362.9	837.5	1,200
203	217.7	389.0	2.110	363.3	837.1	1,200
204	218.7	389.4	2.100	363.8	836.8	1,200
205	219.7	389.8	2.091	364.2	836.4	1,200
206	220.7	390.2	2.082	364.6	836.0	1,200
207	221.7	390.6	2.073	365.0	835.7	1,200
208	222.7	391.0	2.064	365.4	835.3	1,200
209	223.7	391.4	2.055	365.8	835.0	1,200
210	224.7	391.8	2.046	366.2	834.6	1,200
211	225.7	392.1	2.037	366.6	834.2	1,200
212	226.7	392.5	2.028	367.0	833.9	1,200
213	227.7	392.9	2.020	367.5	833.5	1,201
214	228.7	393.3	2.011	367.9	833.2	1,201
215	229.7	393.6	2.003	368.3	832.8	1,201
216	230.7	394.0	1.994	368.7	832.5	1,201

217 Steam Pressure 218 psig	231.7 Steam Pressure 232.7 psia	394.4 Saturation Temperature 394.8 °F	1.966 Specific Volume cu.ft./lb.	369.5 Heat Content (above 32°F) Btu/lb.	831.8 Sensible Latent	1,201 Total
220	234.7	395.5	1.961	370.3	831.1	1,201
221	235.7	395.9	1.953	370.7	830.8	1,201
222	236.7	396.3	1.945	371.1	830.4	1,201
223	237.7	396.6	1.937	371.5	830.1	1,201
224	238.7	397.0	1.929	371.9	829.7	1,201
225	239.7	397.4	1.921	372.3	829.4	1,201
226	240.7	397.7	1.914	372.7	829.0	1,201
227	241.7	398.1	1.906	373.0	828.7	1,201
228	242.7	398.4	1.898	373.4	828.3	1,201
229	243.7	398.8	1.891	373.8	828.0	1,201
230	244.7	399.2	1.883	374.2	827.6	1,201
231	245.7	399.5	1.876	374.6	827.3	1,201
232	246.7	399.9	1.869	375.0	826.9	1,201
233	247.7	400.2	1.862	375.3	826.6	1,201
234	248.7	400.6	1.854	375.7	826.2	1,201
235	249.7	400.9	1.847	376.1	825.9	1,202
236	250.7	401.3	1.840	376.5	825.6	1,202
237	251.7	401.6	1.833	376.8	825.3	1,202
238	252.7	402.0	1.826	377.2	824.9	1,202
239	253.7	402.3	1.819	377.6	824.6	1,202
240	254.7	402.7	1.812	378.0	824.3	1,202
241	255.7	403.0	1.805	378.4	824.0	1,202
242	256.7	403.4	1.798	378.7	823.7	1,202
243	257.7	403.7	1.791	379.1	823.3	1,202
244	258.7	404.1	1.785	379.5	822.9	1,202
245	259.7	404.4	1.778	379.9	822.6	1,202
246	260.7	404.7	1.771	380.3	822.3	1,202
247	261.7	405.1	1.765	380.6	822.0	1,202
248	262.7	405.4	1.758	381.0	821.6	1,202
249	263.7	405.8	1.752	381.3	821.3	1,202
250	264.7	406.1	1.745	381.7	821.0	1,202
251	265.7	406.4	1.739	382.1	820.7	1,202
252	266.7	406.8	1.733	382.4	820.4	1,202

253 Steam 254 Pressure	267.7 Steam 268.7 Pressure	407.1 Saturation 407.4 Temperature	1.726 Specific 1.720 Volume	382.8 Heat Content (above 383.2 32° F)	820.0 Btu/lb.	1,202
255 psig	269.7 psia	407.8 °F	1.714 cu.ft./lb.	383.6 Sensible	819.3 Latent	1,202
256	270.7	408.1	1.707	383.9	819.0	1,202
257	271.7	408.4	1.701	384.3	818.7	1,203
258	272.7	408.8	1.695	384.6	818.4	1,203
259	273.7	409.1	1.689	385.0	818.0	1,203
260	274.7	409.4	1.683	385.3	817.7	1,203
261	275.7	409.7	1.677	385.7	817.4	1,203
262	276.7	410.1	1.671	386.0	817.1	1,203
263	277.7	410.4	1.666	386.4	816.7	1,203
264	278.7	410.7	1.660	386.7	816.4	1,203
265	279.7	411.1	1.654	387.1	816.1	1,203
266	280.7	411.4	1.648	387.5	815.8	1,203
267	281.7	411.7	1.642	387.8	815.5	1,203
268	282.7	412.0	1.637	388.2	815.2	1,203
269	283.7	412.3	1.631	388.5	814.9	1,203
270	284.7	412.7	1.625	388.9	814.6	1,203
271	285.7	413.0	1.620	389.2	814.3	1,203
272	286.7	413.3	1.614	389.5	814.0	1,203
273	287.7	413.6	1.609	389.9	813.6	1,203
274	288.7	413.9	1.603	390.3	813.3	1,203
275	289.7	414.2	1.598	390.6	813.0	1,203
276	290.7	414.5	1.593	390.9	812.7	1,203
277	291.7	414.9	1.587	391.3	812.3	1,203
278	292.7	415.2	1.582	391.6	812.0	1,203
279	293.7	415.5	1.577	392.0	811.7	1,203
280	294.7	415.8	1.571	392.3	811.4	1,203
281	295.7	416.1	1.566	392.6	811.1	1,203
282	296.7	416.4	1.561	393.0	810.8	1,203
283	297.7	416.7	1.556	393.3	810.5	1,203
284	298.7	417.0	1.551	393.7	810.2	1,203
285	299.7	417.3	1.546	394.0	809.9	1,203
286	300.7	417.6	1.541	394.3	809.6	1,203
287	301.7	417.9	1.536	394.7	809.3	1,204
288	302.7	418.2	1.531	395.0	809.0	1,204
289	303.7	418.5	1.526	395.3	808.7	1,204

289	303.7	418.5	1.520	395.5	808.7	1,204
Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lb.	Heat Content (above 32° F) Sensible	Latent	Total
290	304.7	418.8	1.521	395.7	808.4	1,204
291	305.7	419.2	1.516	396.0	808.1	1,204
292	306.7	419.5	1.511	396.3	807.8	1,204
293	307.7	419.8	1.507	396.6	807.5	1,204
294	308.7	420.1	1.502	397.0	807.2	1,204
295	309.7	420.4	1.497	397.3	806.9	1,204
296	310.7	420.6	1.492	397.6	806.6	1,204
297	311.7	420.9	1.488	397.9	806.3	1,204
298	312.7	421.2	1.483	398.3	806.0	1,204
299	313.7	421.5	1.478	398.6	805.7	1,204
300	314.7	421.8	1.474	398.9	805.4	1,204
310	324.7	424.7	1.429	402.1	802.4	1,204
320	334.7	427.6	1.387	405.3	799.4	1,204
330	344.7	430.4	1.347	408.3	796.5	1,204
340	354.7	433.1	1.310	411.3	793.7	1,205
350	364.7	435.7	1.274	414.3	790.9	1,205
360	374.7	438.3	1.240	417.1	788.1	1,205
370	384.7	440.9	1.208	420.0	785.4	1,205
380	394.7	443.4	1.178	422.8	782.6	1,205
390	404.7	445.8	1.149	425.5	780.0	1,205
400	414.7	448.2	1.121	428.2	777.4	1,205
410	424.7	450.6	1.095	430.8	774.8	1,205
420	434.7	452.9	1.069	433.4	772.2	1,205
430	444.7	455.2	1.045	436.0	769.6	1,205
440	454.7	457.4	1.022	438.6	767.0	1,205
450	464.7	459.6	1.000	441.0	764.5	1,205
460	474.7	461.8	0.979	443.5	762.0	1,205
470	484.7	463.9	0.958	445.9	759.5	1,205
480	494.7	466.0	0.939	448.3	757.1	1,205
490	504.7	468.1	0.920	450.6	754.7	1,205
500	514.7	470.1	0.901	453.0	752.2	1,205
510	524.7	472.1	0.884	455.2	749.9	1,205
520	534.7	474.1	0.867	457.5	747.5	1,205
530	544.7	476.0	0.851	459.8	745.1	1,204
540	554.7	478.0	0.835	461.9	742.8	1,204
550	564.7	479.9	0.820	464.1	740.5	1,204

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu. ft./lb.	Heat Content (above 32°F) Btu/lb.	Sensible Latent	Total
550	564.7	479.9	0.820	464.1	740.5	1,204
560	574.7	481.7	0.805	466.3	738.2	1,204
570	584.7	483.6	0.791	468.4	735.9	1,204
580	594.7	485.4	0.777	472.7	731.3	1,204
590	604.7	487.2	0.764	474.7	729.1	1,203
600	614.7	488.9	0.751	476.7	726.9	1,203
610	624.7	490.7	0.739	478.7	724.7	1,203
620	634.7	492.4	0.727	480.7	722.5	1,203
630	644.7	494.1	0.715	482.7	720.3	1,203
640	654.7	495.8	0.704	484.7	718.1	1,202
650	664.7	497.5	0.693	486.7	715.9	1,202
660	674.7	499.2	0.682	488.6	713.8	1,202
670	684.7	500.8	0.671	490.5	711.6	1,202
680	694.7	502.4	0.661	492.4	709.5	1,201
690	704.7	504.0	0.651	494.3	707.3	1,201
700	714.7	505.5	0.642	496.2	705.2	1,201
710	724.7	507.1	0.632	498.0	703.1	1,201
720	734.7	508.7	0.623	499.8	701.0	1,200
730	744.7	510.2	0.614	501.6	698.9	1,200
740	754.7	511.7	0.606	503.4	696.8	1,200
750	764.7	513.2	0.597	505.2	694.8	1,200
760	774.7	514.7	0.589	507.0	692.7	1,199
770	784.7	516.1	0.581	508.8	690.7	1,199
780	794.7	517.6	0.573	510.5	688.6	1,199
790	804.7	519.0	0.566	512.3	686.5	1,198
800	814.7	520.5	0.558	514.0	684.6	1,198
810	824.7	521.9	0.551	515.7	682.6	1,198
820	834.7	523.3	0.544	517.4	680.6	1,198
830	844.7	524.7	0.537	519.0	678.6	1,197
840	854.7	526.0	0.530	520.7	676.6	1,197
850	864.7	527.4	0.523	522.4	674.6	1,197
860	874.7	528.7	0.517	524.1	672.6	1,196
870	884.7	530.1	0.511	525.7	670.6	1,196
880	894.7	531.4	0.504	527.4	668.6	1,196
890	904.7	532.7	0.498	529.0	666.6	1,195
900	914.7	534.0	0.492	530.6	664.7	1,195
910	924.7	535.3	0.486			

930 Steam Pressure 940 psig	934.7 Steam Pressure 954.7 psia	536.6 Saturation Temperature 537.9 539.1 °F	Specific Volume 0.470 cu.ft./lb.	532.2 Heat Content (above 533.8 32° F) 535.4 Sensible	652.7 660.7 658.7 Latent	1,194.7 1,194.7 1,194.7 Total
950	964.7	540.4	0.464	536.9	656.8	1,193.7
960	974.7	541.6	0.459	538.5	654.9	1,193.4
970	984.7	542.9	0.454	540.0	653.0	1,193.0
980	994.7	544.1	0.449	541.6	651.0	1,192.6
990	1,004.7	545.3	0.444	543.1	649.1	1,192.2
1,000	1,014.7	546.5	0.439	544.6	647.2	1,191.8
1,050	1,064.7	552.4	0.416	552.2	637.6	1,189.8
1,100	1,114.7	558.1	0.395	559.5	628.2	1,187.7
1,150	1,164.7	563.6	0.375	566.7	618.9	1,185.6
1,200	1,214.7	568.9	0.357	573.7	609.6	1,183.3
1,250	1,264.7	574.0	0.341	580.6	600.3	1,180.9
1,300	1,314.7	579.0	0.325	587.4	591.1	1,178.5
1,350	1,364.7	583.9	0.311	594.0	581.9	1,176.0
1,400	1,414.7	588.6	0.298	600.5	572.8	1,173.3
1,450	1,464.7	593.2	0.285	607.0	563.6	1,170.6
1,500	1,514.7	597.7	0.274	613.4	554.5	1,167.9
1,550	1,564.7	602.0	0.263	619.6	545.4	1,165.0
1,600	1,614.7	606.3	0.252	625.8	536.2	1,162.0
1,650	1,664.7	610.4	0.242	632.0	527.1	1,159.1
1,700	1,714.7	614.5	0.233	638.0	517.9	1,156.0
1,750	1,764.7	618.5	0.224	644.1	508.7	1,152.8
1,800	1,814.7	622.3	0.216	650.0	499.4	1,149.4
1,850	1,864.7	626.1	0.208	655.9	490.0	1,145.9
1,900	1,914.7	629.8	0.200	661.8	480.6	1,142.4
1,950	1,964.7	633.5	0.193	667.7	471.2	1,138.9
2,000	2,014.7	637.0	0.187	673.6	461.5	1,135.1
2,050	2,064.7	640.5	0.179	679.4	451.8	1,131.2
2,100	2,114.7	643.9	0.173	685.3	442.1	1,127.4
2,150	2,164.7	647.3	0.167	691.1	432.1	1,123.2
2,200	2,214.7	650.6	0.161	697.0	422.0	1,119.0
2,250	2,264.7	653.8	0.155	702.8	411.7	1,114.5
2,300	2,314.7	657.0	0.150	708.7	401.3	1,110.0
2,350	2,364.7	660.1	0.144	714.6	390.6	1,105.3

2,400 Steam Pressure	2,414.7 Steam Pressure	663.2 Saturation Temperature	0.139 Specific Volume	720.6 Heat Content (above	379.7 32° F) Btu/lb.	1,100
2,450 psig	2,464.7 psia	666.2 °F	0.134 cu. ft./lb.	726.6 Sensible	368.5 Latent	1,095 Total



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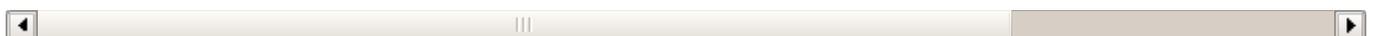
21.04. Steam Flow through Orifices

STEAM FLOW THROUGH ORIFICES

Orifice Dia. Inches	Steam Flow lbs./h									
	Steam Pressure psig									
	2	5	10	15	25	50	75	100	125	150
1/32	0.3	0.5	0.6	0.7	0.9	1.5	2.1	2.7	3.3	3.9
1/16	1.3	1.9	2.3	2.8	3.8	6.1	8.5	10.8	13.2	15.6
3/32	2.8	4.2	5.3	6.3	8.5	13.8	19.1	24.4	29.7	35.1
1/8	4.5	7.5	9.4	11.2	15.0	24.5	34.0	43.4	52.9	62.4
5/32	7.8	11.7	14.6	17.6	23.5	38.3	53.1	67.9	82.7	97.4
3/16	11.2	16.7	21.0	25.3	33.8	55.1	76.4	97.7	119	140
7/32	15.3	22.9	28.7	34.4	46.0	75.0	104	133	162	191
1/4	20.0	29.8	37.4	45.0	60.1	98.0	136	173	212	250
9/32	25.2	37.8	47.4	56.9	76.1	124	172	220	268	316
5/16	31.2	46.6	58.5	70.3	94.0	153	212	272	331	390
11/32	37.7	56.4	70.7	85.1	114	185	257	329	400	472
3/8	44.9	67.1	84.2	101	135	221	306	391	476	561
13/32	52.7	78.8	98.8	119	159	259	359	459	559	659
7/16	61.1	91.4	115	138	184	300	416	532	648	764
15/32	70.2	105	131	158	211	344	478	611	744	877
1/2	79.8	119	150	180	241	392	544	695	847	998

Note:

- 1. team leaks and energy wasted: A1/8" diameter hole in a steam pipe c lbs.Stm./h at 150 psig, resulting in 30 tons of coal, 4800 gallons of oil gas to be wasted each year (assuming 8400 hour per year operation).**



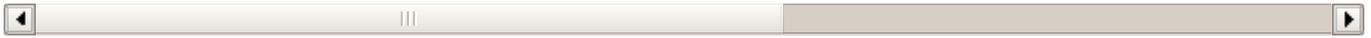
21.05. Flash Steam

FLASH STEAM

Flash Steam Flow lbs. Steam/h per 100 lbs. of S
Flash Steam Flow lbs. Steam/h per 100 lbs. of S

Steam Steam Press.psig Press.psig	Condensate Pressur Condensate Pressur									
	0	1	3	5	7	10	12	15	20	25
0	0.0									
1	0.3	0.0								
3	1.0	0.6	0.0							
5	1.6	1.2	0.6	0.0						
7	2.1	1.8	1.1	0.6	0.0					
10	2.8	2.5	1.9	1.3	0.7	0.0				
12	3.3	3.0	2.3	1.7	1.2	0.5	0.0			
15	3.9	3.6	3.0	2.4	1.8	1.1	0.6	0.0		
20	4.9	4.5	3.9	3.3	2.8	2.1	1.6	1.0	0.0	
25	5.7	5.4	4.8	4.2	3.7	2.9	2.5	1.8	0.9	0.0
30	6.5	6.2	5.5	5.0	4.4	3.7	3.3	2.6	1.7	0.8
40	7.8	7.5	6.9	6.3	5.8	5.1	4.6	4.0	3.0	2.2
50	9.0	8.7	8.1	7.5	7.0	6.3	5.8	5.2	4.2	3.4
60	10.0	9.7	9.1	8.5	8.0	7.3	6.9	6.2	5.3	4.5
75	11.4	11.1	10.5	9.9	9.4	8.7	8.2	7.6	6.7	5.9
85	12.2	11.9	11.3	10.7	10.2	9.5	9.1	8.5	7.5	6.7
100	13.3	13.0	12.4	11.8	11.3	10.6	10.2	9.6	8.7	7.9
120	14.6	14.3	13.7	13.2	12.7	12.0	11.5	11.0	10.0	9.2
125	14.9	14.6	14.0	13.5	13.0	12.3	11.9	11.3	10.4	9.5
150	16.3	16.0	15.4	14.9	14.4	13.7	13.3	12.7	11.8	11.
175	17.6	17.3	16.7	16.2	15.7	15.0	14.6	14.0	13.1	12.
200	18.7	18.4	17.9	17.4	16.9	16.2	15.8	15.2	14.3	13.
225	19.8	19.5	18.9	18.4	17.9	17.3	16.9	16.3	15.4	14.
250	20.8	20.5	19.9	19.4	18.9	18.3	17.8	17.3	16.4	15.
275	21.7	21.4	20.8	20.3	19.8	19.2	18.8	18.2	17.4	16.

300	22.5	22.2	Flash Steam Flow	19.2	20.7	18.1	19.7	18.1	18.2	lbs. of
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21.06. Warm-up Loads

LOW-PRESSURE STEAM PIPING WARM-UP LOADS

Pounds of Steam per 100 Feet of Pipe

Pipe Size	Steam Pressure psig							
	0	1	3	5	7	10	12	15
1/2"	1	1	2	2	2	2	2	2
3/4"	2	2	2	2	2	2	2	2
1"	3	3	3	3	3	3	4	4
1-1/4"	4	4	4	4	4	5	5	5
1-1/2"	5	5	5	5	5	6	6	6
2"	6	6	7	7	7	7	8	8
2-1/2"	10	10	10	11	11	12	12	13
3"	13	13	14	14	15	15	16	17
4"	18	19	19	20	21	22	23	24
5"	25	25	26	27	28	30	31	32
6"	32	33	34	36	37	39	40	42
8"	48	49	51	54	56	58	60	62
10"	68	70	73	76	79	83	85	89
12"	83	85	89	93	96	101	104	108
14"	92	94	98	103	106	111	115	119
16"	105	108	113	118	122	128	132	137
18"	119	122	127	133	137	144	149	154
20"	132	135	142	148	153	160	166	172
22"	146	150	157	164	169	177	183	190
24"	159	163	170	178	184	193	199	207
26"	173	177	185	194	200	210	217	225
28"	187	191	200	209	216	226	234	243
30"	200	205	214	224	232	243	251	260
32"	214	219	229	239	247	259	268	278

Pipe Size	Pounds of Steam per 100 Feet of Pipe							
	Steam Pressure psig							
	0	1	3	5	7	10	12	15
34"	227	233	243	254	263	275	284	295
36"	241	246	258	269	278	292	301	313
42"	281	288	301	314	325	341	352	366
48"	321	328	343	358	371	389	402	417
54"	361	370	387	404	418	438	453	470
60"	402	411	430	449	465	487	503	523
72"	483	494	517	539	558	585	604	628
84"	564	577	603	629	652	683	706	733
96"	645	660	690	720	745	781	807	838
Corr. Factor	1.50	1.49	1.46	1.44	1.43	1.41	1.40	1.39

Notes:

1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F, multiply table values by correction factor.

MEDIUM-PRESSURE STEAM PIPING WARM-UP LOADS

Pounds of Steam per 100 Feet of Pipe

Pipe Size	Steam Pressure psig								
	20	25	30	40	50	60	75	85	100
1/2"	2	2	2	2	2	3	3	3	3
3/4"	3	3	3	3	3	3	4	4	4
1"	4	4	4	5	5	5	5	6	6
1-1/4"	5	6	6	6	7	7	7	8	8
1-1/2"	6	7	7	7	8	8	9	9	10
2"	8	9	9	10	11	11	12	12	13
2-1/2"	13	14	15	16	17	17	19	19	20
3"	18	18	19	21	22	23	24	25	27
4"	25	26	27	29	31	32	35	36	38
Notes:	34	35	37	40	42	44	47	49	51

Pipe Size	Pounds of Steam per 100 Feet of Pipe								
	20	25	30	40	50	60	75	85	100
6"	44	46	48	51	55	57	61	63	66
8"	66	69	72	77	82	86	92	95	100
10"	94	98	102	110	116	122	130	135	142
12"	115	120	125	134	142	149	159	165	173
14"	126	132	138	148	157	164	175	182	191
16"	145	152	158	170	180	188	201	209	219
18"	163	171	178	191	203	213	227	235	247
20"	182	191	198	213	226	237	252	262	275
22"	201	211	220	236	250	262	279	290	304
24"	219	229	239	257	272	285	304	316	331
26"	238	250	260	279	296	310	331	344	360
28"	257	269	280	301	319	334	356	370	388
30"	275	289	300	323	342	358	382	397	416
32"	294	308	321	344	365	382	408	424	444
34"	312	327	341	366	388	407	434	450	472
36"	331	347	361	388	411	431	459	477	500
42"	386	405	422	453	480	503	536	557	584
48"	441	463	482	517	548	574	612	636	667
54"	497	521	542	583	617	647	690	717	751
60"	552	579	603	648	686	719	767	797	835
72"	664	696	724	778	825	864	921	957	1,003
84"	775	812	846	908	963	1,009	1,075	1,117	1,171
96"	886	929	967	1,039	1,101	1,153	1,230	1,278	1,340
Corr. Factor	1.37	1.36	1.35	1.32	1.31	1.29	1.28	1.27	1.26

Notes:

- 1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**
- 2. For ambient temperatures of 0°F, multiply table values by the correction factor.**

HIGH-PRESSURE STEAM PIPING WARM-UP LOADS

Pounds of Steam per 100 Feet of Pipe

Pipe Size	Steam Pressure psig								
	120	125	150	175	200	225	250	275	300
1/2"	3	3	3	4	4	4	4	4	5
3/4"	4	4	4	5	5	5	5	6	7
1"	6	6	7	7	7	8	8	8	11
1-1/4"	8	9	9	9	10	10	11	11	15
1-1/2"	10	10	11	11	12	12	13	13	18
2"	14	14	14	15	16	17	17	18	25
2-1/2"	21	22	23	24	25	26	27	28	39
3"	28	28	30	32	33	34	36	37	52
4"	40	40	43	45	47	49	51	53	75
5"	54	55	58	61	64	66	69	71	104
6"	70	71	75	79	83	86	89	92	144
8"	106	107	113	119	125	129	134	139	218
10"	150	152	161	169	177	184	191	197	275
12"	183	186	197	206	216	225	233	241	329
14"	202	204	217	227	238	247	257	266	362
16"	231	234	248	261	273	284	295	305	416
18"	261	264	280	294	308	320	332	343	470
20"	290	294	312	327	343	356	370	382	523
22"	322	326	345	362	380	394	409	423	578
24"	350	354	375	394	413	429	445	460	631
26"	381	386	409	429	449	467	485	501	684
28"	410	416	440	462	484	503	522	540	739
30"	440	446	472	496	519	540	560	579	794
32"	469	476	504	529	554	576	598	618	844
34"	499	506	536	562	589	612	635	657	900
36"	528	536	567	596	624	648	673	696	955
42"	617	626	663	696	729	757	786	813	1,116
48"	705	714	757	794	832	865	898	928	1,275
54"	794	805	852	895	937	974	1,011	1,045	1,436
60"	883	894	948	995	1,042	1,083	1,124	1,162	1,597
Notes:	1,060	1,075	1,139	1,195	1,252	1,301	1,350	1,396	1,946

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe								
	Steam Pressure psig								
84"	1,238	1,254	1,270	1,286	1,302	1,318	1,334	1,350	1,366
90"	1,415	1,435	1,455	1,475	1,495	1,515	1,535	1,555	1,575
Corr. Factor	1-120	1-125	1-150	1-175	1-200	1-225	1-250	1-275	1-300

Notes:

1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F, multiply table values by the correction factor.

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21.07. Steam Operating Loads

LOW-PRESSURE STEAM PIPING OPERATING LOADS

Pounds of Steam per Hour per 100 Feet of Pipe

Pipe Size	Steam Pressure psig							
	0	1	3	5	7	10	12	15
1/2"	2	2	2	2	3	3	3	3
3/4"	3	3	3	3	3	3	3	4
1"	3	3	3	4	4	4	4	4
1-1/4"	4	4	4	4	5	5	5	5
1-1/2"	4	4	5	5	5	6	6	6
2"	5	5	6	6	6	7	7	7
2-1/2"	6	6	7	7	7	8	8	9
3"	7	8	8	8	9	9	10	10
4"	9	9	10	10	11	12	12	13
5"	11	11	12	13	13	14	15	15
6"	13	13	14	15	15	16	17	18
8"	16	17	18	19	19	21	22	23
Notes:	20	20	21	23	24	25	26	28
12"	23	24	25	26	28	29	31	32
14"	25	26	27	29	30	32	33	35

1. Table based on 70°F ambient temperature, standard weight steel

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe							
	Steam Pressure psig							
16"	28	29	31	32	34	36	38	40
18"	31	32	34	36	39	41	42	44
20"	34 ₀	35 ₁	37 ₃	39 ₅	41 ₇	44 ₁₀	46 ₁₂	48 ₁₅
22"	37	38	41	43	45	48	50	53
24"	40	41	44	47	49	52	54	57
26"	47	48	51	54	57	60	63	66
28"	50	52	55	58	61	65	68	72
30"	54	56	59	62	65	70	73	77
32"	57	59	63	67	70	74	78	82
34"	61	63	67	71	74	79	83	87
36"	65	67	71	75	78	84	87	92
42"	75	78	83	87	92	98	102	107
48"	86	89	94	100	105	112	117	123
54"	97	100	106	112	118	125	131	138
60"	108	111	118	125	131	139	146	153
72"	129	133	141	150	157	167	175	184
84"	151	156	165	175	183	195	204	215
96"	172	178	189	200	209	223	233	245
Corr. Factor	1.70	1.68	1.66	1.64	1.60	1.58	1.57	1.55

Notes:

- 1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.**
- 2. For ambient temperatures of 0°F, multiply the table values by the correction factor.**
- 3. Table values include convection and radiation loads with 80 percent efficient insulation.**

MEDIUM-PRESSURE STEAM PIPING OPERATING LOADS

Pounds of Steam per Hour per 100 Feet of Pipe

Pipe Size	Steam Pressure psig
-----------	---------------------

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe								
	20	25	30	40	50	60	75	85	100
1/2"	3	3	4	4	4	5	5	5	6
3/4"	4	4	4	5	5	6	6	6	7
1"	5	5	5	6	6	7	7	8	8
1-1/4"	6	6	6	7	8	8	9	9	10
1-1/2"	6	7	7	8	9	9	10	11	11
2"	8	8	9	10	11	11	12	13	14
2-1/2"	9	10	10	12	12	13	14	15	16
3"	11	12	12	14	15	16	17	18	19
4"	14	15	16	17	18	20	21	23	24
5"	17	18	19	21	22	24	26	27	29
6"	19	21	22	24	26	28	30	32	34
8"	25	26	28	30	33	35	38	40	43
10"	30	32	34	37	40	43	47	49	53
12"	35	37	39	43	47	50	54	57	61
14"	38	40	43	47	51	54	59	62	67
16"	43	45	48	53	57	61	67	70	75
18"	47	50	53	59	64	68	74	78	84
20"	52	56	59	65	70	75	82	86	92
22"	57	60	64	70	76	81	89	94	101
24"	61	65	69	76	83	88	96	102	109
26"	72	77	81	89	97	103	113	110	117
28"	77	82	87	96	104	111	122	129	138
30"	83	88	93	103	112	119	131	138	148
32"	88	94	100	110	119	127	139	147	157
34"	94	100	106	117	127	135	148	156	167
36"	99	106	112	124	134	143	157	166	177
42"	116	124	131	144	157	167	183	193	207
48"	132	141	149	165	179	191	209	221	236
54"	149	159	168	186	201	215	235	248	266
60"	165	177	187	206	224	239	261	276	295
Notes:	199	212	224	247	268	287	314	331	354
84"	232	247	261	289	313	334	366	386	413
96"	265	283	299	330	358	382	418	442	472

1. Table based on 70°F ambient temperature, standard weight steel pipe to 350 psi and extra strength weight steel pipe above 350

Corr. Pipe Factor Size	Pounds of Steam per Hour per 100 Feet of Pipe								
	Steam Pressure psig								
<i>Notes:</i>	20	25	30	40	50	60	75	85	100
	1.52	1.51	1.50	1.48	1.47	1.45	1.43	1.42	1.41

1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F, multiply the table values by the correction factor.
3. Table values include convection and radiation loads with 80 percent efficient insulation.

HIGH-PRESSURE STEAM PIPING OPERATING LOADS

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe								
	Steam Pressure psig								
	120	125	150	175	200	225	250	275	300
1/2"	6	6	7	7	8	8	8	9	9
3/4"	7	7	8	9	9	10	10	11	11
1"	9	9	10	10	11	12	12	13	14
1-1/4"	11	11	12	13	14	14	15	16	17
1-1/2"	12	12	13	14	15	16	17	18	19
2"	15	15	16	18	19	20	21	22	23
2-1/2"	18	18	19	21	22	23	25	26	27
3"	21	21	23	25	26	28	29	31	32
4"	26	27	29	31	33	35	37	38	40
5"	31	32	35	37	40	42	44	46	49
6"	37	38	41	44	46	49	52	54	57
8"	47	48	52	55	59	62	66	69	72
10"	57	58	63	67	72	76	80	84	88
12"	66	68	73	79	84	89	93	98	103
14"	72	74	80	85	91	96	102	107	112
<i>Notes:</i>	81	83	90	96	103	109	115	121	126
18"	91	92	100	107	115	121	128	134	141

Pipe Size	100	102	110	118	126	134	141	148	155
20"	100	102	110	118	126	134	141	148	155
22"	109	111	120	129	138	146	154	161	169
24"	120	125	130	140	150	158	167	175	180
26"	127	129	140	150	161	170	179	188	197
28"	149	152	165	177	189	182	192	201	211
30"	160	163	177	190	203	214	226	237	249
32"	170	174	189	202	216	229	241	253	265
34"	181	185	200	215	230	243	256	269	282
36"	192	195	212	228	243	257	271	285	299
42"	224	228	248	265	284	300	317	332	348
48"	256	261	283	303	324	343	362	380	398
54"	287	293	318	341	365	386	407	427	448
60"	319	326	354	379	406	429	452	475	498
72"	383	391	425	455	487	514	543	570	597
84"	447	456	495	531	568	600	633	665	697
96"	511	521	566	607	649	686	724	760	796
Corr. Factor	1.39	1.39	1.39	1.38	1.37	1.37	1.36	1.36	1.35

Notes:

1. Table based on 70°F ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F, multiply the table values by the correction factor.
3. Table values include convection and radiation loads with 80 percent efficient insulation.

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21.08. Boiling Points of Water

BOILING POINTS OF WATER

Psia	Boiling Point of	Psia	Boiling Point of	Psia	Boiling Point of
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0.5 Psia	Point °F Boiling Point °F	44 Psia	Point °F Boiling Point °F	150 Psia	Point °F Boiling Point °F
1	101.7	46	275.8	175	371.8
2	126.0	48	278.5	200	381.9
3	141.4	50	281.0	225	391.9
4	152.9	52	283.5	250	401.0
5	162.2	54	285.9	275	409.5
6	170.0	56	288.3	300	417.4
7	176.8	58	290.5	325	424.8
8	182.8	60	292.7	350	431.8
9	188.3	62	294.9	375	438.4
10	193.2	64	297.0	400	444.7
11	197.7	66	299.0	425	450.7
12	201.9	68	301.0	450	456.4
13	205.9	70	303.0	475	461.9
14	209.6	72	304.9	500	467.1
14.69	212.0	74	306.7	525	472.2
15	213.0	76	308.5	550	477.1
16	216.3	78	310.3	575	481.8
17	219.4	80	312.1	600	486.3
18	222.4	82	313.8	625	490.7
19	225.2	84	315.5	650	495.0
20	228.0	86	317.1	675	499.2
22	233.0	88	318.7	700	503.2
24	237.8	90	320.3	725	507.2
26	242.3	92	321.9	750	511.0
28	246.4	94	323.4	775	514.7
30	250.3	96	324.9	800	518.4

32 Psia	254 Boiling Point °F	98 Psia	326 Boiling Point °F	825 Psia	511 Boiling Point °F
34	257.6	100	327.9	850	525.4
36	261.0	105	331.4	875	528.8
38	264.2	110	334.8	900	532.1
40	267.3	115	338.1	950	538.6
42	270.2	120	341.3	1000	544.8

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21.09. Steam Heating Units of Measure

COMPARISON OF COMMON STEAM HEATING UNITS OF MEASURE

MBH (1000 Btuh)	Steam lbs./h	EDR sq.ft.	Boiler hp	Condensate Flow Rate GPM	Cond. Pump Capacity GPM (2)
10	10.6	42	0.3	0.02	0.06
25	26.4	104	0.7	0.05	0.15
50	52.9	208	1.5	0.10	0.30
75	79.3	313	2.2	0.16	0.48
100	105.8	417	2.9	0.21	0.63
200	211.5	833	5.8	0.41	1.23
300	317.3	1,250	8.7	0.62	1.86
400	423.0	1,667	11.6	0.83	2.49
500	528.8	2,083	14.5	1.03	3.09
750	793.1	3,125	21.7	1.55	4.65
1,000	1,058	4,167	29.0	2.07	6.21
1,250	1,322	5,208	36.2	2.58	7.74
1,500	1,418	6,250	43.5	3.10	9.30
1,750	1,851	7,292	50.7	3.62	10.8
Notes:	2,115	8,333	58.0	4.13	12.4

Pipe Size	Pressure Drop psig/100 ft.				Steam Flow lbs/h		governs pipe sizes Velocity FPM (mph)
	4	6	9	18	29	these pipe Velocity	
1-1/4	44	62	87	49	67	135	8,000
1-1/2	68	90	125	67	95	135	(91)
2	137	194	274	111	135	222	(68)
2-1/2	226	320	452	158	317		
3	414	585	822	245	489	734	
4	874	1,236	1,748	421	842	1,263	1,685
5	1,608	2,274	3,217	659	1,318	1,978	2,637
6	2,654	3,753	5,308	956	1,912	2,867	3,823
8	5,525	7,813		1,655	3,310	4,965	6,620
10	10,082	14,258	with sizes	2,609	5,218	7,826	10,435
12	16,181			3,742	7,483	11,225	14,967
14	20,959			4,562	9,123	13,685	18,247
16	30,212	governs pipe		6,043	12,086	18,128	24,171
18	41,576			7,732	15,463	23,195	30,927
20	55,192			9,629	19,257	28,886	38,514
22	Velocity these			11,733	23,466	35,200	46,933
24				14,046	28,092	42,137	56,183
26				16,566	33,132	49,698	66,265
28				19,294	38,589	57,883	77,178
30				22,231	44,461	66,692	88,922
32				25,375	50,749	76,124	101,498
34				28,726	57,453	86,179	114,906
36				32,286	64,572	96,859	129,145
42				44,213	88,425	132,638	176,851
48				58,010	116,020	174,030	232,040
54				73,678	147,356	221,034	294,712
60				91,217	182,434	273,651	364,868
Notes:				131,907	263,815	395,722	527,629
84				180,081	360,162	540,243	720,324

96				235,738	471,475	707,213	942,951
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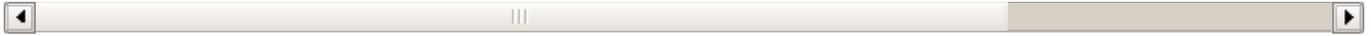
Steam Flow lbs./h

Notes: Pressure Drop psig/100 Pipe ft.

Velocity FPM (mph)

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,000

2. Table based on Standard Weight Steel Pipe using steam equations in (23) (45) (68) (91)



3 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Steam Flow lbs./h

Pipe Pressure Drop psig/100 Size ft.

Velocity FPM (mph)

0.125 0.25 0.5 2,000 4,000 6,000 8,000 (23) (45) (68) (91)

1/2	5	6	9		Pressure	drop	governs
3/4	10	15	21	20	these	pipe	sizes
1	21	30	42	32			
1-	46	65	92	55			
1/4	72	101	143	75			
1-	145	205	290	124	248		
1/2							
2							
2-	239	338	478	177	354		
1/2	437	619	870	274	547	821	
3	924	1,307	1,849	471	942	1,413	
4							
5	1,701	2,405	3,402	737	1,475	2,212	2,949
6	2,807	3,969	5,614	1,069	2,138	3,207	4,276
8	5,843	8,263		1,851	3,702	5,553	7,404
10	10,662	15,078	with	2,918	5,835	8,753	11,670
12	17,112	24,200	sizes	4,185	8,369	12,554	16,738
14	22,165			5,102	10,204	15,305	20,407
Notes:	31,951	governs		6,758	13,516	20,275	27,033
18	43,968	pipe		8,647	17,294	25,941	34,588
20	58,368			10,768	21,537	32,305	43,074

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,000

Pipe Size	Pressure Drop psig/100 ft.	0.125	0.25	0.5	Steam Flow lbs./h			Velocity FPM (mph)
					2,000 (23)	4,000 (45)	6,000 (68)	
22	75,290				13,122	26,245	39,367	52,489
24					15,709	31,417	47,126	62,834
26					18,527	37,055	55,582	74,110
28	Velocity these				21,500	43,000	64,500	86,000
30					24,257	48,515	72,772	97,029
32					28,379	56,757	85,136	113,515
34					32,127	64,255	96,382	128,509
36					36,109	72,217	108,326	144,434
42					49,447	98,894	148,341	197,788
48					64,878	129,755	194,633	259,511
54					82,401	164,801	247,202	329,603
60					102,016	204,032	306,048	408,064
72					147,524	295,047	442,571	590,094
84					201,400	402,801	604,201	805,601
96					263,646	527,292	790,939	1,054,585

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,000
2. Table based on Standard Weight Steel Pipe using steam equations in



5 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./h							Pressure drop pipe governs sizes
	Pressure Drop psig/100 ft.			Velocity FPM (mph)				
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	5	7	10					Pressure drop pipe governs sizes
3/4	11	15	22	22				
1	22	31	44	35				
Notes:	48	69	97	61				
1/4	75	106	150	83				
1-	153	216	305	137	275			
1-1/2								

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,000

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h				Velocity FPM (mph)
	0.125	0.25	0.5	(23)	(45)	(68)	(91)	
2	251	355	503	196	392	587	782	
3	460	651	914	302	605	907	1210	
4	972	1,375	1,944	520	1,040	1,560	2,080	
5	1,789	2,529	3,577	815	1,631	2,446	3,261	
6	2,952	4,174	5,903	1,182	2,364	3,546	4,728	
8	6,144	8,689		2,047	4,094	6,141	8,188	
10	11,212	15,856		3,226	6,453	9,679	12,906	
12	17,995	25,449		4,628	9,255	13,883	18,510	
14	23,309	32,964		5,642	11,284	16,926	22,567	
16	33,599			7,474	14,947	22,421	29,894	
18	46,237			9,562	19,125	28,687	38,250	
20	61,380			11,908	23,817	35,725	47,633	
22	79,175			14,511	29,023	43,534	58,045	
24	99,764			17,371	34,743	52,114	69,486	
26				20,489	40,977	61,466	81,955	
28				23,863	47,726	71,589	95,452	
30				27,494	54,988	82,483	109,977	
32				31,383	62,765	94,148	125,531	
34	Velocity	governs	with	35,528	71,056	106,585	142,113	
36	these	pipe	sizes	39,931	79,862	119,792	159,723	
42				54,681	109,362	164,044	218,725	
48				71,745	143,491	215,236	286,981	
54				91,123	182,247	273,370	364,493	
60				112,815	225,630	338,445	451,260	
72							163,140	
84							222,720	
96							291,555	

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,000 FPM
2. Table based on Standard Weight Steel Pipe using steam equations in

7 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Steam Flow lbs./h

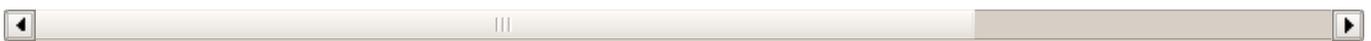
Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mp			
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	5	7	10		Pressure drop these pipe	governs sizes	
3/4	11	16	23				
1	23	33	46	39			
1-1/4	51	72	101	67	300		
1-1/2	79	111	157	91			
2	160	226	319	150			
2-1/2	263	372	526	214			
3	481	680	956	331	429	1,709	
4	1,016	1,438	2,033	570			
5	1,870	2,645	3,741	892			
6	3,087	4,365	6,174	1,293			
8	6,426	9,087	12,851	2,239	1,783	2,675	3,567
10	11,726	16,583	with sizes	3,529	7,057	10,586	14,115
12	18,819	26,614		5,061	10,122	15,183	20,244
14	24,376	34,473		6,170	12,341	18,511	24,682
16	35,138	governs pipe		8,174	16,348	24,521	32,695
18	48,354		10,458	20,917	31,375	41,833	
20	64,191		13,024	26,048	39,072	52,096	
22	82,801		15,871	31,742	47,613	63,483	
24	104,332		18,999	37,998	56,997	75,996	
26	128,924		22,408	44,816	67,224	89,633	
Notes:	Velocity			26,099	52,197	78,296	104,394
30	these		30,070	60,140	90,210	120,280	
32			34,323	68,646	102,968	137,291	

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6.00

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
34				38,857	106,570	155,427	
36				43,672	87,344	131,015	174,687
42				59,804	119,608	179,412	239,210
48				78,467	156,934	235,401	313,868
54				99,660	199,321	298,981	398,641
60				123,384	246,768	370,153	493,537
72				178,424	356,847	535,271	713,695
84				243,585	487,171	730,756	974,342
96				318,869	637,739	956,608	1,275,478

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./6,000 FPM
2. Table based on Standard Weight Steel Pipe using steam equations in



10 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h				Velocity FPM (mp)
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	
	1/2	8	11	15	15	Pressure	drop pipe	
3/4	17	24	34	27	these		sizes	
1	35	49	69	44				
1-	76	108	152	76	151			
1/4	118	167	236	103	206			
1-	240	339	479	169	339			
1/2								
2								
2-	395	558	790	242	484	725		
1/2	723	1,016	1,445	373	747	1,120		
3	1,527	2,160	3,054	643	1,286	1,929	2,572	
4								
Notes:	2,810	3,974	5,620	1,006	2,013	3,019	4,025	

Pipe Size	Pressure Drop psig/100 ft.		with sizes 1	Steam Flow lbs./h			
	0.25	0.5		2,000	4,000	6,000	8,000
6	4,637	6,558		1,459	5,836		
8	9,654	13,652		2,526	5,053	7,579	10,105
10	17,616	24,912		3,982	7,964	11,946	15,929
12	28,273			5,711	11,423	17,134	22,846
14	38,621			6,963 (23)	13,927 (45)	20,890 (68)	27,853 (91)
16	52,789	governs pipe		9,224	18,448	27,672	36,896
18				11,802	23,604	35,406	47,208
20				14,697	29,395	44,092	58,790
22	Velocity these			17,910	35,820	53,730	71,641
24				21,440	42,880	64,320	85,760
26				25,287	50,575	75,862	101,150
28				29,452	58,904	88,356	117,808
30				33,934	67,868	101,802	135,735
32				38,733	77,466	116,199	154,932
34				43,849	87,699	131,548	175,398
36				49,283	98,567	147,850	197,133
42				67,488	134,977	202,465	269,954
48				88,549	177,098	265,648	354,197
54			112,466	224,932	337,397	449,863	
60			139,238	278,476	417,714	556,952	
72			201,350	402,699	604,049	805,399	
84			274,884	549,768	824,653	1,099,537	
96			359,841	719,683	1,079,524	1,439,360	

Notes:

1. Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./6,000 FPM
2. Table based on Standard Weight Steel Pipe using steam equations in



12 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.		Steam Flow lbs./h			
	0.25	0.5	2,000	4,000	6,000	8,000
6	4,637	6,558	1,459	5,836		
8	9,654	13,652	2,526	5,053	7,579	10,105
10	17,616	24,912	3,982	7,964	11,946	15,929
12	28,273		5,711	11,423	17,134	22,846
14	38,621		6,963 (23)	13,927 (45)	20,890 (68)	27,853 (91)
16	52,789	governs pipe	9,224	18,448	27,672	36,896
18				11,802	23,604	35,406
20			14,697	29,395	44,092	58,790
22	Velocity these		17,910	35,820	53,730	71,641
24			21,440	42,880	64,320	85,760
26			25,287	50,575	75,862	101,150
28			29,452	58,904	88,356	117,808
30			33,934	67,868	101,802	135,735
32			38,733	77,466	116,199	154,932
34			43,849	87,699	131,548	175,398
36			49,283	98,567	147,850	197,133
42			67,488	134,977	202,465	269,954
48			88,549	177,098	265,648	354,197
54		112,466	224,932	337,397	449,863	
60		139,238	278,476	417,714	556,952	
72		201,350	402,699	604,049	805,399	
84		274,884	549,768	824,653	1,099,537	
96		359,841	719,683	1,079,524	1,439,360	

Pipe Size	Pressure Drop psig/100 ft.				Pressure these sizes	Velocity FPM (m/s)	
	0.25	0.5	1	2,000 (23)		4,000 (45)	6,000 (68)
8	18	25	36	47	221		
10	36	51	72	81	365		
1-1/4	79	112	158	111	221		
1-1/2	123	173	245	182	365		
2	249	352	497				
2-1/2	410	579	819	260	520	780	
3	750	1,054	1,499	402	803	1,205	
4	1,584	2,240	3,168	692	1,383	2,075	2,767
5	2,915	4,122	5,830	1,083	2,165	3,248	4,331
6	4,810	6,803		1,570	3,139	4,709	6,279
8	10,013	14,161		2,718	5,436	8,154	10,873
10	18,272			4,284	8,569	12,853	17,138
12	29,326			6,145	12,290	18,435	24,580
14	37,986			7,492	14,984	22,475	29,967
16	54,755	governs pipe sizes	with sizes	9,924	19,848	29,773	39,697
18	75,351			12,698	25,396	38,094	50,792
20				15,813	31,626	47,439	63,252
22	Velocity these sizes			19,270	38,539	57,809	77,079
24				23,068	46,135	69,203	92,270
26				27,207	54,414	81,621	108,828
28				31,688	63,375	95,063	126,750
30				36,510	73,019	109,529	146,039
32				41,673	83,346	125,019	166,693
34				47,178	94,356	141,534	188,712
36		53,024	103,048	159,073	212,097		
42	72,611	145,223	217,834	290,445			
48	95,271	190,542	285,812	381,093			
54	121,003	242,006	363,008	484,011			
60	149,807	299,615	449,422	599,229			

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			Velocity FPM (m/s)
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
72				216,634	433,267	649,901	866,535
84				295,750	591,500	887,250	1,183,000
96				387,156	774,312	1,161,468	1,548,624

Notes:

1. Maximum recommended pressure drop/velocity: 0.5 (68) psig/100 ft. (91) fpm
2. Table based on Standard Weight Steel Pipe using steam equations in



15 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./h						
	Pressure Drop psig/100 ft.			Velocity FPM (m/s)			
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
1/2	8	12	16		Pressure	drop pipe	governs sizes
3/4	19	26	37	32	these		
1	38	53	75	52			
1-1/4	83	117	166	90			
1-1/2	129	182	258	122	244		
2	261	370	523	201	403		
2-1/2	430	609	861	287	575	862	
3	788	1,107	1,575	444	887	1,331	3,055
4	1,665	2,354	3,329	764	1,528	2,291	
5	3,063	4,332	6,126	1,196	2,391	3,587	4,782
6	5,055	7,149	10,110	1,733	3,467	5,200	6,934
8	10,522	14,881		3,002	6,003	9,005	12,006
10	19,201	27,155	with sizes	4,731	9,463	14,194	18,925
12	30,817			6,786	13,572	20,358	27,143
14	39,918			8,273	16,546	24,820	33,093
Notes:	57,540	governs		10,959	21,918	32,878	43,837

Pipe Size	Pressure Drop psig/100 ft.	ft.	1	Steam Flow lbs./h			Velocity FPM (mp)
				2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)
18	79,183	pipe		14,022	28,045	42,067	56,089
20				17,462	34,925	52,387	69,849
22	Velocity these			21,279	42,559	63,838	85,118
24				25,473	50,947	76,420	101,894
26	0.25	0.5	1	30,044 (23)	60,089 (45)	90,133 (68)	120,178 (91)
28				34,992	69,985	104,977	139,970
30				40,317	80,635	120,952	161,270
32				46,019	92,039	138,058	184,078
34				52,098	104,197	156,295	208,394
36				58,554	117,109	175,663	234,218
42				80,184	160,368	240,553	320,737
48					105,207	210,414	315,621
54					133,623	267,245	400,868
60					165,431	330,863	496,294
72	239,227				478,455	717,682	956,909
84	326,595				653,190	979,785	1,306,38
96	427,534				855,069	1,282,603	1,710,13

Notes:

1. Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./6,000
2. Table based on Standard Weight Steel Pipe using steam equations in



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21.11. Medium-Pressure Steam Pipe Sizing Tables (20-100 psig)

20 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h				Velocity FPM (n
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,0 (11)	

Notes:	9	13	18		Pressure	drop pipe	govern
3/4	20	29	40		these		sizes
1	Maximum recommended pressure drop/velocity: 0.5 psig/100 ft. / 8,000						

1- Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)
1	41	57	81				
1-1/4	89	126	178				
1-1/2	139	196	277				
2	281	397	562	466			
2-1/2	463	655	926	665			
3	847	1,191	1,695	1,026	1,540		
4	1,790	2,532	3,581	1,767	2,651	3,535	
5	3,295	4,659	6,589	2,766	4,150	5,533	
6	5,437	7,689	10,874	4,011	6,016	8,022	10,027
8	11,318	16,006	22,636	6,945	10,418	13,891	17,364
10	20,653	29,208	with sizes	10,948	16,421	21,895	27,369
12	33,148	46,878		15,702	23,553	31,403	39,254
14	42,936	60,720		19,143	28,715	38,286	47,858
16	61,891	87,527		25,358	38,038	50,717	63,390
18	85,170	120,449		32,446	48,669	64,892	81,114
20	113,063			40,406	60,609	80,812	101,000
22	145,843	governs pipe		49,238	73,857	98,476	123,000
24	183,768			58,943	88,414	117,885	147,300
26	227,082			69,519	104,279	139,039	173,700
28	276,022			80,969	121,453	161,937	202,400
30	330,813		93,290	139,935	186,580	233,200	
32	397,670		106,484	159,726	212,968	266,200	
34	Velocity these		120,550	180,825	241,100	301,300	
36			135,488	203,232	270,977	338,700	
42			185,537	278,306	371,075	463,800	
48			243,437	365,156	486,875	608,500	
54		309,188	463,782	618,376	772,900		
60		382,790	574,185	765,580	956,900		
72		553,546	830,318	1,107,091	1,383,000		
84		755,705	1,133,557	1,511,409	1,889,000		
96		989,267	1,483,901	1,978,534	2,473,000		

Notes:

Steam Flow lbs./h

1. Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000 FPM

Pressure Drop psig/100

2. Table based on Standard Weight Steel Pipe using steam equations in

Pipe Size **Velocity FPM (ft/min)**

4,000 6,000 8,000 10,000

25 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./h						
	Pressure Drop psig/100 ft.				Velocity FPM (ft/min)		
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (113)
1/2	9	13	19		Pressure drop pipe these govern size:		
3/4	21	30	43				
1	43	61	86				
1-1/4	95	134	190	529			
1-1/2	148	209	295				
2	299	423	599				
2-1/2	493	697	986	754	1,747		
3	902	1,269	1,805	1,164			
4	1,907	2,697	3,814	2,005			
5	3,509	4,963	7,018	3,138	4,708	6,277	11,300
6	5,791	8,190	11,582	4,550	6,825	9,100	
8	12,055	17,048	24,110	7,879	11,819	15,759	
10	21,998	31,110	43,996	12,420	18,629	24,839	31,000
12	35,306	49,930		17,813	26,719	35,626	44,500
14	45,731	64,674		21,717	32,576	43,434	54,200
16	65,920	93,225	with sizes	28,768	43,152	52,536	71,900
18	90,715	128,291		36,809	55,213	73,617	92,000
20	120,424	170,306		45,839	68,758	91,677	114,000
Notes:	155,339	governs		55,858	83,788	111,717	139,000
24	195,732	pipe		66,868	100,302	133,735	167,000

Pipe Size	Pressure Drop psig/100 ft.		with sizes	Steam Flow lbs./h				Velocity FPM (ft/min)
	0.25	0.5		1	2	3	4	
2-1/2	521	737	1,043	843				
3	954	1,342	1,909	1,302				
4	2,195	2,852	4,000	2,243				
5	3,711	5,249	7,423	3,510	5,268	7,821	10,000	
6	6,125	8,662	12,249	5,065	7,668	10,979	14,000	
8	12,749	18,030	25,499	8,813	13,220	17,626	22,000	
10	23,265	32,902	46,530	13,891	20,837	27,783	34,700	
12	37,340	52,806	74,679	19,924	29,886	39,848	49,800	
14	48,365	68,399		24,291	36,436	48,582	60,700	
16	69,717	98,595	governs pipe	32,178	48,266	64,355	80,400	
18	95,940	135,680		41,171	61,757	82,342	102,000	
20	127,361	180,116		51,271	76,907	102,543	128,000	
22	164,286	232,336		62,479	93,718	124,957	156,000	
24	207,006			74,793	112,189	149,586	186,000	
26	255,799			88,214	132,321	176,428	220,000	
28	310,927			102,742	154,113	205,483	256,000	
30	372,647			118,376	177,565	236,753	295,000	
32	441,200			135,118	202,677	270,236	337,000	
34	516,825			152,967	229,450	305,933	382,000	
36	599,748		171,922	257,883	343,844	429,000		
42			235,430	353,145	470,860	588,000		
48	Velocity		308,900	463,349	617,799	772,000		
54	these		392,331	588,497	784,662	980,000		
60			485,725	728,587	971,450	1,210,000		
72			702,398	1,053,597	1,404,796	1,750,000		
84			958,919	1,438,379	1,917,839	2,390,000		
96			1,255,289	1,882,933	2,510,577	3,130,000		

Notes:

1. Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000
2. Table based on Standard Weight Steel Pipe using steam equations in

Steam Flow lbs./h

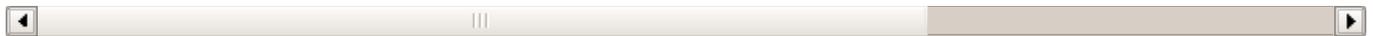
Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (ft/min)		
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (113)
	1/2	16	22	31		Pressure drop pipe these	drop pipe
3/4	35	50	71				
1	71	100	142				
1-1/4	156	221	312				
1-1/2	242	343	485	433			
2	492	695	984	713			
2-1/2	810	1,145	1,620	1,017	1,526		
3	1,473	2,097	2,965	1,571	2,356		
4	3,133	4,430	6,265	2,705	4,058	5,410	
5	5,764	8,152	11,529	4,234	6,352	8,469	10,5
6	9,513	13,453	19,026	6,139	9,209	12,278	15,3
8	19,802	28,005	39,605	10,631	15,946	21,261	26,5
10	36,136	51,103	with sizes	16,757	25,135	33,513	41,8
12	57,996	82,019		24,033	36,050	48,066	60,0
14	75,122	106,239		29,301	43,951	58,602	73,2
16	108,286	governs pipe		38,814	58,221	77,628	97,0
18	149,016		49,662	74,493	99,325	124,	
20	197,819		61,846	92,769	123,692	154,	
22	255,172			75,364	113,047	150,729	188,
24	321,526			90,218	135,327	180,437	225,
26	397,311			106,407	159,611	212,815	266,
28	Velocity these			123,932	185,897	247,863	309,
30		142,791	214,186	285,582	356,		
32		162,985	244,478	325,971	407,		
Notes:				184,515	276,773	369,030	461,
36				207,380	311,070	414,760	518,
42				283,986	425,979	567,972	709,

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,000

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h				Velocity FPM (ft/min)
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (118)	
48				372,608	558,912	745,216	931,104	1,118
54				473,247	709,871	946,494	1,188,000	1,46
60				585,903	878,854	1,171,805	1,46	
72	0.5	1	2	847,264	1,270,895	1,694,527	2,118,152	2,71
84				1,156,691	1,755,036	2,313,382	2,89	(1
96				1,514,184	2,271,277	3,028,369	3,78	

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,000 lbs./h
2. Table based on Standard Weight Steel Pipe using steam equations in



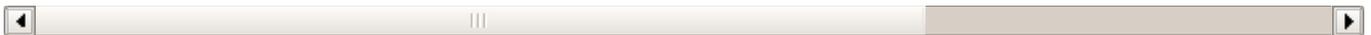
50 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h				Velocity FPM (ft/min)
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (118)	
	1/2	17	24	34				
3/4	38	54	76					
1	77	109	154					
1-	169	239	338					
1/4	263	371	525	508				
1-	533	753	1,065	837				
1/2								
2								
2-	877	1,241	1,755	1,194		6,348		
1/2	1,569	2,271	3,212	1,843	2,765			
3	3,393	4,799	6,786	3,174	4,761			
4								
5	6,244	8,830	12,488	4,968	7,453	9,937	12,4	
6	10,304	14,573	20,609	7,203	10,805	14,407	18,0	
8	21,450	30,335	42,900	12,473	18,710	24,947	31,1	

Pipe Size	Pressure Drop, psig/100 ft.			with sizes	Steam Flow lbs./h			
	0.5	1	2		4,000 (45)	6,000 (68)	8,000 (91)	10,000 (118)
10	39,142	55,355	with	19,661	29,492	39,322	49,152	
12	62,822	88,844	sizes	28,199	42,298	56,398	70,497	
14	81,373	115,078	2	34,380	51,570	68,759	85,948	
16	117,296	165,882		45,542	68,313	91,084	113,855	
18	161,415	1		58,270	87,406	116,541	145,677	
20	214,279			72,566	108,849	145,132	181,267	
22	276,404	governs pipe		88,428	132,641	176,855	221,070	
24	348,279			105,856	158,784	211,712	264,927	
26	430,370			124,851	187,277	249,703	312,552	
28	523,121			145,413	218,120	290,826	363,951	
30	626,961			167,541	251,312	335,083	418,218	
32				191,236	286,854	382,473	478,785	
34	Velocity these	216,498		324,747	432,996	541,245		
36		243,326		364,989	486,652	608,902		
42		333,210		499,815	666,420	833,527		
48		437,194		655,790	874,387	1,094,112		
54		555,277		832,915	1,110,553	1,386,679		
60		687,459		1,031,189	1,374,918	1,719,294		
72		994,123		1,491,184	1,988,245	2,486,700		
84		1,357,184		2,035,776	2,714,368	3,395,520		
96		1,776,643	2,664,965	3,553,286	4,442,112			

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,000 lbs./h
2. Table based on Standard Weight Steel Pipe using steam equations in



60 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (118)
18	25	36		Pressure	drop pipe	gove	

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h				Velocity FPM (ft/min)
	41	58	82	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (118)	
1/4	181	256	362					
1/2	281	397	562					
1	570.5	806.1	1,140.2	957 (45)	6,000 (68)	8,000 (91)	10,000 (118)	
1 1/2								
2								
2 1/2	938	1,327	1,877	1,366				
3	1,707	2,429	3,436	2,109	3,164			
4	3,630	5,133	7,260	3,632	5,449			
5	6,680	9,446	13,359	5,686	8,529	11,371		
6	11,023	15,589	22,046	8,243	12,365	16,487	20,6	
8	22,946	32,451	45,893	14,274	21,412	28,549	35,6	
10	41,873	59,217	83,745	22,500	33,750	45,000	56,2	
12	67,204	95,041		32,270	48,406	64,541	80,6	
14	87,049	123,106		39,344	59,015	78,687	98,3	
16	125,479	177,454	with sizes governs pipe	52,117	78,176	104,235	130,	
18	172,676	244,200		66,684	100,026	133,368	166,	
20	229,227	324,176		83,043	124,565	166,086	207,	
22	295,686			101,195	151,793	202,391	252,	
24	372,575			121,140	181,710	242,280	302,	
26	460,392			142,878	214,317	285,756	357,	
28	559,614			166,408	249,613	332,817	416,	
30	670,697			191,732	287,598	383,464	479,	
32	794,082			218,848	328,272	437,696	547,	
34	Velocity these			247,757	371,635	495,514	619,	
36			278,459	417,688	556,917	696,		
42			381,321	571,981	762,641	953,		
48			500,318	750,477	1,000,636	1,25		
54			635,450	953,176	1,270,901	1,58		
60			786,718	1,180,077	1,573,436	1,96		
Notes:				1,137,659	1,706,489	2,275,318	2,84	
84				1,553,141	2,329,711	3,106,282	3,88	
96				2,033,164	3,049,746	4,066,328	5,08	

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,000 FPM

Steam Flow lbs./h

Notes:

Pressure Drop psig/100

1. **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft. / 12,000 FPM**

2. **Table based on Standard Weight Steel Pipe using steam equations in**

0.5 1 2 4,000 6,000 8,000 10,000
(45) (68) (91) (114) (137) (160) (183)



75 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Steam Flow lbs./h

Pipe Pressure Drop psig/100 ft.

Velocity FPM

Size

0.5

1

2

**4,000
(45)**

**6,000
(68)**

**8,000
(91)**

**10,000
(114)**

1/2	20	28	39		Pressure drop pipe these	drop pipe go siz	
3/4	45	63	89				
1	90	127	179				
1-1/4	197	279	394				
1-1/2	306	433	612				
2	621	879	1,243	1,138			
2-1/2	1,023	1,447	2,046	1,624			
3	1,862	2,649	3,746	2,507			
4	3,957	5,597	7,915	4,318	6,477		
5	7,283	10,299	14,565	6,758	10,138	13,517	
6	12,018	16,997	24,036	9,799	14,698	19,597	
8	25,018	35,380	50,035	16,967	25,451	33,935	42
10	45,652	64,562	91,304	26,745	40,117	53,489	66
12	73,270	103,620		38,359	57,538	76,718	95
14	94,906	134,218		46,766	70,150	93,533	11
16	136,805	193,471	with	61,950	92,925	123,900	15
18	188,261	266,242	sizes	79,265	118,897	158,530	19
20	249,917	353,436		98,711	148,066	197,422	24
Notes:	322,374	governs		120,288	180,431	240,575	30
24	406,202	size		142,006	215,002	287,001	35

Pipe Size	Pressure Drop psig/100 ft.		Steam Flow lbs./h		Velocity FPM	
	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	
24	406,203	pipe	143,996	215,993	287,991	35
26	501,947		169,834	254,752	339,669	42
28	610,125		197,804	296,707	395,609	49
30	731,235		227,909	341,009	458,011	56
32	865,756		260,458	390,206	520,275	65
34	1,014,152		294,501	441,751	589,001	73
36	1,176,871		330,995	496,492	661,990	82
42			453,264	679,896	906,527	1,100
48	Velocity these		594,712	892,068	1,189,424	1,400
54			755,340	1,133,009	1,510,679	1,800
60			935,147	1,402,720	1,870,293	2,200
72			1,352,299	2,028,449	2,704,598	3,200
84		1,846,169	2,769,254	3,692,339	4,400	
96		2,416,757	3,625,136	4,833,514	6,000	

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,000
2. Table based on Standard Weight Steel Pipe using steam equations in



85 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			Velocity FPM
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	21	29	41		Pressure drop pipe these		g s
3/4	47	66	94				
1	94	133	188				
1-1/4	207	293	415				
1-1/2	322	455	644				
2	653	924	1,306	1,258			
Notes:	1,076	1,521	2,151	1,794			

3 4 Pipe Size	1,957 4,160 Pressure	2,784 5,883 Drop psig/100 ft.	3,938 8,320	2,771 4,771	Steam Flow lbs./h 7,157	Velocity FP	
				4,000 7,468 (45)	6,000 11,202 (68)	8,000 14,936 (91)	
5	7,605	10,826	15,211	7,468 (45)	11,202 (68)	14,936 (91)	
6	12,633	17,866	25,267	10,828	16,241	21,655	
8	26,298	37,192	52,597	18,749	28,124	37,499	4
10	47,989	67,867	95,979	29,553	44,330	59,107	7
12	77,021	108,925	154,043	42,387	63,580	84,774	1
14	99,765	141,089		51,678	77,516	103,355	1
16	143,808	203,376		68,456	102,684	136,911	1
18	197,899	279,872		87,589	131,383	175,178	2
20	262,712	371,531		109,077	163,615	218,153	2
22	338,879	479,247		132,919	199,379	265,839	3
24	426,999			159,117	238,675	318,234	3
26	527,645			187,669	281,504	375,338	4
28	641,361			218,576	327,865	437,153	5
30	768,671			251,838	377,758	503,677	6
32	910,079			287,455	431,183	574,910	7
34	1,066,072	governs pipe with sizes	with sizes	325,427	488,140	650,854	8
36	1,237,121			365,753	548,630	731,507	9
42	1,845,105			500,862	751,293	1,001,724	1
48	Velocity			657,164	985,746	1,314,328	1
54	these			834,660	1,251,989	1,669,319	2
60				1,033,349	1,550,023	2,066,697	2
72	1,494,307			2,241,461	2,988,614	3,735,768	4
84	2,040,040	3,060,060	4,080,080	5,100,099	6		
96	2,670,546	4,005,820	5,341,093	6,676,366	8		

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,000
2. Table based on Standard Weight Steel Pipe using steam equations in

Steam Flow lbs./h

Pipe Size	Pressure Drop psig/100 ft.			Velocity FP			g s
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	
	1/2	22	31	44		Pressure these	
3/4	50	71	100				
1	101	142	201				
1-1/4	222	313	443				
1-1/2	344	486	688				
2	698	987	1,396				
2-1/2	1,149	1,625	2,299	2,049	8,173		
3	2,091	2,975	4,208	3,164			
4	4,446	6,287	8,891	5,449			
5	8,181	11,569	16,362	8,529	12,793	24,730	5
6	13,501	19,093	27,001	12,365	18,548		
8	28,104	39,744	56,207	21,412	32,117		
10	51,283	72,526	102,567	33,750	50,624	67,499	8
12	82,308	116,402	164,617	48,406	72,608	96,811	1
14	106,613	150,773	213,226	59,015	88,523	118,031	1
16	153,680	217,336	with sizes	78,176	117,264	156,352	1
18	211,483	299,083		100,026	150,039	200,052	2
20	280,745	397,033		124,565	186,847	249,129	3
22	362,139	512,142	governs pipe	151,793	227,689	303,586	3
24	456,309	645,318		181,710	272,565	363,421	4
26	563,863	797,422		214,317	321,475	428,634	5
28	685,384			249,613	374,419	499,225	6
30	821,433			287,598	431,397	575,195	7
32	972,548			328,272	492,408	656,544	8
34	1,139,248			371,635	557,453	743,271	9
36	1,322,038			417,688	626,532	835,376	1
42	1,971,754			571,981	857,971	1,143,962	1

Pipe Size	Pressure Drop psig/100 ft.	Steam Flow lbs./h			Velocity FPI		
		1	2				
48	2,783,057			750,477	1,125,715	1,500,954	1
54				953,176	1,429,763	1,906,351	2
60				1,180,077	1,770,116	2,360,154	2
72	Velocity 0.5	1	2	1,706,489	2,359,733	3,412,977	4
84	these			2,329,711	3,494,567	4,659,423	5
96				3,049,746	4,574,618	6,099,491	7

Notes:

1. Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./12,000
2. Table based on Standard Weight Steel Pipe using steam equations in



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21.12. High-Pressure Steam Pipe Sizing Tables (120-300 psig)

120 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			Velocity FPI
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	34	48	75				1
3/4	76	108	171				2
1	154	217	344				2
1-1/4	338	478	756	746			4
1-1/2	525	743	1,174	1,015			5
2	1,065	1,507	2,382	1,673			7
2-1/2	1,755	2,481	3,923	2,387	3,581	12,696	10
3	3,212	4,542	7,181	3,686	5,530		15
4	6,786	9,597	15,175	6,348	9,522		20
Notes:	12,488	17,661	27,924	9,937	14,905	19,873	24
6	20,609	29,145	46,083	14,407	21,610	28,813	36
8	42,900	60,670	94,447	24,947	37,420	49,894	62

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000

Pipe Size	Pressure Drop psig/100 ft.			with sizes	Steam Flow lbs./h			Velocity FPM
	1	2	5		4,000 (45)	6,000 (68)	8,000 (91)	
10	78,284	110,711			39,322	58,983	78,644	98
12	125,544	177,898			56,398	84,597	112,796	14
14	162,745	230,156			68,750	103,130	137,510	17
16	234,593	331,764			91,064	136,925	182,167	22
18	322,831				116,541	174,811	233,082	29
20	428,558				145,132	217,697	290,263	36
22	552,808	governs pipe			176,855	265,283	353,711	44
24	696,558				211,712	317,568	423,425	52
26	860,739				249,703	374,554	499,405	62
28	1,046,243			290,826	436,239	581,652	72	
30	1,253,922			335,083	502,624	670,165	83	
32				382,473	573,709	764,945	95	
34	Velocity these			432,996	649,493	865,991	1,0	
36				486,652	729,978	973,304	1,2	
42				666,420	999,630	1,332,840	1,6	
48				874,387	1,311,581	1,748,775	2,2	
54				1,110,553	1,665,830	2,221,107	2,7	
60				1,374,918	2,062,378	2,749,837	3,4	
72				1,998,245	2,982,368	3,976,491	4,9	
84				2,714,368	4,071,552	5,428,736	6,7	
96				3,553,286	5,329,929	7,106,572	8,8	

Notes:

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000
2. Table based on Standard Weight Steel Pipe using steam equations in



125 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h			
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	1
Notes:	34	48	77		Pressure	drop pipe	go

Pipe Size	Pressure Drop psig/100 ft.				Steam Flow lbs./h		Velocity FPI
	78	110	174		6,000	8,000	
1/4	156	221	350	1,051	4,000	6,000	8,000
1/2	344	487	770	1,733	(45)	(68)	(91)
3/4	534	756	1,155	2,472	3,708	13,146	
1	1,084	1,533	2,424	3,817	5,726		
1 1/2				6,573	9,860		
2	1,785	2,525	3,992	10,289	15,433	20,578	25
2 1/2	3,268	4,622	7,308	14,917	22,376	29,834	37
3	6,905	9,766	15,441	25,831	38,746	51,661	64
4							
5	12,707	17,971	28,414	40,715	61,073	81,430	10
6	20,971	29,657	46,892	58,396	87,594	116,792	14
8	43,654	61,735		71,195	106,793	142,391	17
10	79,659	112,655	with	94,310	141,466	188,621	23
12	127,850	180,808	sizes	120,670	181,005	241,339	30
14	165,603	234,198		150,273	225,410	300,546	37
16	238,712	337,590		183,121	274,681	366,242	45
18	328,499			219,213	328,819	438,426	54
20	436,083			258,549	387,823	517,098	64
22	562,515	governs		301,129	451,694	602,259	75
24	708,789	pipe		346,954	520,431	693,908	86
26	875,854			396,023	594,034	792,045	99
28	1,064,614			448,336	672,504	896,671	1,1
30	1,275,940			503,893	755,839	1,007,786	1,1
32				690,030	1,035,045	1,380,060	1,1
34	Velocity			905,365	1,358,047	1,810,730	2,1
36	these			1,149,898	1,724,847	2,299,796	2,1
42				1,423,629	2,135,443	2,847,258	3,1
48				2,058,684	3,088,027	4,117,369	5,1
54				2,810,532	4,215,798	5,621,064	7,0
60				3,679,171	5,518,757	7,358,343	9,1
Notes:							
84							
96							

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000

Notes:

Steam Flow lbs./h

- Pipe Pressure Drop psig/100 ft. Velocity FPI**
1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000
Size 4,000 6,000 8,000 1
2. Table based on Standard Weight Steel Pipe using steam equations in
(45) (68) (91)

150 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Steam Flow lbs./h

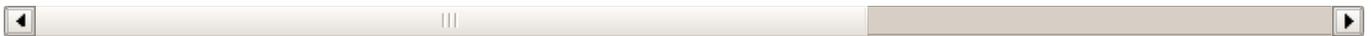
Pipe Pressure Drop psig/100 ft. Velocity FPI
Size 1 2 5 4,000 6,000 8,000
(45) (68) (91)

1/2	37	52	83		Pressure drop pipe these	g s	
3/4	84	119	188				
1	169	239	378				
1-	372	526	832	1,230			
1/4	578	817	1,292	2,027			
1-	1,173	1,658	2,622				
1/2							
2							
2-	1,931	2,731	4,318	2,893	6,700	15,382	
1/2	3,535	4,999	7,905	4,466	11,537		
3	7,470	10,564	16,703	7,691			
4							
5	13,746	19,439	30,736	12,039	18,059	24,078	3
6	22,684	32,080	50,724	17,455	26,182	34,909	4
8	47,221	66,780	105,589	30,225	45,337	60,449	7
10	86,168	121,861		47,641	71,462	95,282	1
12	138,298	195,583		68,330	102,494	136,659	1
14	179,135	253,336		83,306	124,960	166,613	2
16	258,219	365,176		110,354	165,530	220,707	2
18	355,343	502,531		141,197	211,795	282,394	3
20	471,718			175,836	263,754	351,672	4
Notes:	608,481			214,272	321,407	428,543	5
24	766,709			256,503	384,755	513,006	6

24	700,700			230,500	304,700	310,000	0
26	947,425			302,531	453,796	605,061	7
Pipe Size	Pressure Drop psig/100 ft.	governs	with		Steam Flow lbs./h	Velocity F	
28	1,151,610	pipe	sizes	352,354	528,532	704,709	8
30	1,380,205			405,000	608,000	818,000	1
32	1,634,114			467,480	697,680	926,920	1
34	1,914,211			524,602	786,903	1,049,204	1
36				589,610	884,415	1,179,220	1
42				807,411	1,211,116	1,614,822	2
48				Velocity these	1,059,376	1,589,065	2,118,753
54	1,345,507				2,018,260	2,691,013	3
60	1,665,802				2,498,703	3,331,604	4
72	2,408,887				3,613,330	4,817,773	6
84	3,288,631	4,932,946	6,577,262	8			
96	4,305,034	6,457,551	8,610,068	1			

Notes:

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000
2. Table based on Standard Weight Steel Pipe using steam equations in



175 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Steam Flow lbs./h

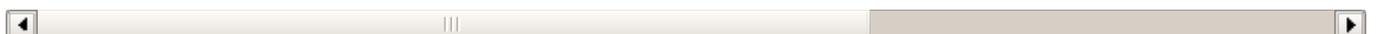
Pipe Size	Pressure Drop psig/100 ft.			Velocity F		
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)

1/2	40	56	89	2,322	Pressure these	drop pipe
3/4	90	127	201			
1	181	256	405			
1-1/4	398	563	891	3,312	7,672	17,614
1-1/2	618	875	1,383			
2	1,255	1,775	2,806			
Notes:	2,067	2,923	4,621			

Pipe Size	Pressure Drop psig/100 ft.	Steam Flow lbs./h	Velocity F			
1/2	3,783	5,350	8,459	5,114	13,211	
3/4	7,993	11,304	17,874	8,807		
5	14,709	20,802	32,891	13,786	20,679	27,572
6	24,274	34,329	54,279	19,987	29,981	39,974
8	50,531	71,461	112,990	34,610	51,916	69,221
10	92,208	130,402	with sizes	54,554	81,831	109,108
12	147,992	209,292		78,245	117,367	156,489
14	191,692	271,093		95,394	143,092	190,789
16	276,318	390,773		126,366	189,549	252,732
18	380,251	537,756		161,685	242,527	323,370
20	504,783	713,872		201,351	302,026	402,701
22	651,133	governs pipe		245,363	368,045	490,726
24	820,451			293,723	440,584	587,445
26	1,013,835			346,429	519,643	692,858
28	1,232,333			403,482	605,223	806,964
30	1,476,951			464,882	697,324	929,765
32	1,748,657			530,630	795,944	1,061,259
34	2,048,388			600,724	901,085	1,201,447
36	2,377,048			675,165	1,012,747	1,350,329
42			924,569	1,386,853	1,849,138	
48	Velocity		1,213,095	1,819,643	2,426,191	
54	these	1,540,744	2,311,117	3,081,489		
60		1,907,515	2,861,273	3,815,031		
72	2,758,425	4,137,637	5,516,849	6,896,061		
84	3,765,823	5,648,734	7,531,645	9,414,556		
96	4,929,710	7,394,564	9,859,419	12,324,274		

Notes:

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000
2. Table based on Standard Weight Steel Pipe using steam equations in



Steam Flow lbs:/h

Pipe Size	Pressure Drop psig/100 ft:			Velocity		
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)

1/2	42	59	94		Pressure drop pipe these	
3/4	96	135	214			
1	192	272	430			
1-	423	598	946	2,616		
1/4	656	928	1,468			
1-	1,332	1,884	2,978			
1/2						
2-	2,194	3,102	4,905	3,732	8,644	
1/2	4,015	5,679	8,979	5,763	14,885	
3	8,485	11,999	18,972	9,923		
4						
5	15,613	22,081	34,913	15,533	23,299	31,066
6	25,766	36,439	57,616	22,520	33,780	45,040
8	53,637	75,854	119,935	38,996	58,494	77,992
10	97,876	138,418	218,858	61,467	92,200	122,934
12	157,089	222,157		88,159	132,239	176,319
14	203,475	287,757		107,482	161,224	214,965
16	293,303	414,794	with sizes	142,379	213,568	284,758
18	403,625	570,811		182,173	273,260	364,346
20	535,812	757,753		226,865	340,297	453,730
22	691,157	977,444		276,455	414,682	552,909
24	870,884	1,231,615		330,942	496,413	661,884
26	1,076,154			390,327	585,491	780,654
28	1,308,083	governs pipe		454,610	681,915	909,220
30	1,567,737		523,791	785,686	1,047,581	
32	1,856,146		597,869	896,804	1,195,738	
34	2,174,300			676,845	1,015,268	1,353,690
36	2,523,162			760,719	1,141,078	1,521,438
42	3,763,171			1,041,727	1,562,590	2,083,454
48	5,411,000			1,366,015	2,050,000	2,722,000

Pipe Size	Pressure Drop psig/100 ft.	Steam Flow lbs./h			Velocity		
		1	2	5			
48	Velocity these				1,366,815	2,050,222	2,733,629
54					1,735,982	2,603,973	3,471,964
60					2,149,229	3,223,844	4,298,438
72					3,400,562	4,661,943	6,215,925
84					4,245,014	6,364,221	8,486,028
96					5,554,385	8,331,577	11,108,770

Notes:

1. Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000
2. Table based on Standard Weight Steel Pipe using steam equations in



225 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Steam Flow lbs./h

Pipe Size	Pressure Drop psig/100 ft.			Velocity		
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)
1/2	44	63	99		Pressure these	drop pipe
3/4	101	143	225			
1	203	287	453			
1-1/4	446	631	998	2,912		
1-1/2	693	980	1,549			
2	1,405	1,987	3,142			
2-1/2	2,314	3,273	5,175	4,154	16,568	
3	4,236	5,991	9,473	6,414		
4	8,952	12,660	20,017	11,046		
5	16,473	23,296	36,834	17,290	25,935	34,579
6	27,185	38,445	60,787	25,067	37,601	50,134
8	56,589	80,029	126,536	43,407	65,110	86,814
Notes:	103,263	146,036	230,904	68,419	102,629	136,838
12	165,735	234,384		98,131	147,196	196,262

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000

Pipe Size	Pressure Drop psig/100 ft.			with sizes	Steam Flow lbs./h		
	1	2	5		4,000 (45)	6,000 (68)	8,000 (91)
14	214,674	303,595		119,639	179,459	239,279	
16	309,447	437,623		158,483	237,724	316,966	
18	425,840	602,228		202,778	304,167	405,556	
20	565,302	799,458		252,929	378,799	505,050	
22	729,198	1,031,241		307,724	461,585	615,447	
24	918,816	1,299,402		368,374	552,561	736,748	
26	1,135,385	1,605,676		434,476	651,714	868,952	
28	1,380,078	governs pipe		506,029	759,044	1,012,059	
30	1,654,023			583,035	874,552	1,166,070	
32	1,958,305			665,492	998,238	1,330,984	
34	2,293,971			753,401	1,130,101	1,506,802	
36	2,662,034			846,761	1,270,142	1,693,523	
42	3,970,291			1,159,553	1,739,330	2,319,107	
48	5,603,917		1,521,411	2,282,116	3,042,821		
54			1,932,333	2,898,500	3,864,666		
60			2,392,321	3,588,482	4,784,643		
72	Velocity		3,459,494	5,189,240	6,918,987		
84	these		4,722,928	7,084,391	9,445,855		
96			6,182,623	9,273,934	12,365,246		

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000 ft./hr.
2. Table based on Standard Weight Steel Pipe using steam equations in



250 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			4,000 (45)	Steam Flow lbs./h	
	1	2	5		6,000 (68)	8,000 (91)
1/2	47	66	104		Pressure drop pipe these	
3/4	106	150	236			
1	213	301	476			
Notes:	168	662	1,047	3,205		

Pipe Size	Pressure Drop psig/100 ft.				Steam Flow lbs./h		
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	
1-1/4	727	1,028	1,625	3,200			
2							
2-1/2	2,428	3,434	5,430	4,573	18,239		
3	4,445	6,286	9,939	7,061			
4	9,392	13,283	21,002	12,160			
5	17,283	24,442	38,647	19,033	28,550	38,066	
6	28,522	40,337	63,778	27,595	41,393	55,190	
8	59,374	83,967	132,764	47,784	71,676	95,568	
10	108,345	153,223	242,267	75,319	112,978	150,638	
12	173,891	245,919	388,831	108,027	162,040	216,054	
14	225,238	318,535		131,705	197,557	263,409	
16	324,675	459,160		174,465	261,698	348,930	
18	446,796	631,865		223,227	334,841	446,455	
20	593,122	838,801		277,991	416,986	555,982	
22	765,083	1,081,991		338,756	508,134	677,512	
24	964,032	1,363,348		405,522	608,284	811,045	
26	1,191,259	1,684,694		478,291	717,436	956,581	
28	1,447,994	2,047,773		557,060	835,590	1,114,120	
30	1,735,421			641,831	962,747	1,283,662	
32	2,054,677			732,604	1,098,905	1,465,207	
34	2,406,861	governs pipe	with sizes	829,378	1,244,067	1,658,755	
36	2,793,037			932,153	1,398,230	1,864,306	
42	4,165,676			1,276,489	1,914,733	2,552,977	
48	5,879,695			1,674,837	2,512,256	3,349,675	
54	7,959,549			2,127,200	3,190,800	4,254,399	
60				2,633,575	3,950,363	5,267,151	
72	Velocity				3,808,367	5,712,550	7,616,734
84	these				5,199,212	7,798,818	10,398,424
96					6,806,111	10,209,166	13,612,224

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000

2. Table based on Standard Weight Steel Pipe using steam equations in
Pipe Pressure Drop psig/100 ft. Steam Flow lbs./h Velocity

275 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.				Steam Flow lbs./h		Velocity
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	
1/2	49	69	109		Pressure	drop pipe	
3/4	110	156	247				
1	222	314	497				
1-	489	692	1,094				
1/4	759	1,074	1,689				
1-	1,541	2,179	3,445				
1/2							
2-	2,537	3,589	5,674	4,994	19,916		
1/2	4,645	6,569	10,386	7,711			
3	9,815	13,880	21,946	13,278			
4							
5	18,061	25,542	40,385	20,783	31,175	60,265	
6	29,805	42,151	66,646	30,133			
8	62,044	87,743	138,734	52,178			
10	113,217	160,113	253,161	82,245	123,368	164,490	
12	181,710	256,977	406,316	117,961			
14	235,367	332,859	526,296	143,816			
16	339,275	479,807	with sizes	190,508	285,762	381,017	
18	466,887	660,278		243,754			
20	619,793	876,519		303,554			
22	799,486	1,130,644		369,907	554,860	739,813	
24	1,007,382	1,424,653		442,813			
26	1,244,826	1,760,450		522,272			
Notes:	1,513,106	2,139,855		608,285	912,428	1,216,570	

30	1,813,457	2,564,616		700,851	1,051,277	1,401,703
32	2,147,070			799,971	1,199,956	1,599,942
Pipe Size	Pressure Drop psig/100 ft.	governs	5		Steam Flow lbs./h	Velocity
34	2,515,091	pipe 2		905,644	1,358,466	1,811,288
36	2,918,632			1,017,870	1,536,805	2,035,741
42	4,352,994			1,393,869	2,090,804	2,787,739
48	6,144,088			1,828,849	2,743,273	3,657,698
54	8,317,466			2,322,809	3,484,213	4,645,617
60				2,875,748	4,313,623	5,751,497
72	Velocity			4,158,569	6,237,854	8,317,138
84	these			5,677,311	8,515,966	11,354,620
96				7,431,974	11,147,960	14,863,940

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000
2. Table based on Standard Weight Steel Pipe using steam equations in



300 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Steam Flow lbs./h		
	1	2	5	4,000 (45)	6,000 (68)	8,000 (9)
1/2	51	72	113		Pressure	drop pipe
3/4	115	163	257		these	
1	232	327	518			
1-	509	720	1,139			
1/4	791	1,118	1,768			
1-	1,604	2,269	3,587			
1/2						
2						
Notes:	2,642	3,736	5,908	5,413	21,591	
1/2	4,836	6,839	10,814	8,359		
3	10,219	14,451	22,850	14,394		

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000
2. Table based on Standard Weight Steel Pipe using steam equations in

Pipe Size	Pressure Drop psig/100 ft.	Steam Flow lbs/hr	Velocity			
5	18,804	26,593	42,048	22,530	1,311	31
6	31,032	43,886	69,390	32,665	48,998	113,128
8	64,598	91,356	144,446	56,564	84,846	
				4,000		
10	117,879	166,706	263,586	89,158	6,000 (68)	8,000 (9)
12	189,193	267,559	423,047	127,875	139,737	178,316
14	245,059	346,565	547,968	155,904	191,813	255,751
16	353,245	499,564	with sizes	206,521	233,855	311,807
18	486,113	687,467		264,242	309,781	413,042
20	645,315	912,613		329,068	396,364	528,485
22	832,408	1,177,203		400,998	493,602	658,136
24	1,048,864	1,483,318		480,032	601,497	801,996
26	1,296,086	1,832,942		566,170	720,048	960,064
28	1,575,413	2,227,971		659,413	849,256	1,132,341
30	1,888,133	2,670,223		759,760	989,119	1,318,820
32	2,235,482	3,161,450		867,210	1,139,639	1,519,519
34	2,618,658	governs pipe		981,766	1,300,816	1,734,421
36	3,038,816		1,103,425	1,472,648	1,963,531	
42	4,532,243		1,511,028	1,655,137	2,206,841	
48	6,397,091		1,982,568	2,266,541	3,022,051	
54	8,659,966		2,518,046	2,973,852	3,965,131	
60	11,345,797		3,117,462	3,777,069	5,036,091	
72	Velocity these		4,508,107	4,676,193	6,234,921	
84			6,154,503	6,762,160	9,016,211	
96			8,056,649	9,231,754	12,309,001	
				12,084,973	16,113,201	

Notes:

1. Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000 lbs/hr
2. Table based on Standard Weight Steel Pipe using steam equations in



Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 21: Steam Piping Systems, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

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Part 22: Steam Condensate Piping Systems

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22. Part 22: Steam Condensate Piping Systems

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22.01. Steam Condensate Piping

A. Steam Condensate Pipe Sizing

1. Steam condensate pipe sizing criteria limits:
 - a. Pressure drop: 1/16–1.0 psig/100 ft.
 - b. Velocity–liquid systems: 150 ft./min. max.
 - c. Velocity–vapor systems: 5,000 ft./min. max.
2. Recommended steam condensate pipe sizing criteria:
 - a. Low-pressure systems:
 1. Pressure drop: 1/8–1/4 psig/100 ft.
 2. Velocity–vapor systems: 5,000 ft. per minute.
 - b. Medium-pressure systems:
 1. Pressure drop: 1/8–1/4 psig/100 ft.
 2. Velocity–vapor systems: 5,000 ft. per minute.
 - c. High-pressure systems:
 1. Pressure drop: 1/4–1/2 psig/100 ft.
 2. Velocity–vapor systems: 5,000 ft. per minute.
3. *Wet Returns.* Return pipes contain only liquid, no vapor. Wet condensate returns connect to the boiler below the waterline so the piping is always flooded.

4. *Dry Returns.* Return pipes contain saturated liquid and saturated vapor (most common). Dry condensate returns connect to the boiler above the waterline so the piping is not flooded and must be pitched in the direction of flow. Dry condensate returns often carry steam, air, and condensate.
5. *Open Returns.* The return system is vented to the atmosphere and condensate lines are essentially at atmospheric pressure (gravity flow lines).
6. *Closed Returns.* The return system is not vented to the atmosphere.
7. Steam traps and steam condensate piping should be selected to discharge at four times the condensate rating of air handling heating coils and three times the condensate rating of all other equipment for system startup.
8. Steam condensate liquid to steam volume ratio is 1:1600 at 0 psig.
9. *Flash Steam.* Flash steam is formed when hot steam condensate under pressure is released to a lower pressure; the temperature drops to the boiling point of the lower pressure, causing some of the condensate to evaporate forming steam. Flash steam occurs whenever steam condensate experiences a drop in pressure and thus produces steam at the lower pressure.
 - a. Low-pressure steam systems' flash steam is negligible and can be generally be ignored.
 - b. Medium- and high-pressure steam systems' flash steam is important to utilize and consider when sizing condensate piping.
 - c. Flash steam recovery requirements:
 1. To utilize flash steam recovery, the condensate must be at a reasonably high pressure (medium- and high-pressure steam systems) and the traps supplying the condensate must be capable of operating with the back pressure of the flash steam system.
 2. There must be a use or demand for the flash steam at the reduced pressure. Demand for steam at the lower pressure should be greater than the supply of flash steam. The demand for steam should occur at the same time as the flash steam supply.
 3. The steam equipment should be in close proximity to the flash steam source to minimize installation and radiation losses and to fully take advantage of the flash steam recovery system. Flash steam recovery

systems are especially advantageous when steam is utilized at multiple pressures within the facility and the distribution systems are already in place.

B. Steam Condensate System Design and Pipe Installation Guidelines

1. The minimum recommended steam condensate pipe size is 3/4 in.
2. Locate all valves, strainers, unions, and flanges so they are accessible. All valves (except control valves) and strainers should be the full size of the pipe before reducing the size to make connections to equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 ft. or more), to permit disassembly for alteration and repairs.
3. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level. The chain should extend to 5'0"-7'0" above the floor level.
4. All valves should be installed so the valve remains in service when equipment or piping on the equipment side of the valve is removed.
5. Locate all flow measuring devices in accessible locations with a straight section of pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of the device, or as recommended by the manufacturer.
6. Provide vibration isolators for all piping supports connected to, and within 50 ft. of, isolated equipment, except at base elbow supports and anchor points, throughout mechanical equipment rooms, and for supports of steam mains within 50 ft. of the boiler or pressure reducing valves.
7. Drip leg collection points on steam piping should be the same size as the steam piping to prevent steam condensate from passing over the drip leg and thus decreasing the risk of water hammer. The drip leg collection point should be a minimum of 12 in. long, including a minimum 6-in.-long dirt leg with the steam trap outlet above the dirt leg.
8. Pitch all steam return lines downward in the direction of condensate flow 1/2" per 10 ft. (1" per 20 ft.) minimum.
9. Drip legs must be installed at all low points, downfed runouts to all equipment, at the end of mains, the bottom of risers, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.

10. On straight runs with no natural drainage points, install drip legs at intervals not exceeding 200 ft. where the pipe is pitched downward in the direction of steam flow, and a maximum of 100 ft. where the pipe is pitched up so that condensate flow is opposite of steam flow.
11. Steam traps used on steam mains and branches shall be at minimum 3/4" size.
12. When elevating steam condensate to an overhead return main, it requires 1 psi to elevate condensate 2 ft. Try to avoid elevating condensate.
13. Steam condensate in a steam system should be maintained at a pH of approximately 8-9. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline.

C. Low-Pressure Steam Condensate Pipe Materials (0-15 psig)

1. 2" and smaller:

a. Pipe:	black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B.</i>
Fittings:	black cast iron screw fittings, 250 lbs., <i>ANSI/ASME B16.4.</i>
Joints:	pipe threads, general purpose (American) <i>ANSI/ASME B1.20.1.</i>

2. 2-1/2" and larger:

a. Pipe:	black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B.</i>
Fittings:	steel butt-welding fittings, 250 lbs., <i>ANSI/ASME B16.9.</i>
Joints:	welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9.</i>

D. Medium-Pressure Steam Condensate Pipe Materials (16-100 psig)

1. 2" and smaller:

a. Pipe:	black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B.</i>
Fittings:	black cast iron screw fittings, 250 lbs., <i>ANSI/ASME B16.4.</i>
Joints:	pipe threads, general purpose (American) <i>ANSI/ASME B1.20.1.</i>

2. 2-1/2" and larger:

a. Pipe:	black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B.</i>
Fittings:	steel butt-welding fittings, 250 lbs., <i>ANSI/ASME B16.9.</i>
Joints:	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

E. High-Pressure Steam Condensate Pipe Materials (100-300 psig)

1. 1-1/2" and smaller:

a. Pipe	black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B.</i>
Fittings	forged steel socket-weld, 300 lbs., <i>ANSI B16.11.</i>
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.
b. Pipe	carbon steel pipe, <i>ASTM A106, Schedule 80, Grade B.</i>
Fittings	forged steel socket-weld, 300 lbs., <i>ANSI B16.11.</i>
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

2. 2" and larger:

a. Pipe	black steel pipe, <i>ASTM A53, Schedule 80</i> , Type E or S, Grade B.
Fittings	steel butt-welding fittings, 300 lbs., <i>ANSI/ASME B16.9</i> .
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.
b. Pipe	carbon steel pipe, <i>ASTM A106, Schedule 80</i> , Grade B.
Fittings	steel butt-welding fittings, 300 lbs., <i>ANSI/ASME B16.9</i> .
Joints	welded pipe, ANSI/AWS D1.1 and ANSI/ASME Sec. 9.

F. Pipe Testing

1. 1.5 × system working pressure.
2. 100 psi minimum.

G. Steam Traps

1. Steam trap types:
 - a. A steam trap is a self-actuated valve that closes in the presence of steam and opens in the presence of steam condensate or noncondensable gases.
 - b. Thermostatic traps: React to differences in temperature between steam and cooled condensate. Condensate must be subcooled for the trap to operate properly. Thermostatic traps work best in drip and tracing services and where steam temperature and pressure are constant and predictable.
 1. Liquid expansion thermostatic trap.
 2. Balanced pressure thermostatic trap:
 - a. Balanced pressure traps change their actuation temperature automatically with changes in steam pressure. Balanced pressure traps are used in applications where system pressure varies.

- b. During startup and operation, this trap discharges air and other noncondensables very well. This trap is often used as a standalone air vent in steam systems.
 - c. The balanced pressure trap will cause condensate to back up in the system.
3. Bimetal thermostatic trap:
- a. Bimetal traps are rugged and resist damage from steam system events such as water hammer, freezing, superheated steam, and vibration.
 - b. Bimetal traps cannot compensate for steam system pressure changes.
 - c. Bimetal traps have a slow response time to changing process pressure and temperature conditions.
4. Bellows thermostatic trap.
5. Capsule thermostatic trap.
- c. Mechanical traps: Operate according to the difference in density between steam and condensate (buoyancy operated).
1. Float and thermostatic (F&T) traps:
- a. Process or modulating applications—will work in almost any application—heat exchangers, coils, humidifiers, etc.
 - b. The simplest type of mechanical trap.
 - c. The F&T trap is the only trap that provides continuous, immediate, and modulating condensate discharge.
 - d. A thermostat valve opens when cold or when below saturation (steam) temperature in order to allow air to bleed out during system startup and operation. The valve closes when the system reaches steam temperature.
2. Inverted bucket traps:
- a. Work best in applications with constant load and constant pressure—drips.
 - b. When the inverted bucket is filled with steam, it rises and closes the discharge valve preventing the discharge of steam. When the

inverted bucket is filled with condensate, it drops, opening the valve and discharging the condensate.

- c. Inverted bucket traps are poor at removing air and other noncondensable gases.
 - d. Kinetic traps: Rely on the difference in flow characteristics of steam and condensate and the pressure created by flash steam.
 1. Thermodynamic traps:
 - a. Thermodynamic traps work best in drip and tracing services.
 - b. Thermodynamic traps can remove air and other noncondensables during startup only if the system pressures are increased slowly. Because of this, thermodynamic traps often require a separate air vent.
 - c. These traps snap open and snap shut and the sound can be annoying if used in noise-sensitive areas.
 - d. The thermodynamic trap is rugged because it has only one moving part and is resistant to water hammer, superheated steam, freezing, and vibration.
 2. Impulse or piston traps.
 3. Orifice traps.
2. Steam trap selection:
 - a. HVAC equipment steam traps should be selected to discharge three to four times the condensate rating of the equipment for system startup.
 - b. Boiler header steam traps should be selected to discharge three to five times the condensate carryover rating of the boilers (typically 10 percent).
 - c. Steam main piping steam traps should be selected to discharge two to three times the condensate generated during the start-up mode caused by radiation losses.
 - d. Steam branch piping steam traps should be selected to discharge three times the condensate generated during the startup mode caused by radiation losses.
 - e. Use float and thermostatic (F&T) traps for all steam-supplied equipment.
 1. Thermostatic traps may be used for steam radiators, steam finned

tube, and other noncritical equipment, in lieu of F&T traps.

2. A combination of an inverted bucket trap and an F&T trap, in parallel with an F&T trap installed above an inverted bucket trap, may be used in lieu of F&T traps.

f. Use inverted bucket traps for all pipeline drips.

3. Steam trap functions:

- a. Steam traps allow condensate to flow from the heat exchanger or other device to minimize fouling, prevent damage, and to allow the heat transfer process to continue.
- b. Steam traps prevent steam escape from the heat exchanger or other devices.
- c. Steam traps vent air or other noncondensable gases to prevent corrosion and allow heat transfer.

4. Common steam trap problems:

- a. Steam leakage: Like all valves, the steam trap seat is subject to damage, corrosion, and/or erosion. When the trap seat is damaged, the valve will not seal; thus, the steam trap will leak live steam.
- b. Air binding: Air, carbon dioxide, hydrogen, and other noncondensable gases trapped in a steam system will reduce heat transfer and can defeat steam trap operation.
- c. Insufficient pressure difference: Steam traps rely on a positive pressure difference between the upstream steam pressure and the downstream condensate pressure to discharge condensate. When this is not maintained, the discharge of condensate is impeded.
 - 1. Overloading of the condensate return system is one cause: too much back pressure.
 - 2. Steam pressure that is too low is another cause.
- d. Dirt: Steam condensate often contains dirt, particles of scale and corrosion, and other impurities from the system that can erode and damage the steam traps. Strainers should always be placed upstream of the steam traps to extend life.

- e. Freezing: Freezing is normally only a problem when the steam system is shut down or idles, and liquid condensate remains in the trap.
- f. Noise: Thermodynamic traps are generally the only trap that produces noise when they operate. All other traps operate relatively quietly.
- g. Maintenance: Steam traps, as with all valves, must be maintained. Most steam traps can be maintained inline without removing the body from the connecting piping.

5. Steam trap characteristics are given in the following table.

STEAM TRAP COMPARISON

Characteristic	Steam Trap Type		
	Inverted Bucket	Float & Thermostatic	Liquid Expansion Thermostatic
Method of Operation	Intermittent, condensate drainage is continuous; discharge is intermittent	Continuous	Intermittent
No Load	Small dribble	No action	No action
Light Load	Intermittent	Usually continuous but may cycle at high pressures	Continuous; usually dribble action
Normal Load	Intermittent	Usually continuous but may cycle at high pressures	May blast at high pressures
Full or Overload	Continuous	Continuous	Continuous
Energy Conservation	Excellent	Good	Fair
Resistance to Wear	Excellent	Good	Fair
Corrosion	Excellent	Good	Good

Corrosion Resistance	Excellent	Good	Good
Resistance to Characteristic Hydraulic Shock	Excellent Inverted Bucket	Poor Float & Thermostatic	Poor Liquid Expansion Thermostatic
Vent Air and CO ₂ at Steam Temperature	Yes	No	No
Capability to Vent Air at Very Low Pressure (1/4 psig)	Poor	Excellent	Good
Capability to Handle Startup Air Loads	Fair	Excellent	Excellent
Operation Against Back Pressure	Excellent	Excellent	Excellent
Resistance to Damage from Freezing; Cast Iron Trap Not Recommended	Good	Poor	Good
Capability to Purge System	Excellent	Fair	Good
Performance on Very Light Loads	Excellent	Excellent	Excellent
Responsiveness to Slugs of Condensate	Immediate	Immediate	Delayed
Capability to Handle Dirt	Excellent	Poor	Fair
Comparative Physical Size	Large	Large	Small

Capability to Handle Flash Steam Characteristic	Fair	Steam Trap Type	Poor
	Inverted Bucket	Float & Thermostatic	Liquid Expansion
Usual Mechanical Failure Mode	Open	Closed with air vent open	Thermostatic Open or closed depending on design
Subcooling	No	No	Yes
Venting	Fair	Excellent	Excellent
Seat Pressure Rating	Yes	Yes	N/a
Advantages	Rugged	Continuous condensate discharge	Utilizes sensible heat of condensate
	Tolerates water hammer without damage	Handles rapid pressure changes	Allows discharge of noncondensables at startup to the set point temperature
		High noncondensable capacity	Not affected by superheated steam, water hammer, or vibration
			Resists freezing
Disadvantages	Discharges noncondensables slowly (additional air vent required)	Float can be damaged by water hammer	Element subject to corrosion damage
	Level of condensate can freeze, damaging the trap body	Level of condensate in chamber can freeze, damaging float	Condensate backs up into the drain line and/or process

		Steam Trap Type	
Characteristic	Must have water seal to operate; subject to losing prime Inverted Bucket	Some thermostatic air vent designs are susceptible to corrosion Float & Thermostatic	Liquid Expansion Thermostatic
	Pressure fluctuations and superheated steam can cause loss of the water seal		
Recommended Services	Continuous operation where noncondensable venting is not critical and rugged construction is important	Heat exchangers with high and variable heat transfer rates	Ideal for tracing used for freeze protection
		When condensate pump is required	Freeze protection—water and condensate lines and traps
		Batch processes that require frequent startup of an air-filled system	Noncritical temperature control of heated tanks



STEAM TRAP COMPARISON

	Steam Trap Type		
Characteristic	Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynamic

Method of Operation Characteristic	Thermostatic		Steam Trap Type
	Balanced Pressure Intermittent No action	Thermostatic Intermittent No action	Bimetal Thermostatic Intermittent No action
No Load	Intermittent No action	Intermittent No action	Intermittent No action
Light Load	Continuous; usually dribble action	Continuous; usually dribble action	Intermittent
Normal Load	May blast at high pressures	May blast at high pressures	Intermittent
Full or Overload	Continuous	Continuous	Continuous
Energy Conservation	Fair	Fair	Poor
Resistance to Wear	Fair	Fair	Poor
Corrosion Resistance	Good	Good	Excellent
Resistance to Hydraulic Shock	Good	Good	Excellent
Vent Air and CO ₂ at Steam Temperature	No	No	No
Capability to Vent Air at Very Low Pressure (1/4 psig)	Good	Good	Not recommended for low-pressure applications
Capability to Handle Startup Air Loads	Excellent	Excellent	Poor
Operation Against Back Pressure	Excellent	Excellent	Poor
Resistance to Damage from	Good	Good	Good

Freezing; Cast Iron Trap Not Recommended Characteristic	Steam Trap Type		
	Balanced Pressure	Bimetal	Thermodynamic
Capability to Purge System	Good	Good	Excellent
Performance on Very Light Loads	Excellent	Excellent	Poor
Responsiveness to Slugs of Condensate	Delayed	Delayed	Delayed
Capability to Handle Dirt	Fair	Fair	Poor
Comparative Physical Size	Small	Small	Small
Capability to Handle Flash Steam	Poor	Poor	Poor
Usual Mechanical Failure Mode	Open or closed depending on design	Open or closed depending on design	Open, dirt can cause to fail closed
Subcooling	Yes	Yes	No
Venting	Excellent	Excellent	Fair
Seat Pressure Rating	N/a	N/a	N/a
Advantages	Small and lightweight	Small and lightweight	Rugged, withstands corrosion, water hammer, high pressure, and superheated steam
	Maximum discharge of	Maximum discharge of	Handles wide pressure range

	noncondensables at startup	noncondensables at startup	
Characteristic	Balanced Pressure Thermostatic Unlikely to freeze	Bimetal Thermostatic Unlikely to freeze and unlikely to be damaged if it does freeze	Thermodynamic Compact and simple
		Rugged; withstands corrosion, water hammer, high pressure, and superheated steam	Audible operations warn when repair is needed
Disadvantages	Some types of damage by water hammer, corrosion, and superheated steam	Responds slowly to load and pressure changes	Poor operation with very low-pressure steam or high back pressure
	Condensate backs up into the drain line and/or process	More condensate backup than balance pressure thermostatic trap	Requires slow pressure buildup to remove air at startup to prevent air binding
		Back pressure changes operating characteristics	Noisy operation
Recommended Services	Batch processing requiring rapid discharge of noncondensables at startup	Drip legs on constant-pressure steam mains	Steam main drips, tracers
	Drip legs on steam mains and tracing	Installations subject to ambient	Constant-pressure, constant-load

	tracing	ambient Steam Trap Type conditions below freezing	constant-load applications
Characteristic	Balanced Pressure Thermostatic Installations subject to ambient conditions below freezing	Bimetal Thermostatic Installations subject to ambient conditions below freezing	Thermodynamic Installations subject to ambient conditions below freezing

6. Steam trap inspection:

a. Method #1 is shown in the following table:

Trap Failure Rate	Steam Trap Inspection Frequency
Over 10%	Every 2 months
5-10%	Every 3 months
Less than 5%	Every 6 months

b. Method #2 is shown in the following table:

System Pressure	Steam Trap Inspection Frequency
0-30 psig	Annually
30-100 psig	Semi-annually
100-250 psig	Quarterly or monthly
Over 250 psig	Monthly or weekly

22.02. Steam Condensate System Design Criteria

System Type	Initial Steam Pressure psig	Maximum System Back Pressure psig	Maximum Pressure Drop psig/100 ft.	Maximum Velocity FPM
Low Pressure	1	0	1/8	5,000
	3	0	1/8	5,000
	5	0	1/8	5,000
	7	0	1/8	5,000
	10	3	1/4	5,000
	12	4	1/4	5,000
	15	5	1/4	5,000
Medium Pressure	20	6	1/4	5,000
	25	8	1/4	5,000
	30	10	1/4	5,000
	40	13	1/4	5,000
	50	16	1/4	5,000
	60	20	1/4	5,000
	75	25	1/4	5,000
	85	28	1/4	5,000
	100	33	1/4	5,000
High Pressure	120	40	1/4	5,000
	125	41	1/4	5,000
	150	50	1/4	5,000
	175	58	1/4	5,000
	200	66	1/2	5,000
	225	75	1/2	5,000
	250	83	1/2	5,000
	275	91	1/2	5,000
	300	100	1/2	5,000

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22.03. Low-Pressure Steam Condensate System Pipe Sizing Tables (15 psig and Less)

1 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

**Pressure Drop psig/100
ft.**

Velocity FPM (mph)

**Pipe
Size**

0.125

0.25

0.5

2,000 (23)

3,000 (34)

4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

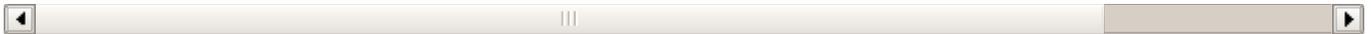
1/2	843	1,192	1,686		Pressure with these	drop pipe
3/4	2,067	2,923	4,134	3,954		
1	4,329	6,122	8,658	6,577		
1-	9,965	14,093	19,930	11,729	17,594	54,000
1/4	15,758	22,285	31,515	16,158	24,237	
1-	32,660	46,189	65,321	27,000	40,500	
1/2						
2-	54,310	76,806		38,753	58,130	77,507
1/2	100,865	142,645		60,396	90,594	120,792
3	216,701			105,124	157,686	210,247
4						
5	405,300			166,358	249,536	332,715
6				238,345	357,518	476,690
8				417,533	626,299	835,065
10				682,684	1,024,026	1,365,369
12				991,486	1,487,228	1,982,971
14				1,213,661	1,820,491	2,427,322
16	Velocity	governs	with	1,615,821	2,423,731	3,231,642
18	these	pipe	sizes	2,075,432	3,113,148	4,150,864
20				2,592,495	3,888,742	5,184,990
22				3,167,009	4,750,513	6,334,018
24				3,798,974	5,698,462	7,597,949
26				4,488,391	6,732,587	8,976,782
28				5,235,260	7,852,889	10,470,519
30				6,039,579	9,059,369	12,079,159
32				6,901,350	10,352,026	13,802,701
Notes:				7,820,573	11,730,859	15,641,146
36				8,797,247	13,195,870	17,594,494

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48				15,863,770	23,795,655	31,727,540
54				20,172,626	30,258,938	40,345,251
60				24,998,544	37,497,816	49,997,088
72				36,201,568	54,302,353	72,403,137
84				49,472,844	74,209,266	98,945,687
96				64,812,370	97,218,554	129,624,739

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,000 FPM (60 mph)
2. Table based on heavy weight steel pipe using steam equations in Part 1



3 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	293	414	586		Pressure with these	drop pipe
3/4	718	1,015	1,436	1,373		
1	1,504	2,127	3,008	2,285		
1-1/4	3,462	4,895	6,923	4,074	6,112	18,758
1-1/2	5,474	7,741	10,947	5,613	8,419	
2	11,345	16,045	22,690	9,379	14,069	
2-1/2						
3	18,866	26,680	with	13,462	20,193	26,923
4	35,037	49,550	sizes	20,980	31,469	41,959
5	75,275			36,517	54,775	73,033
6	140,788	governs pipe		57,787	86,681	115,575
8				82,794	124,190	165,587
				145,038	217,556	290,075
Notes:	Velocity			237,143	355,714	474,286

12 Pipe 14 Size	these Pressure Drop psig/100 ft.			344,411 421,588	516,616 632,381 Velocity FPM (mph)	688,822 843,175
16	0.125	0.25	0.5	561,285 2,000 (23)	841,928 3,000 (34)	1,123,570 4,000 (45)
18				720,940	1,081,409	1,441,879
20				900,551	1,350,826	1,801,102
22				1,100,119	1,650,178	2,200,238
24				1,319,644	1,979,466	2,639,287
26				1,559,125	2,338,688	3,118,251
28				1,818,564	2,727,846	3,637,128
30				2,097,959	3,146,939	4,195,918
32				2,397,311	3,595,967	4,794,622
34				2,716,620	4,074,930	5,433,240
36				3,055,886	4,583,829	6,111,771
42				4,193,424	6,290,135	8,386,847
48				5,510,573	8,265,859	11,021,145
54				7,007,333	10,511,000	14,014,666
60				8,683,705	13,025,557	17,367,409
72				12,575,282	18,862,922	25,150,563
84				17,185,304	25,777,955	34,370,607
96				22,513,770	33,770,656	45,027,541

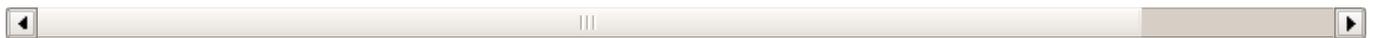
Steam Condensate Flow lbs./h 1 psig Back Pressure

1/2	461	653	923		Pressure	drop pipe
3/4	1,132	1,601	2,264	2,232	with these	
1	2,370	3,352	4,741	3,713		
1-	5,456	7,716	10,912	6,621	9,932	
1/4	8,628	12,201	17,255	9,121	13,682	
1-	17,882	25,289	35,764	15,242	22,862	30,483
1/2						
2						
2-	29,736	42,053	with	21,876	32,814	43,753
1/2	55,226	78,101	sizes	34,093	51,140	68,187
3	118,648			59,342	89,014	118,685
4						
Notes:	221,910	governs		93,909	140,863	187,818
6		pipe		134,546	201,819	269,092

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
10				235,697	353,546	471,394
12				385,375	578,063	770,751
14				685,112	1,027,668	1,370,224
16				912,131	1,368,197	1,824,262
18				1,171,582	1,757,373	2,343,163
20				1,463,464	2,195,195	2,926,927
22				1,787,777	2,681,665	3,575,554
24				2,144,521	3,216,782	4,289,043
26				2,533,697	3,800,546	5,067,395
28				2,955,305	4,432,957	5,910,609
30				3,409,343	5,114,015	6,818,686
32				3,895,813	5,843,720	7,791,626
34				4,414,714	6,622,071	8,829,429
36				4,966,047	7,449,070	9,932,094
42				6,814,632	10,221,949	13,629,265
48				8,955,100	13,432,650	17,910,200
54				11,387,450	17,081,174	22,774,899
60				14,111,681	21,167,521	28,223,362
72				20,435,790	30,653,684	40,871,579
84				27,927,426	41,891,139	55,854,852
96				36,586,590	54,879,885	73,173,180

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,000 FPM (23 mph)
2. Table based on heavy weight steel pipe using steam equations in Part 1 of the ASME B31.1 Code



5 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

Pipe Size	Pressure Drop	Drop	psi	ft	Pressure Velocity with these	drop pipe FPM (mph)
1	449 940 0.125	63 1,329 0.25	898 1,880 0.5	858 1,428 2,000 (23)	3,000 (34)	4,000 (45)
1-1/4	2,163	3,060	4,327	2,546	3,820	
1-1/2	3,421	4,838	6,842	3,508	5,262	
2	7,091	10,028	14,182	5,862	8,793	11,724
2-1/2	11,791	16,675		8,414	12,620	16,827
3	21,898	30,969		13,112	19,668	26,224
4	47,047			22,823	34,234	45,646
5	87,993			36,117	54,176	72,234
6				51,746	77,619	103,492
8				90,649	135,973	181,297
10	Velocity	governs	with	148,214	222,322	296,429
12	these	pipe	sizes	215,257	322,885	430,513
14				263,492	395,238	526,984
16				350,803	526,205	701,606
18				450,587	675,881	901,174
20				562,844	844,266	1,125,689
22				687,574	1,031,361	1,375,149
24				824,777	1,237,166	1,649,555
26				974,453	1,461,680	1,948,907
28				1,136,602	1,704,904	2,273,205
30				1,311,224	1,966,837	2,622,449
32				1,498,319	2,247,479	2,996,639
34				1,697,888	2,546,831	3,395,775
36				1,909,929	2,864,893	3,819,857
42				2,620,890	3,931,335	5,241,780
48				3,444,108	5,166,162	6,888,216
54				4,379,583	6,569,375	8,759,166
60				5,427,315	8,140,973	10,854,631
Notes:				7,859,551	11,789,327	15,719,102
84				10,740,815	16,111,222	21,481,629

Pipe Size	Pressure Drop psig/100 ft.	14,071,107	21,106,660	28,142,213	Velocity FPM (mph)	
Steam Condensate Flow lbs./h 1 psig Back Pressure						
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	240	340	481		Pressure	drop pipe
3/4	590	834	1,179	1,163	with these	
1	1,235	1,746	2,470	1,934		
1-	2,843	4,020	5,685	3,450	5,175	
1/4	4,495	6,357	8,990	4,752	7,128	
1-	9,317	13,176	18,634	7,941	11,911	15,882
1/2						
2						
2-	15,493	21,910	with	11,398	17,097	22,795
1/2	28,773	40,691	sizes	17,763	26,644	35,526
3	61,817			30,918	46,377	61,836
4						
5	115,617	governs		48,927	73,391	97,855
6		pipe		70,100	105,149	140,199
8				122,800	184,200	245,600
10	Velocity			200,784	301,176	401,568
12	these			291,605	437,408	583,210
14				356,949	535,423	713,898
16				475,228	712,842	950,456
18				610,404	915,606	1,220,808
20				762,477	1,143,715	1,524,954
22				931,447	1,397,170	1,862,894
24				1,117,314	1,675,971	2,234,627
26				1,320,078	1,980,116	2,640,155
28				1,539,739	2,309,608	3,079,477
30				1,776,296	2,664,445	3,552,593
32				2,029,751	3,044,627	4,059,503
34				2,300,103	3,450,155	4,600,207
36				2,587,352	3,881,028	5,174,704
42				3,550,481	5,325,721	7,100,962
Notes:				4,665,682	6,998,524	9,331,365
54				5,932,957	8,899,435	11,865,914
60				7,357,304	11,078,257	14,704,609

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,0

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72				10,647,218	15,970,827	21,294,486
84				14,550,424	21,825,635	29,100,847
96				19,061,921	28,592,881	38,123,842

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



7 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	136	192	271		Pressure	drop pipe
3/4	333	471	666	636	with these	
1	697	986	1,394	1,059		
1-	1,604	2,269	3,208	1,888	2,832	
1/4	2,537	3,587	5,073	2,601	3,902	
1-	5,258	7,435	10,515	4,346	6,520	8,693
1/2						
2						
2-	8,743	12,364	with	6,238	9,358	12,477
1/2	16,237	22,962	sizes	9,722	14,583	19,444
3	34,884			16,922	25,384	33,845
4						
5	65,243	governs		26,780	40,169	53,559
6		pipe		38,368	57,552	76,736
8				67,213	100,819	134,425
10	Velocity			109,896	164,843	219,791
12	these			159,605	239,408	319,210
14				195,370	293,055	390,740
Notes:				260,108	390,162	520,215

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
18				334,094	501,141	668,188
20				417,328	625,995	834,657
22				509,811	764,717	1,019,622
24				611,542	917,313	1,223,084
26				722,522	1,083,782	1,445,043
28				842,749	1,264,124	1,685,498
30				972,225	1,458,337	1,944,450
32				1,110,949	1,666,424	2,221,898
34				1,258,921	1,888,382	2,517,843
36				1,416,142	2,124,213	2,832,284
42				1,943,294	2,914,941	3,886,588
48				2,553,680	3,830,520	5,107,360
54				3,247,301	4,870,951	6,494,601
60				4,024,156	6,036,234	8,048,312
72				5,827,570	8,741,354	11,655,139
84				7,963,921	11,945,882	15,927,842
96				10,433,211	15,649,816	20,866,421

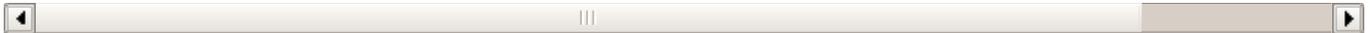
Steam Condensate Flow lbs./h 1 psig Back Pressure

1/2	166	235	333		Pressure with these	drop pipe
3/4	408	577	816	805		
1	854	1,208	1,709	1,338		
1-	1,967	2,781	3,933	2,387	3,580	10,988
1/4	3,110	4,398	6,220	3,288	4,932	
1-	6,446	9,116	12,892	5,494	8,241	
1/2						
2-	10,719	15,159	with sizes	7,886	11,828	15,771
1/2	19,907	28,153		12,289	18,434	24,579
3	42,769			21,391	32,086	42,782
4						
5	79,991	governs pipe		33,851	50,776	67,702
6			48,499	72,749	96,998	
8			84,961	127,441	169,921	
Notes:	Velocity			138,914	208,372	277,829
12	these			201,750	302,625	403,500

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
16				246,959	370,438	493,918
18				328,791	493,187	657,583
20				420,914	639,471	844,029
22				527,528	791,291	1,055,055
24				644,431	966,647	1,288,862
26				773,025	1,159,538	1,546,050
28				913,310	1,369,964	1,826,619
30				1,065,284	1,597,926	2,130,568
32				1,228,949	1,843,424	2,457,899
34				1,404,305	2,106,457	2,808,609
36				1,591,351	2,387,026	3,182,701
42				1,790,087	2,685,130	3,580,173
48				2,456,437	3,684,656	4,912,875
54				3,228,001	4,842,002	6,456,002
60				4,104,778	6,157,167	8,209,557
66				5,086,769	7,630,153	10,173,537
72				7,366,389	11,049,584	14,732,779
84				10,066,863	15,100,294	20,133,726
96				13,188,190	19,782,284	26,376,379

Notes:

1. Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./5,000 FPM (20 mph)
2. Table based on heavy weight steel pipe using steam equations in Part 1 of the ASME B31.1 Code



10 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	101	143	202			
3/4	247	350	494	473		
1	518	732	1,035	786		

Steam Condensate Flow lbs./h 0 psig Back Pressure

					Pressure drop pipe	
					with these	

Pipe Size	Pressure Drop psig/100			Velocity FPM (mph)		
	1,402 1,884 3,905 0.125	1,685 2,664 5,523 0.25	2,104 2,898 4,842 3,000 (34)	1,402 1,932 3,228 2,000 (23)	2,104 2,898 4,842 3,000 (34)	6,457 4,000 (45)
1-1/2						
2						
2-1/2	6,494	9,183	with	4,634	6,950	9,267
3	12,060	17,055	sizes	7,221	10,832	14,442
4	25,910			12,569	18,854	25,138
5	48,460	governs pipe		19,891	29,836	39,781
6				28,498	42,747	56,996
8				49,922	74,884	99,845
10	Velocity these			81,625	122,438	163,251
12				118,547	177,821	237,094
14				145,112	217,667	290,223
16				193,196	289,794	386,392
18				248,149	372,224	496,299
20				309,972	464,958	619,944
22				378,664	567,996	757,328
24				454,225	681,338	908,450
26				536,655	804,983	1,073,311
28				625,955	938,932	1,251,910
30				722,124	1,083,185	1,444,247
32				825,161	1,237,742	1,650,323
34				935,068	1,402,603	1,870,137
36				1,051,845	1,577,767	2,103,689
42				1,443,389	2,165,083	2,886,777
48				1,896,755	2,845,133	3,793,510
54				2,411,944	3,617,917	4,823,889
60				2,988,956	4,483,435	5,977,913
72				4,328,448	6,492,673	8,656,897
84				5,915,231	8,872,847	11,830,463
96				7,749,305	11,623,958	15,498,610

Steam Condensate Flow lbs./h 1 psig Back Pressure

Notes:	118	167	235		Pressure	drop nine	r
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1/2 3/4 1	Pressure 289 605	Drop 408 855 ft.	psig/100 978 1,210	569 947	Pressure with these Velocity	Drop pipe FPM (mph)	5 5
1- 1/4 1- 1/2 2	0.125 1,392 2,201 4,563	0.25 1,969 3,113 6,452	0.5 2,784 4,403 9,125	2,000 (23) 1,689 2,327 3,889	3,000 (34) 2,534 3,491 5,833	4,000 (45) 7,778	5 5 5 5
2- 1/2 3 4	7,587 14,091 30,272	10,730 19,927		5,582 8,699 15,141	8,372 13,048 22,711	11,163 17,397 30,282	5 6 7 8
5 6 8	56,619	governs pipe	with sizes	23,960 34,329 60,137	35,940 51,493 90,205	47,921 68,657 120,273	5 8 10
10 12 14	Velocity these			98,326 142,803 174,802	147,489 214,204 262,203	196,652 285,605 349,604	2 3 4
16 18 20				232,725 298,922 373,394	349,087 448,383 560,091	465,450 597,844 746,788	5 7 9
22 24 26				456,141 547,162 646,458	684,211 820,743 969,687	912,281 1,094,324 1,292,916	10 11 12
28 30 32				754,028 869,874 993,993	1,131,043 1,304,810 1,490,990	1,508,057 1,739,747 1,987,987	13 14 15
34 36 42				1,126,388 1,267,057 1,738,713	1,689,582 1,900,586 2,608,069	2,252,776 2,534,114 3,477,426	16 17 18
48 54 60				2,284,840 2,905,440 3,600,511	3,427,261 4,358,160 5,400,767	4,569,681 5,810,880 7,201,022	19 20 21
Notes: 84 96				5,214,070 7,125,516 9,334,850	7,821,105 10,688,274 14,002,275	10,428,140 14,251,032 18,669,700	22 23 24

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop 0.125 ft.	Pressure Drop 0.25 ft.	Pressure Drop 0.5 ft.	Back Pressure 2,000 (23)	Back Pressure 3,000 (34)	Back Pressure 4,000 (45)	Velocity FPM (mph)
1/2	167	236	333	2,000 (23)	3,000 (34)	4,000 (45)	9
3/4	408	578	817	2,000 (23)	3,000 (34)	4,000 (45)	9
1	855	1,210	1,711	1,417	with these		
1-	1,969	2,784	3,938	2,527	3,791		
1/4	3,113	4,403	6,227	3,481	5,222		
1-	6,453	9,126	12,906	5,817	8,726	11,635	
1/2							
2							
2-	10,730	15,175	with	8,350	12,524	16,699	2
1/2	19,928	28,183	sizes	13,013	19,519	26,025	3
3	42,814			22,649	33,974	45,299	5
4							
5	80,076	governs		35,842	53,764	71,685	8
6		pipe		51,352	77,029	102,705	1
8				89,959	134,939	179,918	2
10	Velocity			147,087	220,631	294,174	3
12	these			213,620	320,429	427,239	5
14				261,488	392,232	522,976	6
16				348,135	522,203	696,270	8
18				447,160	670,740	894,321	1
20				558,564	837,845	1,117,127	1
22				682,345	1,023,517	1,364,690	1
24				818,504	1,227,757	1,637,009	2
26				967,042	1,450,563	1,934,084	2
28				1,127,958	1,691,937	2,255,916	2
30				1,301,252	1,951,878	2,602,504	3
32				1,486,924	2,230,386	2,973,848	3
34				1,684,974	2,527,461	3,369,949	4
36				1,895,403	2,843,104	3,790,805	4
42				2,600,957	3,901,435	5,201,913	6
48				3,417,914	5,126,871	6,835,828	8
54				4,346,274	6,519,411	8,692,549	1
60				5,386,038	8,079,057	10,772,076	1

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
96				7,799,775	11,699,663	15,599,551
				10,659,126	15,988,688	21,318,251
				13,964,089	20,946,133	27,928,178

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1

12 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	87	123	174		Pressure with these	drop pipe
3/4	213	301	426	408		
1	446	631	893	678		
1-1/4	1,028	1,453	2,055	1,210	1,814	5,569
1-1/2	1,625	2,298	3,250	1,666	2,499	
2	3,368	4,763	6,736	2,784	4,177	
2-1/2	5,601	7,921	with sizes	3,996	5,995	
3	10,402	14,710		6,228	9,342	12,457
4	22,347			10,841	16,261	21,682
5	41,797	governs pipe		17,156	25,733	34,311
6				24,579	36,869	49,159
8				43,058	64,587	86,116
10	Velocity these			70,402	105,603	140,804
12				102,247	153,370	204,494
14				125,159	187,738	250,318
Notes:				166,632	249,947	333,263
18				214,029	321,043	428,058

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2000 (23)	3000 (34)	4000 (45)
22				267,351	401,027	534,702
24				326,598	489,897	653,196
26				462,865	694,298	925,731
28				539,886	809,829	1,079,772
30				622,832	934,247	1,245,663
32				711,702	1,067,553	1,423,404
34				806,497	1,209,745	1,612,993
36				907,216	1,360,824	1,814,432
42				1,244,923	1,867,384	2,489,845
48				1,635,951	2,453,927	3,271,903
54				2,080,302	3,120,453	4,160,604
60				2,577,975	3,866,962	5,155,950
72				3,733,287	5,599,930	7,466,573
84				5,101,887	7,652,831	10,203,774
96				6,683,776	10,025,663	13,367,551

Steam Condensate Flow lbs./h 1 psig Back Pressure

1/2	100	141	199		Pressure with these	drop pipe
3/4	245	346	489	482		
1	512	724	1,024	802		
1-	1,179	1,667	2,357	1,430	2,146	6,585
1/4	1,864	2,636	3,728	1,970	2,956	
1-	3,863	5,463	7,726	3,293	4,939	
1/2						
2-	6,424	9,085	with	4,726	7,089	9,452
1/2	11,930	16,872	sizes	7,365	11,048	14,730
3	25,631			12,820	19,229	25,639
4						
5	47,939	governs		20,287	30,430	40,574
6		pipe		29,066	43,598	58,131
8				50,917	76,376	101,834

Notes: Velocity 83,252 124,878 166,504
 12 these 120,909 181,364 241,819
1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
14				148,003	222,003	290,000
16				197,046	295,569	394,091
18				253,094	379,641	506,189
20				316,149	474,223	632,298
22				386,210	579,314	772,419
24				463,276	694,915	926,553
26				547,349	821,024	1,094,699
28				638,428	957,642	1,276,856
30				736,513	1,104,770	1,473,026
32				841,604	1,262,406	1,683,208
34				953,701	1,430,552	1,907,403
36				1,072,805	1,609,207	2,145,609
42				1,472,151	2,208,226	2,944,301
48				1,934,551	2,901,827	3,869,102
54				2,460,007	3,690,010	4,920,013
60				3,048,516	4,572,775	6,097,033
72				4,414,700	6,622,050	8,829,400
84				6,033,102	9,049,654	12,066,205
96				7,903,723	11,855,585	15,807,447

Steam Condensate Flow lbs./h 3 psig Back Pressure

1/2	134	189	268		Pressure drop pipe with these	
3/4	329	465	657			
1	688	973	1,376	1,140		
1-	1,584	2,240	3,168	2,033	3,049	9,359
1/4	2,504	3,542	5,009	2,801	4,201	
1-	5,191	7,341	10,382	4,680	7,020	
1/2						
2						
2-	8,632	12,207	with	6,717	10,075	13,434
1/2	16,031	22,671	sizes	10,468	15,702	20,936
3	34,442			18,220	27,330	36,440
4						
Notes:	64,417	governs		28,833	43,250	57,666
6		pipe		41,310	61,965	82,620
1	Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000			72,367	108,551	144,734
8						

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
14				118,323	177,485	236,647
16				171,845	257,768	343,690
18				210,353	315,529	420,705
20				280,055	420,083	560,111
22				359,716	539,573	719,431
24				449,333	674,000	898,667
26				548,909	823,363	1,097,817
28				658,441	987,662	1,316,883
30				777,932	1,166,898	1,555,863
32				907,380	1,361,069	1,814,759
34				1,046,785	1,570,177	2,093,570
36				1,196,148	1,794,222	2,392,296
42				1,355,468	2,033,202	2,710,936
48				1,524,746	2,287,119	3,049,492
54				2,092,325	3,138,488	4,184,650
60				2,749,522	4,124,283	5,499,044
72				3,496,336	5,244,504	6,992,672
84				4,332,768	6,499,153	8,665,537
96				6,274,486	9,411,729	12,548,972
				8,574,674	12,862,012	17,149,349
				11,233,334	16,850,001	22,466,667

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



15 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
Notes: 73	103	146			Pressure	drop pipe

3/4 Pipe 1 Size	179 Pressure Drop 375	253 Drop 530 ft.	358 psig/100 750	342 570	with these Velocity FPM (mph)	
1- 1/4	863 0.125 1,365	1,221 0.25 1,930	1,726 0.5 2,730	1,016 2,000 (23) 1,400	1,524 3,000 (34) 2,099	4,000 (45)
1- 1/2 2	2,829	4,001	5,658	2,339	3,508	4,677
2- 1/2 3 4	4,704 8,736 18,769	6,652 12,355	with sizes	3,357 5,231 9,105	5,035 7,847 13,658	6,713 10,462 18,210
5 6 8	35,105	governs pipe		14,409 20,644 36,164	21,613 30,966 54,246	28,818 41,288 72,328
10 12 14	Velocity these			59,130 85,877 105,120	88,695 128,815 157,680	118,260 171,753 210,240
16 18 20				139,953 179,762 224,547	209,929 269,643 336,820	279,906 359,524 449,094
22 24 26				274,308 329,045 388,758	411,462 493,568 583,137	548,616 658,090 777,517
28 30 32				453,448 523,113 597,755	680,172 784,670 896,632	906,895 1,046,226 1,195,510
34 36 42				677,372 761,966 1,045,604	1,016,059 1,142,949 1,568,406	1,354,745 1,523,933 2,091,209
48 54 60				1,374,027 1,747,235 2,165,228	2,061,041 2,620,853 3,247,842	2,748,055 3,494,471 4,330,456
72 84 96				3,135,569 4,285,049 5,613,670	4,703,353 6,427,574 8,420,505	6,271,138 8,570,099 11,227,340

Pipe Pressure Drop (psi/100 ft) Back Pressure

Velocity FPM (mph)

Size	82	116	164		Pressure	drop pipe
1/2	201	252	405	2900 (23)	3,000 (34)	4,000 (45)
3/4	422	597	845	661		
1-	972	1,375	1,944	1,180	1,769	
1/4	1,537	2,174	3,074	1,625	2,438	
1-	3,186	4,506	6,372	2,715	4,073	5,431
1/2						
2-	5,298	7,492	with	3,897	5,846	7,795
1/2	9,839	13,915	sizes	6,074	9,111	12,148
3	21,139			10,572	15,859	21,145
4						
5	39,536	governs		16,731	25,096	33,462
6		pipe		23,971	35,956	47,942
8				41,992	62,988	83,984
10	Velocity			68,659	102,988	137,318
12	these			99,716	149,573	199,431
14				122,060	183,090	244,120
16				162,506	243,759	325,012
18				208,730	313,095	417,460
20				260,732	391,098	521,464
22				318,512	477,768	637,024
24				382,070	573,105	764,140
26				451,406	677,109	902,812
28				526,520	789,780	1,053,040
30				607,412	911,118	1,214,823
32				694,082	1,041,122	1,388,163
34				786,530	1,179,794	1,573,059
36				884,755	1,327,133	1,769,511
42				1,214,101	1,821,152	2,428,202
48				1,595,449	2,393,173	3,190,898
54				2,028,798	3,043,198	4,057,597
60				2,514,150	3,771,225	5,028,300
Notes:				3 640 850	5 461 280	7 281 718

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 3 psig Back Pressure								
1/2	105	149	211				Pressure	drop pipe
3/4	258	366	517				with these	
1	541	766	1,083	897				
1-	1,246	1,762	2,492	1,599			2,399	
1/4	1,970	2,786	3,941	2,203			3,305	
1-	4,084	5,775	8,168	3,682			5,522	7,363
1/2								
2								
2-	6,791	9,604	with	5,284			7,926	10,568
1/2	12,612	17,836	sizes	8,235			12,353	16,470
3	27,096			14,334			21,501	28,668
4								
5	50,677	governs		22,683			34,025	45,367
6		pipe		32,499			48,749	64,999
8				56,932			85,398	113,864
10	Velocity			93,087			139,630	186,173
12	these			135,193			202,789	270,386
14				165,487			248,231	330,975
16				220,323			330,485	440,647
18				282,993			424,490	565,986
20				353,497			530,245	706,993
22				431,834			647,751	863,667
24				518,005			777,007	1,036,009
26				612,009			918,014	1,224,018
28				713,848			1,070,771	1,427,695
30				823,520			1,235,279	1,647,039
32				941,025			1,411,538	1,882,051
34				1,066,365			1,599,547	2,132,730
36				1,199,538			1,799,307	2,399,076
42				1,646,060			2,469,090	3,292,120
Notes:				2,163,085			3,244,628	4,326,171

54 Pipe 60 Size	Pressure	Drop	psig/100 ft.	2,750,614 3,408,646	4,125,921 5,122,576	5,501,228 6,800,228	
72 84 96	0.125	0.25	0.5	4,936,221 2,000 (23) 6,745,810	7,404,332 3,000 (34) 10,118,715	9,872,443 4,000 (45) 13,491,620	
				8,837,413	13,256,119	17,674,826	

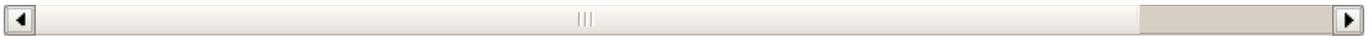
Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2 3/4 1	138 338 708	195 478 1,001	276 676 1,416		Pressure with these	drop pipe	
1- 1/4 1- 1/2 2	1,630 2,577 5,342	2,305 3,645 7,554	3,260 5,154 10,683	2,200 3,030 5,063		10,126	
2- 1/2 3 4	8,883 16,497 35,442	12,562 23,330	17,765	7,267 11,326 19,713	10,901 16,988 29,569	14,534 22,651 39,426	
5 6 8	66,288 107,770	governs pipe	with sizes	31,196 44,695 78,296	46,793 67,042 117,445	62,391 89,390 156,593	
10 12 14	Velocity these			128,018 185,925 227,588	192,027 278,888 341,382	256,036 371,850 455,176	
16 18 20				303,002 389,189 486,149	454,502 583,783 729,224	606,003 778,377 972,298	
22 24 26				593,883 712,390 841,671	890,825 1,068,586 1,262,507	1,187,766 1,424,781 1,683,342	
28 30 32				981,725 1,132,553 1,294,154	1,472,588 1,698,829 1,941,230	1,963,450 2,265,105 2,588,307	
Notes: 36				1,466,528 1,649,675	2,199,792 2,474,513	2,933,056 3,299,351	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48				2,263,759	3,395,638	4,527,517
54				2,974,802	4,462,204	5,949,605
60				4,687,772	7,031,657	9,375,543
72				6,788,583	10,182,874	13,577,165
84				9,277,236	13,915,854	18,554,472
96				12,153,731	18,230,597	24,307,462

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 2



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22.04. Medium-Pressure Steam Condensate System Pipe Sizing Tables (20-100 psig)

20 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	59	83	118		Pressure drop pipe with these	
3/4	144	204	288	276		
1	302	427	604	459		
1-	695	983	1,390	818	1,227	3,767
1/4	1,099	1,555	2,199	1,127	1,691	
1-	2,279	3,222	4,557	1,884	2,826	
1/2						
2						
Notes:	3,789	5,359	with	2,704	4,056	5,407
1/2	7,037	9,952	sizes	4,214	6,320	8,427
3	15,119			7,334	11,001	14,668

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 2

Pipe Size	Pressure Drop psig/100 ft. pipe			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
8				11,606	17,410	23,213
10	Velocity these			16,629	24,943	33,257
12				29,130	43,695	58,260
14				2,000 (23)	3,000 (34)	4,000 (45)
16				47,629	71,444	95,258
18				69,173	103,760	138,347
20				84,674	127,011	169,348
22				112,732	169,098	225,463
24				144,798	217,196	289,595
26				180,872	271,308	361,743
28				220,954	331,431	441,908
30				265,045	397,567	530,089
32				313,144	469,715	626,287
34				365,251	547,876	730,501
36				421,366	632,049	842,732
42				481,490	722,234	962,979
48				545,621	818,432	1,091,243
54				613,761	920,642	1,227,523
60				842,231	1,263,346	1,684,462
72				1,106,775	1,660,162	2,213,549
84				1,407,392	2,111,089	2,814,785
96				1,744,084	2,616,127	3,488,169
				2,525,691	3,788,536	5,051,382
				3,451,594	5,177,391	6,903,187
				4,521,793	6,782,690	9,043,586

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	98	139	197		Pressure	drop pipe
3/4	241	341	482		with these	
1	505	714	1,010	880		
1-	1,163	1,644	2,325	1,569		
1/4	1,839	2,600	3,677	2,162	3,242	
1-	3,811	5,389	7,622	3,612	5,418	7,224
1/2						
2						
Notes:	6,337	8,962	12,674	5,184	7,776	10,369
1/2	11,760	16,644	23,213	8,000	12,110	16,150

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/2	11,709	10,159
3/4	25,284	21,095
1	47,290	38,126
1 1/4	76,883	63,770
1 1/2	111,713	91,328
2	136,991	132,638
2 1/2	162,360	162,360
3	216,160	216,160
3 1/2	277,646	277,646
4	346,817	346,817
4 1/2	423,674	423,674
5	508,216	508,216
5 1/2	600,445	600,445
6	700,358	700,358
6 1/2	807,958	807,958
7	923,243	923,243
7 1/2	1,046,215	1,046,215
8	1,176,871	1,176,871
8 1/2	1,614,956	1,614,956
9	2,122,211	2,122,211
9 1/2	2,698,638	2,698,638
10	3,344,236	3,344,236
10 1/2	4,842,945	4,842,945
11	6,618,340	6,618,340
11 1/2	8,670,419	8,670,419

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	123	174	246		Pressure	drop pipe
3/4	301	426	602		with these	
1	631	892	1,262	1,150		
1 1/4	1,452	2,053	2,904	2,050		
1 1/2	2,296	3,247	4,592	2,824	4,236	
2	4,759	6,730	9,518	4,719	7,079	9,438

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

2. Table based on heavy weight steel pipe using steam equations in Part 1

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	14,697	20,785	29,076	10,160	15,834	21,112
3/4	19,129	27,047	38,768	13,547	21,112	28,150
1	24,661	34,729	49,024	18,374	27,560	36,747
1 1/2	59,055	83,316	119,320	43,614	62,487	83,316
2	96,011	138,981	191,320	62,487	91,658	123,981
2 1/2			290,768	109,464	158,316	215,953
3	Velocity		387,680	178,979	259,938	346,584
3 1/2	these		490,240	259,938	367,472	490,240
4			624,800	318,185	444,576	590,240
4 1/2			784,413	423,620	576,826	771,620
5			984,744	544,116	744,488	996,232
5 1/2			1,244,116	679,674	924,232	1,244,116
6			1,573,530	830,294	1,107,059	1,473,530
6 1/2			1,963,985	995,977	1,327,969	1,773,985
7			2,424,481	1,176,721	1,568,962	2,078,962
7 1/2			2,965,018	1,372,528	1,830,037	2,440,037
8			3,586,597	1,583,396	2,111,195	2,811,195
8 1/2			4,289,218	1,809,327	2,412,435	3,182,435
9			5,073,879	2,050,319	2,733,759	3,593,759
9 1/2			5,940,582	2,306,374	3,075,165	4,045,165
10			6,899,940	3,164,909	4,219,879	5,538,879
10 1/2			8,042,669	4,159,003	5,545,338	7,248,338
11			9,375,771	5,288,656	7,051,541	9,248,541
11 1/2			10,909,244	6,553,866	8,738,489	11,348,489
12			12,642,308	9,490,963	12,654,617	16,648,617
12 1/2			14,575,861	12,970,292	17,293,722	22,648,722
13			16,809,903	16,991,854	22,655,806	29,648,806

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1

25 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)
Steam Condensate Flow lbs./h 0 psig Back Pressure							
1/2	50	71	100		Pressure drop pipe with these		governed size
3/4	123	174	246	235			
1	257	364	515	391			
1-1/4	593	838	1,185	697	1,046	3,211	
1-1/2	937	1,325	1,874	961	1,441		
2	1,942	2,746	3,884	1,605	2,408		
2-1/2	3,229	4,567	with sizes	2,304	3,456		
3	5,997	8,482		3,591	5,387	7,182	8,000
4	12,885			6,251	9,376	12,501	15,000
5	24,099	governs pipe		9,892	14,837	19,783	24,000
6				14,172	21,258	28,344	35,000
8				24,826	37,239	49,653	62,000
10	Velocity these			40,592	60,888	81,184	100,000
12				58,953	88,430	117,906	140,000
14				72,164	108,245	144,327	180,000
16				96,076	144,114	192,152	240,000
18				123,404	185,106	246,808	300,000
20				154,148	231,223	308,297	380,000
22				188,309	282,463	376,617	470,000
24				225,885	338,827	451,770	560,000
26				266,877	400,316	533,755	660,000
28				311,286	466,929	622,571	770,000
30				359,110	538,665	718,220	890,000
32				410,351	615,526	820,701	1,000,000
Notes:				465,007	697,511	930,014	1,100,000

Pipe Size	Pressure Drop psig/100 ft.	523,080	784,619	1,046,159	1,176,690	1,435,586	1,717,793	
48	0.125	0.25	0.5	942,000	1,414,877	1,886,502	2,398,907	
54				1,199,153	1,799,180	2,398,907	3,000 (34)	4,000 (45)
60				1,486,400	2,229,600	2,972,800		
72				2,152,526	3,228,789	4,305,051	5,405,051	
84				2,941,629	4,412,443	5,883,257	7,405,051	
96				3,853,708	5,780,563	7,707,417	9,405,051	

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	78	111	157		Pressure	drop pipe	governor
3/4	192	272	384		with these		sizes
1	402	569	805	701			
1-1/4	926	1,310	1,852	1,250			
1-1/2	1,464	2,071	2,929	1,722	2,583		
2	3,035	4,293	6,071	2,877	4,316	5,754	
2-1/2	5,047	7,138	10,095	4,129	6,194	8,259	16,803
3	9,374	13,257		6,436	9,653	12,871	28,403
4	20,140			11,202	16,803	22,403	
5	37,668	governs	with	17,727	26,590	35,453	44,491
6		pipe	sizes	25,397	38,096	50,795	66,737
8				44,491	66,737	88,982	112,648
10	Velocity			72,745	109,117	145,490	188,117
12	these			105,650	158,475	211,300	269,648
14				129,324	193,986	258,648	329,648
16				172,177	258,266	344,354	434,354
18				221,152	331,728	442,304	552,304
20				276,249	414,373	552,497	699,373
22				337,467	506,201	674,934	849,373
24				404,807	607,211	809,615	1,019,373
26				478,270	717,405	956,539	1,188,373
Notes:				557,854	836,781	1,115,708	1,405,373
30				643,560	965,340	1,287,119	1,605,373

Pipe Size	Pressure Drop psig/100 ft.			Flow Rate (gpm)	Velocity FPM (mph)	Flow Rate (gpm)	Velocity FPM (mph)
	0.125	0.25	0.5				
32				735,387	1,103,081	1,470,775	1,103,081
34				833,337	1,250,006	1,666,674	1,250,006
36	0.125	0.25	0.5	937,409	1,406,113	1,874,817	1,406,113
42				1,266,354	1,929,531	2,572,708	1,929,531
48				1,690,396	2,535,595	3,380,793	2,535,595
54				2,149,535	3,224,303	4,299,071	3,224,303
60				2,663,771	3,995,656	5,327,542	3,995,656
72				3,857,532	5,786,298	7,715,064	5,786,298
84				5,271,680	7,907,520	10,543,360	7,907,520
96				6,906,214	10,359,322	13,812,429	10,359,322

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	94	133	188		Pressure drop pipe with these	drop pipe	gpc si:
3/4	231	326	461				
1	483	683	966	880			
1-1/4	1,112	1,572	2,224	1,570	3,244	7,227	
1-1/2	1,758	2,486	3,516	2,162			
2	3,644	5,153	7,288	3,613			
2-1/2	6,059	8,569	12,119	5,186			
3	11,254	15,915		8,083	7,780	10,373	20
4	24,178	34,192		14,069	12,124	16,166	35
5	45,220	governs pipe	with sizes	22,264	21,103	28,138	
6	73,517			31,898	33,396	44,528	55
8				55,879	47,847	63,796	79
10	Velocity			91,365	83,819	111,758	13
12	these			132,692	137,047	182,729	22
14				162,426	199,038	265,384	33
16				216,248	243,639	324,852	40
18				277,758	324,372	432,495	54
20				346,957	416,637	555,516	69
					520,436	693,915	86

Notes:

24 423,846 635,768 847,691 1,
508,422 762,634 1,016,845 1,
1. Maximum recommended pressure drop/velocity: 0.25 psia/100 ft./5.00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)
26				600,688	901,032	1,201,376	1,401,285
30				700,643	1,050,964	1,401,285	1,616,572
32				808,286	1,212,429	1,616,572	1,947,236
34				923,618	1,385,427	1,847,236	2,231,222
36				1,046,639	1,569,959	2,093,278	2,531,222
42				1,177,349	1,766,023	2,354,698	2,931,222
48				1,615,611	2,423,416	3,231,222	3,931,222
54				2,123,072	3,184,608	4,246,144	5,131,222
60				2,699,733	4,049,599	5,399,466	6,599,466
66				3,345,593	5,018,389	6,691,186	8,191,186
72				4,844,910	7,267,366	9,689,821	11,789,821
84				6,621,025	9,931,538	13,242,050	16,242,050
96				8,673,937	13,010,905	17,347,874	21,347,874

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



30 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)

Steam Condensate Flow lbs./h 0 psig Back Pressure							
Pipe Size	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)
1/2	44	63	88		Pressure drop pipe		gc
3/4	108	153	217	207	with these		si
1	227	321	454	345			
1-	523	739	1,046	615	923		
1/4	827	1,169	1,653	848	1,272		
1-	1,714	2,423	3,427	1,417	2,125	2,833	
1/2							
2							
Notes:	2,849	4,030	with	2,033	3,050	4,066	5,

Pipe Size	Pressure 5 psig	Drop ft.	psig/100 ft.	2,000	3,000 (34)	4,000 (45)	5,000 (56)
4	11,369			3,169	4,753	6,337	7,921
5	21,264	0.25 governs pipe	0.5	8,728	13,092	17,456	21,820
6				12,505	18,757	25,009	31,261
8				21,906	32,858	43,811	54,764
10	Velocity these			35,817	53,725	71,633	89,541
12				52,018	78,026	104,035	130,043
14				63,674	95,511	127,348	159,683
16				84,773	127,159	169,546	211,939
18				108,886	163,329	217,772	276,005
20				136,013	204,020	272,026	341,039
22				166,155	249,232	332,309	417,322
24				199,310	298,965	398,621	500,875
26				235,480	353,220	470,960	592,514
28				274,664	411,996	549,328	698,688
30				316,862	475,293	633,724	800,897
32				362,074	543,111	724,148	913,106
34				410,300	615,450	820,601	1,033,115
36				461,541	692,311	923,082	1,166,694
42				633,347	950,020	1,266,694	1,600,293
48				832,280	1,248,421	1,664,561	2,116,682
54				1,058,341	1,587,512	2,116,682	2,698,773
60				1,311,529	1,967,294	2,623,059	3,333,164
72				1,899,287	2,848,931	3,798,575	4,813,166
84				2,595,555	3,893,332	5,191,109	6,600,662
96				3,400,331	5,100,496	6,800,662	8,600,662

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	66	94	132		Pressure	drop pipe	gc
3/4	162	230	325		with these		si:
1	340	481	680	592			
Notes:	782	1,107	1,565	1,056			
1/4	1,237	1,750	2,475	1,455	2,182		
1-	2,564	3,627	5,129	2,431	3,646	4,861	
1 1/2							

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

1/2 Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
2-	4,264	6,031	8,529	3,489	5,233	6,978	13
1/2	7,125	10,220	0.5	5,437 2,000 (23)	8,000 (34)	10,000 (45)	8
3	17,015			9,464	14,196	18,928	
4							
5	31,824	governs	with	14,977	22,465	29,953	37
6	51,739	pipe	sizes	21,457	32,186	42,915	53
8				37,589	56,383	75,178	93
10	Velocity			61,459	92,189	122,919	15
12	these			89,260	133,889	178,519	22
14				109,261	163,892	218,523	27
16				145,466	218,199	290,932	36
18				186,843	280,265	373,686	46
20				233,392	350,089	466,785	58
22				285,114	427,671	570,227	71
24				342,007	513,011	684,014	85
26				404,073	606,109	808,145	1,
28				471,310	706,966	942,621	1,
30				543,720	815,580	1,087,441	1,
32				621,302	931,953	1,242,604	1,
34				704,056	1,056,084	1,408,113	1,
36				791,983	1,187,974	1,583,965	1,
42				1,086,794	1,630,191	2,173,588	2,
48				1,428,155	2,142,232	2,856,309	3,
54				1,816,064	2,724,097	3,632,129	4,
60				2,250,523	3,375,785	4,501,047	5,
72				3,259,089	4,888,633	6,518,178	8,
84				4,453,851	6,680,777	8,907,702	11
96				5,834,810	8,752,215	11,669,620	14

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	78	110	155		Pressure	drop pipe	gc
3/4	190	269	381		with these		si:
1	399	564	797	727			
Notes:	918	1.298	1.836	1.296			

Pipe Size	Pressure Drop psig/100 ft			Velocity FPM (mph)			
	1,785	2,678	3,571	1,785	2,678	3,571	4,464
1/2	3,008	4,254	6,016	2,983	4,474	5,966	7,458
2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)
2-1/2	5,002	7,074	10,004	4,281	6,422	8,562	10,703
3	9,290	13,137		6,672	10,008	13,344	16,650
4	19,958	28,225		11,613	17,420	23,227	29,034
5	37,328	governs	with	18,378	27,567	36,756	45,945
6	60,686	pipe	sizes	26,331	39,496	52,662	65,827
8				46,127	69,190	92,253	115,316
10	Velocity			75,419	113,128	150,838	188,547
12	these			109,534	164,300	219,067	273,834
14				134,078	201,117	268,156	332,923
16				178,506	267,760	357,013	446,270
18				229,282	343,922	458,563	570,116
20				286,404	429,605	572,807	710,552
22				349,873	524,809	699,745	871,181
24				419,688	629,533	839,377	1,040,017
26				495,851	743,777	991,702	1,240,562
28				578,361	867,541	1,156,721	1,440,807
30				667,217	1,000,826	1,334,434	1,650,952
32				762,421	1,143,631	1,524,841	1,881,097
34				863,971	1,295,956	1,727,942	2,141,242
36				971,868	1,457,802	1,943,736	2,411,387
42				1,333,641	2,000,462	2,667,282	3,301,532
48				1,752,536	2,628,804	3,505,072	4,341,677
54				2,228,553	3,342,830	4,457,106	5,481,822
60				2,761,692	4,142,538	5,523,384	6,781,967
72				3,999,336	5,999,005	7,998,673	9,898,318
84				5,465,469	8,198,203	10,930,938	13,471,063
96				7,160,089	10,740,134	14,320,179	17,460,324

Steam Condensate Flow lbs./h 10 psig Back Pressure

Notes:	99	139	197		Pressure	drop pipe	gc
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3/4 Pipe 1 Size	242 Pressure 506	342 Drop 716 ft.	484 psig/100 1,013	981	with these Velocity FPM (mph)	5,000 3,000 (34) 4,000 (45) 5,000 (53) 6,039	5,000 6,000 7,000 8,000 9,000 10,000 11,000 12,000 13,000 14,000 15,000 16,000 17,000 18,000 19,000 20,000 21,000 22,000 23,000 24,000 25,000 26,000 27,000 28,000 29,000 30,000 31,000 32,000 33,000 34,000 35,000 36,000 37,000 38,000 39,000 40,000 41,000 42,000 43,000 44,000 45,000 46,000 47,000 48,000 49,000 50,000 51,000 52,000 53,000 54,000 55,000 56,000 57,000 58,000 59,000 60,000 61,000 62,000 63,000 64,000 65,000 66,000 67,000 68,000 69,000 70,000 71,000 72,000 73,000 74,000 75,000 76,000 77,000 78,000 79,000 80,000 81,000 82,000 83,000 84,000 85,000 86,000 87,000 88,000 89,000 90,000 91,000 92,000 93,000 94,000 95,000 96,000 97,000 98,000 99,000 100,000
1-	1,166	1,649	2,331	1,749			
1/4	1,813	2,605	3,687	2,409			
1-	3,821	5,403	7,641	4,026			
1/2							
2-	6,353	8,985	12,707	5,778	8,668	11,557	
1/2	11,800	16,687		9,005	13,508	18,011	22,000
3	25,350	35,851		15,675	23,512	31,350	39,000
4							
5	47,413			24,805	37,208	49,610	62,000
6	77,083			35,539	53,309	71,078	88,000
8				62,257	93,386	124,515	155,000
10				101,794	152,690	203,587	255,000
12				147,838	221,758	295,677	365,000
14				180,966	271,450	361,933	450,000
16	Velocity	governs	with	240,932	361,398	481,863	600,000
18	these	pipe	sizes	309,463	464,195	618,927	770,000
20				386,562	579,842	773,123	960,000
22				472,226	708,339	944,452	1,180,000
24				566,457	849,686	1,132,914	1,410,000
26				669,255	1,003,882	1,338,510	1,660,000
28				780,619	1,170,928	1,561,237	1,940,000
30				900,549	1,350,824	1,801,098	2,230,000
32				1,029,046	1,543,569	2,058,092	2,550,000
34				1,166,109	1,749,164	2,332,219	2,890,000
36				1,311,739	1,967,609	2,623,479	3,270,000
42				1,800,028	2,700,041	3,600,055	4,480,000
48				2,365,414	3,548,121	4,730,828	5,920,000
54				3,007,899	4,511,848	6,015,797	7,520,000
60				3,727,481	5,591,222	7,454,963	9,360,000
72				5,397,941	8,096,912	10,795,882	13,480,000
84				7,376,794	11,065,190	14,753,587	18,430,000
96				9,664,039	14,496,058	19,328,077	24,160,000

Notes: Pressure Drop psig/100

Velocity FPM (mph)

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

2. Table based on heavy weight steel pipe using steam equations in Part 1 (23)



40 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

**Pipe Pressure Drop psig/100
Size ft.**

Velocity FPM (mph)

0.125 0.25 0.5 2,000 (23) 3,000 (34) 4,000 (45) 5,000 (50)

Steam Condensate Flow lbs./h 0 psig Back Pressure

Pipe Size	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (50)
1/2	37	52	73		Pressure drop pipe with these		govern these sizes
3/4	90	127	180	172			
1	188	266	376	286			
1-1/4	433	613	867	510	765	2,348	
1-1/2	685	969	1,370	703	1,054		
2	1,420	2,008	2,840	1,174	1,761		
2-1/2							
3	2,361	3,339	with sizes	1,685	2,527	3,370	4,385
4	4,385	6,202		2,626	3,939	5,252	6,856
5	9,422			4,571	6,856	9,141	11,761
6	17,622	governs pipe		7,233	10,849	14,466	18,154
8				10,363	15,544	20,726	27,230
10				18,154	27,230	36,307	45,385
12	Velocity these			29,682	44,523	59,364	74,202
14				43,108	64,662	86,216	107,854
16				52,768	79,152	105,536	132,910
18				70,253	105,380	140,506	176,672
20				90,236	135,354	180,472	225,434
				112,717	169,076	225,434	286,854
Notes:				137,696	206,544	275,392	347,272

Pipe Size	Pressure	Drop	psig/100 ft.	165,173 195,147	247,759 292,721	330,346 390,295	41 48
28	0.125	0.25	0.5	227,000	341,430	455,240	56
30				267,290	393,886	525,181	65
32				300,059	450,088	600,117	75
34				340,025	510,037	680,050	85
36				382,489	573,733	764,978	95
42				524,869	787,303	1,049,737	1,
48				689,729	1,034,594	1,379,458	1,
54				877,071	1,315,606	1,754,141	2,
60				1,086,893	1,630,340	2,173,786	2,
72				1,573,981	2,360,972	3,147,962	3,
84				2,150,993	3,226,490	4,301,986	5,
96				2,817,929	4,226,894	5,635,858	7,

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	52	74	104		Pressure with these	drop pipe	gc si
3/4	128	180	255				
1	267	378	534	465			
1-	615	870	1,230	830			
1/4	972	1,375	1,945	1,143	1,715		
1-	2,015	2,850	4,031	1,910	2,865	3,820	
1/2							
2							
2-	3,351	4,739	6,702	2,742	4,112	5,483	
1/2	6,224	8,802		4,273	6,409	8,545	10
3	13,371			7,437	11,156	14,874	18
4							
5	25,008	governs	with	11,769	17,654	23,538	29
6	40,658	pipe	sizes	16,862	25,293	33,724	42
8				29,539	44,308	59,077	73
10	Velocity			48,297	72,445	96,594	12
12	these			70,143	105,215	140,286	17
14				85,861	128,791	171,722	21
Notes:				114,312	171,468	228,624	28
18				146,827	220,241	293,655	36

Pipe Size	Pressure Drop psig/100 ft.			183,407	275,111	366,814	45
				Velocity FPM (mph)			
22				224,051	336,077	448,103	56
24	0.125	0.25	0.5	268,780	403,140	537,520	67
26				317,533	476,300	635,067	79
28				370,371	555,556	740,742	92
30				427,273	640,909	854,546	1,06
32				488,239	732,359	976,478	1,22
34				553,270	829,905	1,106,540	1,38
36				622,365	933,548	1,244,730	1,56
42				854,037	1,281,056	1,708,075	2,14
48				1,122,290	1,683,434	2,244,579	2,81
54				1,427,121	2,140,682	2,854,243	3,58
60				1,768,533	2,652,800	3,537,066	4,44
72				2,561,096	3,841,644	5,122,193	6,40
84				3,499,979	5,249,968	6,999,957	8,75
96				4,585,180	6,877,770	9,170,361	11,41

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	59	84	119		Pressure	drop pipe	go
3/4	146	206	291		with these		si
1	305	432	610	556			
1-	702	993	1,405	992			
1/4	1,111	1,571	2,221	1,366	2,049		
1-	2,302	3,256	4,604	2,283	3,424	4,566	
1/2							
2							
2-	3,828	5,414	7,656	3,277	4,915	6,553	
1/2	7,110	10,055		5,106	7,660	10,213	12
3	15,275	21,602		8,888	13,332	17,777	22
4							
5	28,568	governs	with	14,066	21,098	28,131	35
6	46,446	pipe	sizes	20,152	30,228	40,304	50
8				35,303	52,954	70,605	88

Notes: Velocity
 12 these
 1. Maximum recommended pressure drop/velocity: 0.25 psia/100 ft./5.00

Pipe Size	Pressure Drop psig/100 ft.			102,616	153,924	205,232	25
	0.125	0.25	0.5				
14				136,619	204,928	273,237	34
18				175,479	263,219	350,958	43
20	0.125	0.25	0.5	219,197 (23)	328,795 (34)	438,394 (45)	54
22				267,772	401,659	535,545	66
24				321,206	481,808	642,411	80
26				379,496	569,244	758,992	94
28				442,644	663,966	885,289	1,111
30				510,650	765,975	1,021,300	1,283
32				583,513	875,270	1,167,026	1,477
34				661,234	991,851	1,322,468	1,693
36				743,812	1,115,719	1,487,625	1,931
42				1,020,693	1,531,039	2,041,386	2,591
48				1,341,291	2,011,937	2,682,582	3,383
54				1,705,607	2,558,411	3,411,215	4,311
60				2,113,642	3,170,462	4,227,283	5,383
72				3,060,864	4,591,296	6,121,728	7,771
84				4,182,958	6,274,437	8,365,916	10,611
96				5,479,924	8,219,886	10,959,848	13,911

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	72	102	144		Pressure drop pipe governs with these sizes	
3/4	177	250	353			
1	370	523	740	717		
1-1/4	852	1,205	1,704	1,278		
1-1/2	1,347	1,905	2,694	1,761	2,641	
2	2,792	3,949	5,585	2,942	4,414	
2-1/2	4,643	6,567	9,287	4,223	6,335	8,446
3	8,624	12,196		6,582	9,872	13,163
4	18,527	26,202		11,456	17,184	22,912
6	34,652			18,129	27,193	36,258
8	56,336			25,974	38,961	51,948
10				45,501	68,251	91,002

Notes: Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM	Velocity FPM (mph)		
	0.125	0.25	0.5		3,000 (34)	4,000 (45)	
10				74,396	111,504	148,792	18
12	these			108,048	162,071	216,095	27
14				132,060 (23)	198,389 3,000 (34)	264,518 4,000 (45)	33 5,
16				176,085	264,127	352,169	44
18				226,171	339,256	452,342	56
20				282,518	423,777	565,036	70
22				345,126	517,689	690,252	86
24				413,995	620,992	827,989	1,03
26				489,124	733,686	978,248	1,22
28				570,514	855,771	1,141,029	1,43
30				658,165	987,248	1,316,331	1,64
32				752,077	1,128,116	1,504,154	1,86
34				852,250	1,278,375	1,704,500	2,09
36				958,683	1,438,025	1,917,366	2,34
42				1,315,548	1,973,322	2,631,096	3,28
48				1,728,760	2,593,140	3,457,520	4,31
54				2,198,319	3,297,479	4,396,638	5,47
60				2,724,225	4,086,338	5,448,451	6,75
72				3,945,079	5,917,619	7,890,158	9,87
84				5,391,321	8,086,982	10,782,642	13,43
96				7,062,952	10,594,427	14,125,903	17,55

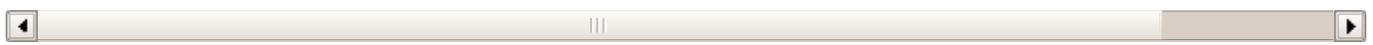
Steam Condensate Flow lbs./h 12 psig Back Pressure

Pipe Size	82	116	164		Pressure with these	drop pipe	gc si:
1/2	82	116	164				
3/4	201	284	402				
1	421	595	842				
1-	969	1,371	1,938	1,508			
1/4	1,533	2,167	3,065	2,077			
1-	3,177	4,492	6,353	3,471	5,207		
1/2							
2							
2-	5,282	7,470	10,564	4,982	7,474	9,965	
1/2	9,810	13,873		7,765	11,647	15,530	19
3	21,076	29,806		13,515	20,273	27,031	35
4							

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
5	39,419	21,388
6	64,086	32,082
8		42,776
10	0.125	53,680
12	0.25	87,770
14	0.5	131,055
16		175,540
18		220,025
20		264,510
22		309,000
24		353,485
26		397,970
28		442,455
30		486,940
32		531,425
34		575,910
36		620,395
42		714,280
48		808,165
54		902,050
60		995,935
72		1,184,720
84		1,373,505
96		1,562,290

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



50 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
Notes:	0.125	0.25
	0.5	2,000
		3,000 (34)
		4,000 (45)
		5,000

Pipe Size	Pressure Drop psig/100 ft			Back Pressure (23)	Velocity FPM (mph)		
	0.125	0.25	0.5		3,000 (34)	4,000 (45)	5,000 (56)
1/2	32	45	64	2,000	Pressure drop with these	pipe	90
3/4	78	111	156	150			
1	164	232	328	249			
1-1/4	377	533	754	444	666	2,044	
1-1/2	596	843	1,193	611	917		
2	1,236	1,748	2,472	1,022	1,533		
2-1/2	2,055	2,907	with sizes	1,467	2,200		
3	3,817	5,398		2,286	3,428	4,571	5,967
4	8,201			3,978	5,967	7,957	9,967
5	15,338	governs pipe		6,296	9,443	12,591	15,338
6				9,020	13,530	18,040	22,710
8				15,801	23,702	31,602	39,504
10	Velocity these			25,836	38,753	51,671	64,588
12				37,522	56,283	75,044	93,805
14				45,930	68,895	91,860	114,825
16				61,149	91,724	122,298	152,873
18				78,543	117,814	157,085	197,297
20				98,110	147,166	196,221	245,445
22				119,852	179,779	239,705	301,531
24				143,769	215,653	287,537	363,363
26				169,859	254,788	339,718	427,509
28				198,123	297,185	396,247	501,655
30				228,562	342,843	457,124	581,801
32				261,175	391,762	522,350	664,487
34				295,962	443,943	591,924	751,633
36				332,923	499,385	665,847	844,779
42				456,852	685,279	913,705	1,164,415
Notes:				600,349	900,524	1,200,698	1,500,873
54				763,414	1,145,120	1,526,827	1,908,435
60				946,046	1,419,069	1,892,092	2,375,699

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000	3,000 (34)	4,000 (45)	
72				1,370,013	2,051,017	2,744,504	3,
84				1,872,252	2,808,378	3,744,504	4,
96				2,452,762	3,679,143	4,905,523	6,
(23)							
Steam Condensate Flow lbs./h 5 psig Back Pressure							
1/2	44	62	88		Pressure	drop pipe	go
3/4	108	152	215		with these		si
1	225	318	450	392			
1-	518	733	1,037	700			
1/4	820	1,159	1,639	964	1,446		
1-	1,699	2,403	3,398	1,610	2,416	3,221	
1/2							
2							
2-	2,825	3,995	5,650	2,311	3,467	4,623	9,
1/2	5,247	7,420		3,602	5,403	7,204	1!
3	11,273			6,270	9,405	12,540	
4							
5	21,083	governs	with	9,922	14,883	19,844	2!
6	34,277	pipe	sizes	14,215	21,323	28,431	3!
8				24,903	37,354	49,805	6!
10	Velocity			40,717	61,075	81,434	10
12	these			59,135	88,702	118,269	1!
14				72,386	108,578	144,771	1!
16				96,371	144,557	192,743	2!
18				123,784	185,675	247,567	3!
20				154,622	231,934	309,245	3!
22				188,888	283,332	377,776	4!
24				226,580	339,870	453,159	5!
26				267,698	401,547	535,396	6!
28				312,243	468,365	624,486	7!
30				360,215	540,322	720,429	9!
32				411,613	617,419	823,225	1,
34				466,437	699,656	932,875	1,
36				524,688	787,033	1,049,377	1,
42				720,001	1,080,002	1,440,002	1,

Pipe Size 48 54 60	Pressure	Drop psig/100 ft.		946,152	1,419,229	1,892,305	2,
				1,203,143	1,804,714	2,406,283	3,
				1,490,972	2,236,458	2,981,944	3,
				2,000	3,000 (34)	4,000 (45)	5,
72	0.125	0.25	0.5	2,152,146	3,238,720	4,318,293	5,
84				2,950,676	4,426,015	5,901,353	7,
96				3,865,562	5,798,343	7,731,123	9,

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	49	70	99		Pressure	drop pipe	go
3/4	121	171	242		with these		si
1	253	358	507	462			
1-	583	825	1,167	824			
1/4	923	1,305	1,845	1,135	1,702		
1-	1,912	2,704	3,824	1,896	2,844	3,792	
1/2							
2							
2-	3,180	4,497	6,359	2,722	4,082	5,443	
1/2	5,905	8,351		4,241	6,362	8,483	10
3	12,687	17,942		7,382	11,074	14,765	18
4							
5	23,728	governs	with	11,683	17,524	23,365	29
6	38,577	pipe	sizes	16,738	25,107	33,476	41
8				29,322	43,983	58,644	71
10	Velocity			47,942	71,914	95,885	118
12	these			69,628	104,443	139,257	171
14				85,231	127,847	170,462	215
16				113,473	170,210	226,947	281
18				145,750	218,625	291,500	361
20				182,062	273,092	364,123	451
22				222,408	333,612	444,815	551
24				266,788	400,183	533,577	651
26				315,204	472,806	630,407	781
28				367,654	551,480	735,307	911
30				424,138	636,207	848,276	1,051
32				484,657	726,986	969,314	1,201
Notes:				549,211	823,816	1,098,422	1,351

Pipe Size	Pressure	Drop	psig/100 ft.	Velocity	FPM (mph)		
36				617,799	926,699	1,235,598	1,
42				847,772	1,271,658	1,695,544	2,
48	0.125	0.25	0.5	1,114,056	1,671,084	2,228,112	3,
54				1,416,651	2,124,977	2,833,303	3,
60				1,755,558	2,633,338	3,511,117	4,
72				2,542,307	3,813,460	5,084,614	6,
84				3,474,301	5,211,452	6,948,602	8,
96				4,551,541	6,827,312	9,103,082	10,

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	58	83	117		Pressure	drop pipe	go
3/4	143	203	286		with these		si
1	300	424	600	581			
1-	690	976	1,381	1,036			
1/4	1,092	1,544	2,184	1,427	2,140		
1-	2,263	3,200	4,526	2,384	3,577		
1/2							
2							
2-	3,763	5,322	7,526	3,422	5,134	6,845	
1/2	6,989	9,883		5,334	8,001	10,668	10,
3	15,015	21,234		9,284	13,926	18,568	20,
4							
5	28,082	governs	with	14,692	22,038	29,383	30,
6	45,655	pipe	sizes	21,049	31,574	42,098	50,
8				36,874	55,311	73,748	90,
10	Velocity			60,291	90,436	120,581	100,
12	these			87,562	131,343	175,124	200,
14				107,183	160,775	214,366	200,
16				142,699	214,049	285,399	300,
18				183,290	274,934	366,579	400,
20				228,953	343,430	457,907	500,
22				279,691	419,536	559,382	600,
24				335,502	503,254	671,005	800,
26				396,387	594,581	792,775	900,
Notes:				462,346	693,520	924,693	1,

30 Pipe Size	Pressure Drop psig/100 ft.			533,379	800,068	1,066,758	1,
32				609,485	914,226	1,199,835	1,
34	0.125	0.25	0.5	690,666	1,035,998	1,381,331	1,
36				776,919	1,109,374	1,499,845	5,
42				1,066,124	1,599,186	2,132,247	2,
48				1,400,992	2,101,488	2,801,984	3,
54				1,781,524	2,672,286	3,563,048	4,
60				2,207,720	3,311,579	4,415,439	5,
72				3,197,103	4,795,654	6,394,205	7,
84				4,369,141	6,553,712	8,738,282	10,
96				5,723,835	8,585,752	11,447,670	14,

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	65	92	130		Pressure	drop pipe	go
3/4	160	226	320		with these		si
1	335	474	670				
1-	771	1,090	1,542	1,199			
1/4	1,219	1,724	2,438	1,652			
1-	2,526	3,573	5,052	2,761	4,141		
1/2							
2							
2-	4,201	5,941	8,402	3,962	5,944	7,925	
1/2	7,802	11,033		6,175	9,263	12,351	11,
3	16,762	23,704		10,749	16,123	21,497	20,
4							
5	31,349	governs	with	17,010	25,514	34,019	41,
6	50,967	pipe	sizes	24,370	36,555	48,740	60,
8				42,691	64,037	85,383	100,
10	Velocity			69,802	104,704	139,605	170,
12	these			101,376	152,065	202,753	250,
14				124,093	186,140	248,186	300,
16				165,213	247,819	330,426	400,
18				212,207	318,310	424,413	500,
20				265,075	397,612	530,150	600,
Notes:				323,817	485,726	647,634	800,
24				388,434	582,651	776,868	900,

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)	1	2	3	4	5	6	7	8	9	10
26			458,925	688,387	917,849	1,147,311	1,376,773	1,606,235	1,835,697	2,065,159	2,294,621	2,524,083
28			535,290	802,934	1,070,579	1,338,223	1,605,867	1,873,511	2,141,155	2,408,800	2,676,444	2,944,088
30	0.125	0.25	611,655	926,293	1,235,058	1,543,823	1,852,588	2,161,353	2,470,118	2,778,883	3,087,648	3,396,413
32	0.125	0.25	704,282	1,058,464	1,411,285	1,764,106	2,116,927	2,469,748	2,822,569	3,175,390	3,528,211	3,881,032
34			799,630	1,199,445	1,599,260	2,000,075	2,400,890	2,801,705	3,202,520	3,603,335	4,004,150	4,404,965
36			899,492	1,349,238	1,798,984	2,248,730	2,698,476	3,148,222	3,597,968	4,047,714	4,497,460	4,947,206
42			1,234,324	1,851,485	2,468,647	3,085,808	3,702,969	4,320,130	4,937,291	5,554,452	6,171,613	6,788,774
48			1,622,023	2,433,035	3,244,046	4,055,057	4,866,068	5,677,079	6,488,090	7,299,101	8,110,112	8,921,123
54			2,062,591	3,093,886	4,125,181	5,156,476	6,187,771	7,219,066	8,250,361	9,281,656	10,312,951	11,344,246
60			2,556,026	3,834,040	5,112,053	6,424,106	7,736,159	9,048,212	10,360,265	11,672,318	12,984,371	14,296,424
72			3,701,502	5,552,253	7,403,004	9,253,755	11,104,506	12,955,257	14,806,008	16,656,759	18,507,510	20,358,261
84			5,058,450	7,587,675	10,116,901	12,646,126	15,175,351	17,704,576	20,233,801	22,763,026	25,292,251	27,821,476
96			6,626,871	9,940,306	13,253,742	16,567,177	19,881,612	23,196,047	26,510,482	29,824,917	33,139,352	36,453,787

Steam Condensate Flow lbs./h 15 psig Back Pressure

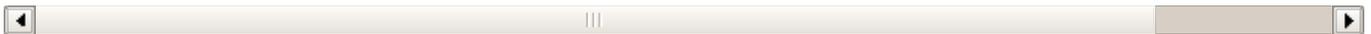
1/2	77	108	153		Pressure	drop pipe	go
3/4	188	266	376		with these		si
1	394	557	788				
1-	907	1,283	1,814	1,483			
1/4	1,434	2,028	2,869	2,044			
1-	2,973	4,204	5,946	3,415	5,122		
1/2							
2							
2-	4,943	6,991	9,887	4,901	7,352	9,802	
1/2	9,181	12,984	18,362	7,638	11,458	15,277	
3	19,724	27,894		13,295	19,943	26,590	3:
4							
5	36,890	52,171	with	21,040	31,559	42,079	5:
6	59,976		sizes	30,144	45,216	60,288	7:
8	126,990			52,806	79,209	105,613	1:
10	Velocity	governs		86,341	129,511	172,681	2:
12	these	pipe		125,395	188,093	250,791	3:
14				153,494	230,242	306,989	3:
Notes:				204,356	306,535	408,713	5:
18				262,484	393,727	524,969	6:
20				327,878	491,818	655,757	8:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			ft.
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
20				327,070	451,010	555,757	0.8
22				400,539	600,808	801,079	1.0
24				480,465	720,697	960,929	1.2
26				567,837	851,485	1,135,313	1.5
28				662,115	993,172	1,324,229	1.8
30				763,839	1,145,758	1,527,678	2.0
32				872,829	1,309,243	1,745,658	2.2
34				989,085	1,483,627	1,978,170	2.5
36				1,112,607	1,668,910	2,225,214	2.8
42				1,526,769	2,290,154	3,053,539	3.5
48				2,006,326	3,009,488	4,012,651	5.0
54				2,551,276	3,826,914	5,102,552	6.0
60				3,161,620	4,742,431	6,323,241	7.0
72				4,578,491	6,867,737	9,156,983	10.0
84				6,256,938	9,385,408	12,513,877	14.0
96				8,196,962	12,295,443	16,393,924	20.0

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



60 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	29	41	57		Pressure	drop pipe	gc
3/4	70	99	141	134	with these		si
1	147	208	294	224			
Notes:	339	479	677	399	598		
1/4	536	757	1,071	549	824		
1-	1,110	1,570	2,220	918	1,376	1,835	

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

1/2 Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
2- 1/2 3 4	1,846 0.125 3,428 7,365	2,610 0.25 4,848	with 0.5 sizes	1,317 2,000 2,053 (23) 3,573	1,976 3,000 (34) 3,079	2,634 4,000 (45) 4,105	3, 5, 8,
5 6 8	13,774	governs pipe		5,654 8,100 14,190	8,481 12,150 21,285	11,308 16,201 28,380	14 20 31
10 12 14	Velocity these			23,201 33,696 41,247	34,802 50,544 61,870	46,403 67,392 82,494	58 84 10
16 18 20				54,915 70,535 88,107	82,372 105,802 132,161	109,829 141,070 176,215	11 17 22
22 24 26				107,633 129,110 152,541	161,449 193,666 228,811	215,265 258,221 305,081	26 32 38
28 30 32				177,923 205,259 234,546	266,885 307,888 351,820	355,847 410,517 469,093	44 51 58
34 36 42				265,787 298,980 410,273	398,680 448,469 615,410	531,573 597,959 820,546	60 74 1,
48 54 60				539,139 685,578 849,590	808,709 1,028,368 1,274,385	1,078,279 1,371,157 1,699,180	1, 1, 2,
72 84 96				1,230,331 1,681,363 2,202,686	1,845,497 2,522,045 3,304,029	2,460,663 3,362,727 4,405,372	3, 4, 5,

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	39	55	77		Pressure	drop pipe	go
3/4	95	134	189		with these		si
1	198	280	396	345			
1 1/2	456	644	911	615			

1- Pipe Size	456 Pressure 721	644 Drop 1,019 ft.	911 psig/100 1,441	615 847	1,272	Velocity FPM (mph)	
1- 1/4	1,494	2,112	2,987	1,416	2,124	2,831	
1/2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
2-	2,484	3,512	4,967	2,032	3,048	4,064	
1/2	4,613	6,523		3,167	4,750	6,333	7,
3	9,910			5,512	8,268	11,024	10,
4							
5	18,535	governs	with	8,723	13,084	17,445	20,
6	30,133	pipe	sizes	12,497	18,746	24,994	30,
8				21,892	32,839	43,785	50,
10	Velocity			35,795	53,693	71,590	80,
12	these			51,986	77,980	103,973	100,
14				63,636	95,454	127,271	100,
16				84,722	127,083	169,444	200,
18				108,821	163,231	217,642	200,
20				135,932	203,898	271,864	300,
22				166,055	249,083	332,110	400,
24				199,191	298,786	398,382	400,
26				235,339	353,009	470,678	500,
28				274,499	411,749	548,999	600,
30				316,672	475,008	633,344	700,
32				361,857	542,786	723,715	900,
34				410,055	615,082	820,110	1,
36				461,265	691,897	922,529	1,
42				632,968	949,452	1,265,936	1,
48				831,782	1,247,674	1,663,565	2,
54				1,057,708	1,586,562	2,115,416	2,
60				1,310,744	1,966,117	2,621,489	3,
72				1,898,151	2,847,226	3,796,301	4,
84				2,594,001	3,891,002	5,188,002	6,
96				3,398,296	5,097,444	6,796,592	8,

Steam Condensate Flow lbs./h 7 psig Back Pressure

Notes: 43	61	86		Pressure	drop pipe	go
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Pipe Size	Pressure psig	Drop ft./100	Velocity FPM (mph)	Notes
1-1/4	508	718	1,016	with these Velocity FPM (mph)
1-1/2	803	1,136	1,607	
2	1,665	2,355	3,330	
2-1/2	2,769	3,915	5,537	
3	5,142	7,272	10,173	
4	11,047	15,623	14,575	
5	20,662	governs pipe	25,532	with sizes
6	33,591		38,298	
8	Velocity		41,746	
10	these		60,630	
12			74,216	
14			98,808	
16			126,913	
18			158,531	
20			193,663	
22			232,308	
24			274,466	
26			320,137	
28			369,321	
30			422,019	
32			478,229	
34			537,953	
36			738,203	
42			970,072	
48			1,233,559	
54			1,528,665	
60			2,213,732	
Notes:			3,320,598	
84			4,427,464	
96			6,050,545	
			7,926,574	

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psi/100 ft.				Velocity FPM (mph)		
	50	71	100	150	2,000	3,000	4,000
1/2	123	174	246	369	23	34	45
3/4	125	175	246	369	23	34	45
1	257	364	514	771	23	34	45
1-1/4	592	837	1,184	1,776	23	34	45
1-1/2	936	1,324	1,873	2,810	34	45	60
2	1,941	2,744	3,881	5,724	45	60	80
2-1/2	3,227	4,564	6,454	9,681	60	80	110
3	5,993	8,476	11,942	17,913	80	110	150
4	12,876	18,209	25,724	38,586	110	150	200
5	24,082			73,921	18,898	25,198	33,597
6	39,152			119,856	27,076	36,102	48,136
8				186,437	47,432	63,243	84,324
10	Velocity	governs	with	51,702	77,554	103,405	137,873
12	these	pipe	sizes	75,089	112,634	150,178	200,237
14				91,915	137,873	183,831	247,776
16				122,373	183,559	244,745	326,328
18				157,181	235,771	314,361	419,144
20				196,340	294,510	392,680	520,243
22				239,850	359,775	479,700	639,584
24				287,711	431,567	575,423	764,561
26				339,924	509,885	679,847	903,776
28				396,487	594,730	792,974	1,055,280
30				457,401	686,102	914,802	1,218,320
32				522,667	784,000	1,045,333	1,393,760
34				592,283	888,424	1,184,566	1,572,160
36				666,250	999,375	1,332,501	1,772,160
42				914,259	1,371,388	1,828,517	2,438,400
48				1,201,426	1,802,139	2,402,852	3,171,200
54				1,527,753	2,291,629	3,055,506	4,073,600
60				1,893,239	2,839,858	3,786,477	5,048,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			Pipe Size
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
1/2	55	78	111		Pressure	drop pipe	6,
3/4	136	192	271		with these		9,
1	284	402	568				1,
1-	654	924	1,307	1,017			
1/4	1,033	1,462	2,067	1,401			
1-	2,142	3,029	4,284	2,341	3,511		
1/2							
2-	3,562	5,037	7,124	3,360	5,040	6,720	
1/2	6,615	9,356		5,236	7,854	10,472	1,
3	14,213	20,100		9,114	13,671	18,228	2,
4							
5	26,582	governs	with	14,423	21,634	28,846	3,
6	43,216	pipe	sizes	20,664	30,996	41,328	5,
8				36,199	54,299	72,398	9,
10	Velocity			59,187	88,781	118,375	1,
12	these			85,960	128,940	171,919	2,
14				105,222	157,833	210,444	2,
16				140,088	210,132	280,177	3,
18				179,936	269,903	359,871	4,
20				224,764	337,146	449,528	5,
22				274,573	411,860	549,146	6,
24				329,363	494,045	658,726	8,
26				389,134	583,701	778,268	9,
28				453,886	680,829	907,772	1,
30				523,619	785,428	1,047,238	1,
32				598,333	897,499	1,196,666	1,
34				678,027	1,017,041	1,356,055	1,
36				762,703	1,144,055	1,525,406	1,
42				1,046,615	1,569,923	2,093,231	2,
Notes:				1,375,356	2,063,034	2,750,712	3,

Pipe Size	Pressure	Drop	psig/100 ft.	1,748,925	2,623,387	3,497,850	4,
				2,167,322	3,250,983	4,334,644	5,
72	0.125	0.25	0.5	3,136,601	4,707,901	6,277,202	7,
84				4,281,93	6,433,789	8,578,386	10,
96				5,619,098	8,428,647	11,238,196	14,

Steam Condensate Flow lbs./h 15 psig Back Pressure

	64	90	128		Pressure	drop pipe	go
1/2	64	90	128		with these		si
3/4	157	221	313				
1	328	464	656				
1-	755	1,067	1,510	1,235			
1/4	1,194	1,688	2,387	1,701			
1-	2,474	3,499	4,948	2,842	4,263		
1/2							
2							
2-	4,114	5,818	8,228	4,079	6,118	8,158	
1/2	7,640	10,805	15,281	6,357	9,535	12,713	
3	16,415	23,214		11,064	16,596	22,129	2,
4							
5	30,700	43,417	with	17,509	26,264	35,018	4,
6	49,912		sizes	25,086	37,629	50,172	6,
8	105,681			43,946	65,918	87,891	10,
10	Velocity	governs		71,853	107,779	143,706	1,
12	these	pipe		104,354	156,532	208,709	20,
14				127,739	191,608	255,477	30,
16				170,066	255,099	340,132	40,
18				218,440	327,661	436,881	50,
20				272,862	409,292	545,723	60,
22				333,330	499,994	666,659	80,
24				399,844	599,766	799,688	90,
26				472,406	708,609	944,812	1,
28				551,014	826,521	1,102,028	1,
30				635,669	953,504	1,271,338	1,
32				726,371	1,089,557	1,452,742	1,
Notes:				823,120	1,234,680	1,646,240	2,
36				925,915	1,388,873	1,851,831	2,

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
42	0.125	2,000 (23)
48	0.25	3,000 (34)
54	0.5	4,000 (45)
60		
72		
84		
96		

Steam Condensate Flow lbs./h 20 psig Back Pressure

1/2	81	114	162		Pressure	drop pipe	go
3/4	198	280	396		with these		si
1	415	587	830				
1-	956	1,352	1,911	1,681			
1/4	1,511	2,137	3,022	2,316			
1-	3,132	4,430	6,265	3,870	5,805		
1/2							
2							
2-	5,209	7,366	10,417	5,555	8,332		
1/2	9,673	13,680	19,347	8,657	12,985	17,314	
3	20,782	29,391		15,068	22,602	30,136	3
4							
5	38,870	54,970	with	23,845	35,767	47,689	5
6	63,194		sizes	34,163	51,244	68,326	8
8	133,803			59,847	89,770	119,693	14
10	Velocity	governs		97,852	146,778	195,704	24
12	these	pipe		142,114	213,170	284,227	3
14				173,959	260,938	347,918	4
16				231,602	347,403	463,204	5
18				297,480	446,220	594,960	7
20				371,592	557,389	743,185	9
22				453,940	680,910	907,880	1,
24				544,522	816,783	1,089,044	1,
26				643,339	965,008	1,286,677	1,
Notes:				750,390	1,125,585	1,500,781	1,
30				865,677	1,298,515	1,731,353	2,

1. - Maximum recommended pressure drop/velocity: 0.25 psia/100 ft./5.00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
32				989,198	1,483,796	1,978,395	2,
36				1,120,953	1,681,430	2,241,907	2,
42				1,260,944	1,891,416	2,521,888	3,
48				1,730,324	2,595,436	3,400,645	5,
54				2,273,816	3,410,724	4,547,633	5,
60				2,891,421	4,337,132	5,782,843	7,
72				3,583,139	5,374,709	7,166,278	8,
84				5,188,913	7,783,369	10,377,825	12,
96				7,091,137	10,636,705	14,182,273	17,
				9,289,811	13,934,716	18,579,622	23,

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



75 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	25	36	50		Pressure	drop pipe	go
3/4	62	87	124	118	with these		si
1	130	183	259	197			
1-1/4	298	422	596	351	526		
1-1/2	471	667	943	483	725		
2	977	1,382	1,954	808	1,212	1,616	
Notes:	1,625	2,298	with	1,159	1,739	2,319	2,
1-1/2	3,018	4,268	sizes	1,807	2,710	3,614	4,
3	6,483			3,145	4,718	6,290	7,

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1

Pipe Size	Pressure	Drop ft.	psig/100	Velocity FPM (mph)			
				0.125	0.25	0.5	
8	these			4,977	7,466	9,954	11
				7,131	10,696	14,262	17
				12,492	18,738	24,984	30
				2,000	3,000 (34)	4,000 (45)	5,000
10				20,425	30,637	40,850	51
12				29,664	44,496	59,327	74
14				36,311	54,466	72,622	90
16							111
18							138
20							169
22							204
24							243
26							286
28							333
30				394			
32				460			
34				541			
36				627			
42				900			
48				1,112			
54				1,365			
60				1,660			
72				2,139			
84				2,727			
96				3,424			

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	33	47	66		Pressure	drop pipe	go
3/4	81	115	163		with these		si
1	170	241	341	297			
1-	392	555	785	530			
1/4	621	878	1,241	730	1,094		
1-	1,286	1,819	2,573	1,219	1,829	2,438	
1/2							
2							
Notes:	2,139	3,025	4,278	1,750	2,625	3,500	
1/2	3,072	5,619		2,727	4,001	5,454	6

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/2	3,972	4,091
3/4	8,534	7,120
1	15,123	11,268
1 1/4	25,951	16,144
1 1/2		21,525
2		37,707
2 1/2		54,803
3		72,963
3 1/2		93,716
4		117,064
4 1/2		143,007
5		171,543
5 1/2		202,674
6		236,399
6 1/2		272,718
7		311,631
7 1/2		353,139
8		397,240
8 1/2		545,111
9		716,330
9 1/2		910,897
10		1,128,811
10 1/2		1,634,685
11		2,233,951
11 1/2		2,926,608

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	37	52	73		Pressure	drop pipe	go
3/4	90	127	180		with these		si
1	188	266	377	343			
Notes:	433	613	867	612			
1/4	685	969	1,370	843	1,264		
1-	1,420	2,009	2,840	1,408	2,113	2,817	

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1

Pipe Size	Pressure Drop psig/100 ft			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
1/2	2,362	3,540	4,723	2,021	3,032	4,043	
3/4	4,386	6,203		3,150	4,726	6,301	7,511
1	9,425	13,327		5,483	8,225	10,967	13,111
1 1/2	17,625	governs pipe sizes		8,677	13,016	17,355	21,011
2	28,654			12,432	18,649	24,865	30,411
3				21,779	32,669	43,558	54,011
4	Velocity			35,610	53,415	71,220	89,011
6	these			51,717	77,576	103,435	130,011
8				63,306	94,960	126,613	158,011
10				84,284	126,425	168,567	212,011
12				108,258	162,386	216,515	274,011
14				135,228	202,843	270,457	340,011
16				165,196	247,794	330,392	414,011
18				198,160	297,240	396,320	498,011
20				234,121	351,182	468,242	588,011
22				273,079	409,618	546,158	688,011
24				315,034	472,550	630,067	788,011
26				359,985	539,977	719,970	898,011
28				407,933	611,899	815,866	1,018,011
30				458,878	688,316	917,755	1,148,011
32				629,692	944,539	1,259,385	1,578,011
34				827,478	1,241,217	1,654,956	2,084,011
36				1,052,234	1,578,352	2,104,469	2,644,011
38				1,303,962	1,955,942	2,607,923	3,304,011
40				1,888,328	2,832,492	3,776,656	4,744,011
42				2,580,578	3,870,867	5,161,155	6,484,011
44				3,380,710	5,071,066	6,761,421	8,524,011

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	42	60	84		Pressure	drop pipe	go
3/4	103	146	206		with these		si
1	216	306	432	419			
Notes:	498	704	995	747			
1 1/2	707	1,110	1,574	1,000	1,540		

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/4	1,631	2,543
1/2	0.125	3,000 (34)
2	0.25	4,000 (45)
2-1/2	0.5	5,000 (57)
3	2,000 (23)	6,000 (68)
4	2,712	7,000 (79)
5	3,835	8,000 (91)
6	5,424	9,000 (103)
8	10,821	10,000 (115)
10	governs pipe	11,000 (125)
12	with sizes	12,000 (137)
14		13,000 (149)
16		14,000 (161)
18		15,000 (173)
20		16,000 (185)
22		17,000 (197)
24		18,000 (209)
26		19,000 (221)
28		20,000 (233)
30		21,000 (245)
32		22,000 (257)
34		23,000 (269)
36		24,000 (281)
42		25,000 (293)
48		26,000 (305)
54		27,000 (317)
60		28,000 (329)
72		29,000 (341)
84		30,000 (353)
96		31,000 (365)

Steam Condensate Flow lbs./h 12 psig Back Pressure

Notes:	46	65	92	Pressure drop pipe	governs
3/4	113	159	225	with these	sizes

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/4	543	845
1/2	859	1,165
3/4	1,125	1,463
1	1,781	1,919
1 1/2	2,961	2,793
2	5,500	4,353
3	11,817	7,578
4	22,101	11,991
6	35,931	17,180
8		30,097
10		49,209
12		71,468
14		87,483
16	Velocity governs	with
18	these	pipe
20		sizes
22		116,472
24		149,602
26		186,873
28		228,285
30		273,838
32		323,533
34		377,369
36		435,346
42		497,464
48		563,724
54		634,125
60		870,174
72		1,143,495
84		1,454,087
96		1,801,950
		2,609,488
		3,566,111
		4,671,817

Notes: Condensate Flow lbs./h 15 psia Back Pressure

Stream conditions flow back to pipe back pressure

Pipe Size	Pressure Drop psig/100 ft.			2,000 (23)	Velocity FPM (mph)	Drop	g
1/2	52	74	104		Pressure		si
3/4	128	181	256		with these		
1	268 0.125	379 0.25	536 0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
1-	617	872	1,234	1,009			
1/4	975	1,379	1,951	1,390			
1-	2,022	2,859	4,043	2,322	3,483		
1/2							
2							
2-	3,362	4,754	6,723	3,333	5,000	6,666	
1/2	6,243	8,830	12,487	5,195	7,792	10,389	
3	13,414	18,970		9,041	13,562	18,083	2:
4							
5	25,088	35,479	with	14,308	21,462	28,616	3:
6	40,787		sizes	20,500	30,749	40,999	5:
8	86,360			35,911	53,867	71,822	8:
10	Velocity	governs		58,716	88,075	117,433	14
12	these	pipe		85,276	127,914	170,552	2:
14				104,385	156,577	208,769	20
16				138,974	208,460	277,947	34
18				178,504	267,756	357,008	44
20				222,976	334,463	445,951	5:
22				272,388	408,583	544,777	68
24				326,743	490,114	653,485	8:
26				386,038	579,057	772,076	90
28				450,275	675,412	900,549	1,
30				519,453	779,179	1,038,905	1,
32				593,572	890,358	1,187,144	1,
34				672,633	1,008,949	1,345,265	1,
36				756,634	1,134,952	1,513,269	1,
42				1,038,288	1,557,432	2,076,575	2,
48				1,364,413	2,046,619	2,728,825	3,
54				1,735,009	2,602,514	3,470,018	4,
60				2,150,077	3,225,116	4,300,154	5,
Notes:				3,113,628	4,670,442	6,227,256	7,

84 Pipe 96 Size	Pressure Drop psig/100 ft.			4,255,065	6,382,597	8,510,130	10
				5,574,388	8,361,561	11,107,176	13
Steam Condensate Flow lbs./h 20 psig Back Pressure							
	0.125	0.25	0.5	2,000	3,000 (34)	4,000 (45)	5,000
	64	90	128	(23)	Pressure	drop pipe	si
1/2	157	222	313		with these		
3/4	328	464	656				
1	755	1,068	1,511	1,329			
1-1/4	1,195	1,689	2,389	1,831			
1-1/2	2,476	3,502	4,952	3,059	4,589		
2	4,117	5,823	8,234	4,391	6,586		
2-1/2	7,647	10,814	15,293	6,843	10,264	13,686	
3	16,428	23,233		11,911	17,866	23,821	29
4	30,726	43,453	with	18,849	28,273	37,697	47
5	49,953		sizes	27,005	40,508	54,010	68
6	105,768			47,307	70,961	94,615	119
8	Velocity	governs		77,350	116,024	154,699	196
10	these	pipe		112,337	168,506	224,675	284
12				137,510	206,265	275,021	349
14				183,076	274,614	366,152	464
16				235,151	352,726	470,301	598
18				293,735	440,602	587,470	750
20				358,829	538,243	717,657	911
22				430,432	645,647	860,863	1,091
24				508,544	762,816	1,017,088	1,299
26				593,166	889,748	1,186,331	1,514
28				684,297	1,026,445	1,368,593	1,757
30				781,937	1,172,906	1,563,874	1,999
32				886,087	1,329,130	1,772,174	2,261
34				996,746	1,495,119	1,993,492	2,543
36				1,367,780	2,051,670	2,735,559	3,456
42				1,797,398	2,696,096	3,594,795	4,549
Notes:				2,285,600	3,428,400	4,571,200	5,823
54							

Pipe Size	Pressure Drop psig/100 ft.	2,832,386	4,248,579	5,664,773	7,080,967
72		4,101,712	6,152,568	8,203,424	10,254,280
84		5,605,375	8,408,062	11,210,749	14,017,436
96	0.125 0.25 0.5	7,342,374	11,015,061	14,686,749	18,358,438
			2,000	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 25 psig Back Pressure

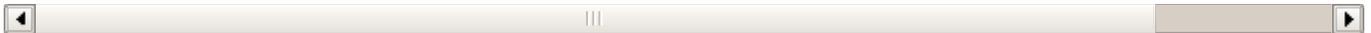
1/2	78	110	156		Pressure	drop pipe	go
3/4	191	270	381		with these		si
1	399	565	799				
1-	919	1,300	1,839	1,723			
1/4	1,454	2,056	2,908	2,373			
1-	3,014	4,262	6,027	3,966	5,948		
1/2							
2							
2-	5,011	7,087	10,022	5,692	8,538		
1/2	9,307	13,162	18,614	8,871	13,306	17,741	
3	19,995	28,277		15,440	23,160	30,880	38
4							
5	37,397	52,888	with	24,434	36,651	48,868	61
6	60,799	85,983	sizes	35,007	52,510	70,014	87
8	128,734			61,325	91,988	122,650	156
10	246,797	governs		100,269	150,404	200,539	256
12		pipe		145,625	218,437	291,249	368
14				178,257	267,385	356,513	451
16	Velocity			237,324	355,986	474,648	599
18	these			304,829	457,244	609,659	768
20				380,773	571,160	761,546	959
22				465,155	697,732	930,310	1,184
24				557,975	836,962	1,115,950	1,411
26				659,233	988,850	1,318,466	1,664
28				768,929	1,153,394	1,537,859	1,951
30				887,064	1,330,596	1,774,128	2,256
32				1,013,637	1,520,455	2,027,273	2,591
Notes:				1,148,648	1,722,971	2,297,295	2,926
36				1,292,097	1,938,145	2,584,193	3,311
42				1,773,073	2,659,610	3,546,146	4,511

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48				2,329,993	3,494,990	4,659,980
54				2,962,857	4,444,285	5,925,714
60				3,671,864	5,507,496	7,343,329
72				5,317,110	7,975,665	10,634,220
84				7,266,330	10,899,495	14,532,660
96				9,519,325	14,278,988	19,038,650

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



85 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	24	33	47	110	Pressure drop pipe with these	governed by pipe size
3/4	58	82	115	184		
1	121	171	242			
1-1/4	278	393	556	327	491	1,508
1-1/2	440	622	880	451	677	
2	912	1,290	1,824	754	1,131	
2-1/2	1,516	2,144	with	1,082	1,623	2,164
3	2,816	3,982	sizes	1,686	2,529	3,372
4	6,050			2,935	4,402	5,870
5	11,315	governs		4,644	6,967	9,289
6		pipe		6,654	9,981	13,309
8				11,657	17,486	23,314

Pipe Size	Velocity these	Pressure Drop psig/100 ft.		19,060	28,590	38,119	47,648
				27,681	41,522	55,362	69,202
				33,884	50,826	67,768	84,710
				40,088	57,608	75,225	92,842
				46,292	64,328	83,382	102,442
				52,496	71,008	91,422	112,042
				58,700	77,688	99,462	121,642
				64,904	84,368	107,502	131,242
				71,108	91,048	115,542	140,842
				77,312	97,728	123,582	150,442
				83,516	104,408	131,622	160,042
				89,720	111,088	139,662	169,642
				95,924	117,768	147,702	179,242
				102,128	124,448	155,742	188,842
				108,332	131,128	163,782	198,442
				114,536	137,808	171,822	208,042
				120,740	144,488	179,862	217,642
				126,944	151,168	187,902	227,242
				133,148	157,848	195,942	236,842
				139,352	164,528	203,982	246,442
				145,556	171,208	212,022	256,042
				151,760	177,888	220,062	265,642
				157,964	184,568	228,102	275,242
				164,168	191,248	236,142	284,842
				170,372	197,928	244,182	294,442
				176,576	204,608	252,222	304,042
				182,780	211,288	260,262	313,642
				188,984	217,968	268,302	323,242
				195,188	224,648	276,342	332,842
				201,392	231,328	284,382	342,442
				207,596	238,008	292,422	352,042
				213,800	244,688	300,462	361,642
				219,604	251,368	308,502	371,242
				225,408	258,048	316,542	380,842
				231,212	264,728	324,582	390,442
				237,016	271,408	332,622	400,042
				242,820	278,088	340,662	409,642
				248,624	284,768	348,702	419,242
				254,428	291,448	356,742	428,842
				260,232	298,128	364,782	438,442
				266,036	304,808	372,822	448,042
				271,840	311,488	380,862	457,642
				277,644	318,168	388,902	467,242
				283,448	324,848	396,942	476,842
				289,252	331,528	404,982	486,442
				295,056	338,208	413,022	496,042
				300,860	344,888	421,062	505,642
				306,664	351,568	429,102	515,242
				312,468	358,248	437,142	524,842
				318,272	364,928	445,182	534,442
				324,076	371,608	453,222	544,042
				329,880	378,288	461,262	553,642
				335,684	384,968	469,302	563,242
				341,488	391,648	477,342	572,842
				347,292	398,328	485,382	582,442
				353,096	405,008	493,422	592,042
				358,900	411,688	501,462	601,642
				364,704	418,368	509,502	611,242
				370,508	425,048	517,542	620,842
				376,312	431,728	525,582	630,442
				382,116	438,408	533,622	640,042
				387,920	445,088	541,662	649,642
				393,724	451,768	549,702	659,242
				399,528	458,448	557,742	668,842
				405,332	465,128	565,782	678,442
				411,136	471,808	573,822	688,042
				416,940	478,488	581,862	697,642
				422,744	485,168	589,902	707,242
				428,548	491,848	597,942	716,842
				434,352	498,528	605,982	726,442
				440,156	505,208	614,022	736,042
				445,960	511,888	622,062	745,642
				451,764	518,568	630,102	755,242
				457,568	525,248	638,142	764,842
				463,372	531,928	646,182	774,442
				469,176	538,608	654,222	784,042
				474,980	545,288	662,262	793,642
				480,784	551,968	670,302	803,242
				486,588	558,648	678,342	812,842
				492,392	565,328	686,382	822,442
				498,196	572,008	694,422	832,042
				504,000	578,688	702,462	841,642
				509,804	585,368	710,502	851,242
				515,608	592,048	718,542	860,842
				521,412	598,728	726,582	870,442
				527,216	605,408	734,622	880,042
				533,020	612,088	742,662	889,642
				538,824	618,768	750,702	899,242
				544,628	625,448	758,742	908,842
				550,432	632,128	766,782	918,442
				556,236	638,808	774,822	928,042
				562,040	645,488	782,862	937,642
				567,844	652,168	790,902	947,242
				573,648	658,848	798,942	956,842
				579,452	665,528	806,982	966,442
				585,256	672,208	815,022	976,042
				591,060	678,888	823,062	985,642
				596,864	685,568	831,102	995,242
				602,668	692,248	839,142	1,004,842
				608,472	698,928	847,182	1,014,442
				614,276	705,608	855,222	1,024,042
				620,080	712,288	863,262	1,033,642
				625,884	718,968	871,302	1,043,242
				631,688	725,648	879,342	1,052,842
				637,492	732,328	887,382	1,062,442
				643,296	739,008	895,422	1,072,042
				649,100	745,688	903,462	1,081,642
				654,904	752,368	911,502	1,091,242
				660,708	759,048	919,542	1,100,842
				666,512	765,728	927,582	1,110,442
				672,316	772,408	935,622	1,120,042
				678,120	779,088	943,662	1,129,642
				683,924	785,768	951,702	1,139,242
				689,728	792,448	959,742	1,148,842
				695,532	799,128	967,782	1,158,442
				701,336	805,808	975,822	1,168,042
				707,140	812,488	983,862	1,177,642
				712,944	819,168	991,902	1,187,242
				718,748	825,848	999,942	1,196,842
				724,552	832,528	1,007,982	1,206,442
				730,356	839,208	1,016,022	1,216,042
				736,160	845,888	1,024,062	1,225,642
				741,964	852,568	1,032,102	1,235,242
				747,768	859,248	1,040,142	1,244,842
				753,572	865,928	1,048,182	1,254,442
				759,376	872,608	1,056,222	1,264,042
				765,180	879,288	1,064,262	1,273,642
				770,984	885,968	1,072,302	1,283,242
				776,788	892,648	1,080,342	1,292,842
				782,592	899,328	1,088,382	1,302,442
				788,396	906,008	1,096,422	1,312,042
				794,200	912,688	1,104,462	1,321,642
				800,004	919,368	1,112,502	1,331,242
				805,808	926,048	1,120,542	1,340,842
				811,612	932,728	1,128,582	1,350,442
				817,416	939,408	1,136,622	1,360,042
				823,220	946,088	1,144,662	1,369,642
				829,024	952,768	1,152,702	1,379,242
				834,828	959,448	1,160,742	1,388,842
				840,632	966,128	1,168,782	1,398,442
				846,436	972,808	1,176,822	1,408,042
				852,240	979,488	1,184,862	1,417,642
				858,044	986,168	1,192,902	1,427,242
				863,848	992,848	1,200,942	1,436,842
				869,652	999,528	1,208,982	1,446,442
				875,456	1,006,208	1,217,022	1,456,042
				881,260	1,012,888	1,225,062	1,465,642
				887,064	1,019,568	1,233,102	1,475,242
				892,868	1,026,248	1,241,142	1,484,842
				898,672	1,032,928	1,249,182	1,494,442
				904,476	1,039,608	1,257,222	1,504,042
				910,280	1,046,288	1,265,262	1,513,642
				916,084	1,052,968	1,273,302	1,523,242
				921,888	1,059,648	1,281,342	1,532,842

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)	9,937	14,906	19,874	24,842	29,810
10	0.125 these	0.25	0.5	28,800	42,693	56,925	71,457
12				41,337	62,005	82,674	103,343
14				50,600	75,899	101,199	127,050
16				67,366	101,050	134,733	168,406
18				86,528	129,793	173,057	216,710
20				108,086	162,128	216,171	271,464
22				132,038	198,057	264,076	330,095
24				158,386	237,579	316,772	395,856
26				187,129	280,693	374,258	467,819
28				218,267	327,401	436,534	544,504
30				251,801	377,701	503,601	624,540
32				287,729	431,594	575,459	718,477
34				326,053	489,080	652,107	810,664
36				366,772	550,159	733,545	909,951
42				503,302	754,953	1,006,603	1,268,156
48				661,388	992,082	1,322,776	1,679,041
54				841,032	1,261,548	1,682,064	2,127,585
60				1,042,233	1,563,349	2,084,465	2,665,129
72				1,509,306	2,263,959	3,018,612	3,823,224
84				2,062,609	3,093,913	4,125,217	5,201,851
96				2,702,140	4,053,210	5,404,280	6,885,560

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	34	48	67	315	Pressure with these	drop pipe	g si
3/4	83	117	165				
1	173	245	346				
1-	398	563	797	562	1,162	2,589	
1/4	630	891	1,260	775	1,942		
1-	1,305	1,846	2,611	1,294			
1/2							
2							

Notes: 2,171 3,070 4,341 1,858 2,787 3,716 7,
1/2 4,031 5,701 2,896 4,343 5,791 1,
1, Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	0,001	12,249		5,040	7,500	10,000	
	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
5	16,199	governs	with	7,976	11,964	15,952	19
6	26,125	pipe	size	11,427	17,000 (34)	22,854 (45)	30
8		0.25	0.5	20,018	30,027	40,036	50
10	Velocity			32,730	49,096	65,461	80
12	these			47,536	71,303	95,071	110
14				58,187	87,281	116,375	140
16				77,468	116,203	154,937	190
18				99,504	149,256	199,008	240
20				124,294	186,441	248,588	300
22				151,838	227,757	303,676	370
24				182,137	273,206	364,274	440
26				215,190	322,785	430,380	520
28				250,998	376,497	501,996	610
30				289,560	434,340	579,120	700
32				330,876	496,315	661,753	800
34				374,947	562,421	749,895	900
36				421,773	632,659	843,546	1,000
42				578,776	868,163	1,157,551	1,400
48				760,568	1,140,853	1,521,137	1,800
54				967,151	1,450,726	1,934,302	2,300
60				1,198,524	1,797,785	2,397,047	2,900
72				1,735,638	2,603,457	3,471,277	4,300
84				2,371,913	3,557,869	4,743,826	5,800
96				3,107,347	4,661,020	6,214,694	7,500

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	38	54	77	382	Pressure	drop pipe	go
3/4	94	133	188		with these		si
1	197	279	395				
Notes:	454	642	908	681	1,408		
1/4	718	1,016	1,436	939	2,353		
1-	1,489	2,105	2,977	1,569			
1 1/2							
2							

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

2. Table based on heavy weight steel pipe using steam equations in Part 2

Pipe Size	Pressure	Drop	psig/100 ft	Velocity	FPM (mph)		
2	2,775	3,301	4,991	2,251	3,377	4,503	8,
3	4,597	6,562		3,509	5,263	7,018	1!
4	9,877	13,968		6,107	9,161	12,215	
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
5	18,473	governs	with	9,665	14,497	19,329	24
6	30,033	pipe	sizes	13,847	20,770	27,694	34
8				24,257	36,386	48,514	60
10	Velocity			39,661	59,492	79,323	99
12	these			57,601	86,402	115,203	14
14				70,509	105,764	141,018	17
16				93,873	140,809	187,746	23
18				120,575	180,862	241,149	30
20				150,614	225,921	301,228	37
22				183,991	275,986	367,982	47
24				220,706	331,059	441,411	57
26				260,758	391,137	521,516	69
28				304,148	456,223	608,297	79
30				350,876	526,314	701,752	89
32				400,942	601,413	801,884	100
34				454,345	681,518	908,690	110
36				511,086	766,629	1,022,172	120
42				701,335	1,052,003	1,402,671	140
48				921,624	1,382,436	1,843,248	170
54				1,171,952	1,757,927	2,343,903	200
60				1,452,319	2,178,478	2,904,638	240
72				2,103,171	3,154,757	4,206,343	300
84				2,874,181	4,311,272	5,748,362	360
96				3,765,348	5,648,023	7,530,697	420

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	42	59	83		Pressure	drop pipe	go
3/4	102	145	205		with these		si
1	214	303	429				

Notes:	494	698	987	768	2,652		
1/4	781	1,104	1,561	1,058			

1. Maximum recommended pressure/drop/velocity: 0.25 psig/100 ft./5,000

1- Pipe 1/2 Size 2	1,618 Pressure Drop ft.	2,288 psig/100 ft.	3,235 psig/100 ft.	1,768 Velocity FPM (mph)			
2-	20,125	3,025	5,080	2,000 (23)	3,800 (34)	4,000 (45)	5,000
1/2	4,996	7,065		2,537	5,932	7,909	10,325
3	10,734	15,180		3,954	10,325	13,766	
4				6,883			
5	20,075	governs	with	10,892	16,339	21,785	27,338
6	32,638	pipe	sizes	15,606	23,409	31,212	41,008
8				27,338	41,008	54,677	
10	Velocity			44,699	67,049	89,399	119,199
12	these			64,919	97,378	129,837	158,931
14				79,466	119,199	158,931	
16				105,798	158,696	211,595	271,782
18				135,891	203,837	271,782	339,493
20				169,746	254,619	339,493	
22				207,363	311,045	414,726	497,484
24				248,742	373,113	497,484	587,764
26				293,882	440,823	587,764	
28				342,784	514,176	685,568	790,896
30				395,448	593,172	790,896	903,746
32				451,873	677,810	903,746	
34				512,060	768,090	1,024,120	1,152,018
36				576,009	864,013	1,152,018	1,580,851
42				790,425	1,185,638	1,580,851	
48				1,038,697	1,558,045	2,077,394	2,641,647
54				1,320,824	1,981,236	2,641,647	3,273,611
60				1,636,806	2,455,209	3,273,611	
72				2,370,335	3,555,503	4,740,671	6,478,572
84				3,239,286	4,858,929	6,478,572	8,487,315
96				4,243,658	6,365,486	8,487,315	

Steam Condensate Flow lbs./h 15 psig Back Pressure

Notes:	47	67	94		Pressure	drop pipe	go
3/4	115	163	231		with these		si
1	242	342	483				5,000

Pipe Size	Pressure Drop psig/100 ft			Velocity FPM (mph)			
	556	786	1,112	909	3,140		
1-1/4	879	1,243	1,758	1,253			
1-1/2	1,822	2,577	3,645	2,093			
2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,
2-1/2	3,030	4,285	6,060	3,004	4,507	6,009	20
3	5,628	7,959	11,255	4,682	7,023	9,364	
4	12,091	17,099		8,150	12,225	16,300	
5	22,613	31,980	with	12,897	19,345	25,794	30
6	36,764		sizes	18,478	27,717	36,956	40
8	77,843			32,369	48,554	64,739	80
10	Velocity	governs		52,925	79,388	105,851	100
12	these	pipe		76,865	115,298	153,731	150
14				94,090	141,134	188,179	200
16				125,267	187,901	250,534	300
18				160,899	241,348	321,797	400
20				200,984	301,476	401,968	500
22				245,524	368,285	491,047	600
24				294,517	441,775	589,034	700
26				347,964	521,946	695,929	800
28				405,866	608,798	811,731	1,000
30				468,221	702,331	936,442	1,200
32				535,030	802,545	1,070,060	1,400
34				606,293	909,440	1,212,586	1,600
36				682,010	1,023,015	1,364,020	1,800
42				935,885	1,403,827	1,871,770	2,200
48				1,229,845	1,844,768	2,459,690	3,000
54				1,563,891	2,345,836	3,127,782	3,600
60				1,938,022	2,907,033	3,876,044	4,200
72				2,806,541	4,209,811	5,613,082	5,000
84				3,835,402	5,753,103	7,670,803	6,000
96				5,024,605	7,536,907	10,049,209	7,000

Steam Condensate Flow lbs./h 20 psig Back Pressure

Pipe Size	Pressure	Drop	psig/100 ft.	Velocity	Pressure with these	drop pipe	governance
	57	80	114				
	139	197	278				
1	292	412	583				
1-	6,125	9,025	1,943	2,000	3,000 (34)	4,000 (45)	5,000
1/4	1,061	1,501	2,123	1,181 (23)			
1-	2,200	3,111	4,400	2,718			
1/2							
2-	3,658	5,174	7,317	3,902	5,852	12,161	20,000
1/2	6,795	9,609	13,589	6,080	9,121	21,167	
3	14,598	20,644		10,584	15,875		
4							
5	27,302	38,611	with	16,748	25,123	33,497	40,000
6	44,387		sizes	23,996	35,994	47,992	50,000
8	93,983			42,036	63,054	84,072	100,000
10	Velocity	governs		68,731	103,096	137,462	150,000
12	these	pipe		99,820	149,730	199,640	250,000
14				122,188	183,282	244,377	300,000
16				162,677	244,015	325,353	400,000
18				208,949	313,424	417,898	500,000
20				261,006	391,509	522,011	600,000
22				318,846	478,269	637,693	700,000
24				382,471	573,706	764,942	900,000
26				451,880	677,819	903,759	1,000,000
28				527,072	790,609	1,054,145	1,200,000
30				608,049	912,074	1,216,099	1,500,000
32				694,810	1,042,215	1,389,620	1,800,000
34				787,355	1,181,033	1,574,710	2,000,000
36				885,684	1,328,526	1,771,368	2,500,000
42				1,215,376	1,823,063	2,430,751	3,000,000
48				1,597,123	2,395,685	3,194,247	3,500,000
54				2,030,928	3,046,392	4,061,856	5,000,000
60				2,516,789	3,775,183	5,033,578	6,000,000
Notes:				3,644,681	5,467,021	7,289,361	9,000,000
84				4,980,798	7,471,197	9,961,597	12,000,000

1. Maximum recommended pressure drop/velocity: 0.25 psia/100 ft./5.00

96 Pipe Size	Pressure Drop psig/100 ft.	Flow lbs./h	25 psig Back Pressure	Velocity FPM (mph)	Pressure drop pipe	with these	5,000 (45)
1/2	68	96	136	2,000	Pressure	3,000 (34)	drop pipe
3/4	0.125 167	0.25 236	0.5 333	(23)	with these	4,000 (45)	5,000 (45)
1	349	494	698				
1-1/4	804	1,136	1,607	1,506	5,199		
1-1/2	1,271	1,797	2,542	2,074			
2	2,634	3,725	5,268	3,466			
2-1/2	4,380	6,194	8,760	4,975	7,462	15,506	30,000
3	8,134	11,504	16,268	7,753	11,629	26,989	
4	17,476	24,714		13,495	20,242		
5	32,685	46,224	with	21,355	32,033	42,710	50,000
6	53,139	75,150	sizes	30,596	45,894	61,192	70,000
8	112,514			53,598	80,398	107,197	120,000
10	215,701	governs		87,636	131,454	175,271	200,000
12		pipe		127,276	190,915	254,553	300,000
14				155,797	233,695	311,594	350,000
16	Velocity			207,422	311,133	414,844	500,000
18	these			266,422	399,633	532,844	600,000
20				332,797	499,195	665,594	800,000
22				406,547	609,820	813,094	1,000,000
24				487,672	731,508	975,344	1,200,000
26				576,172	864,258	1,152,344	1,500,000
28				672,047	1,008,070	1,344,094	1,800,000
30				775,297	1,162,945	1,550,593	2,000,000
32				885,922	1,328,883	1,771,843	2,500,000
34				1,003,922	1,505,883	2,007,843	3,000,000
36				1,129,297	1,693,945	2,258,593	3,500,000
42				1,549,672	2,324,507	3,099,343	4,500,000
Notes:				2,036,422	3,054,632	4,072,843	5,000,000
54				2,589,546	3,884,320	5,179,093	6,000,000
60				3,209,046	4,813,569	6,418,093	8,000,000

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
1/2				4,647,171	6,970,757	9,294,343	11,617,929
3/4				6,350,796	9,526,194	12,701,592	15,876,990
1				8,210,020	12,479,881	16,639,841	20,800,240

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	22	31	43	101	Pressure drop pipe with these	drop pipe	go si
3/4	53	75	106	168			
1	111	157	222				
1-1/4	255	361	510	300	450	1,382	
1-1/2	403	571	807	414	621		
2	836	1,182	1,672	691	1,037		
2-1/2	1,390	1,966		992	1,488	1,984	2,480
3	2,582	3,652		1,546	2,319	3,092	3,868
4	5,548			2,691	4,037	5,383	6,759
5	10,376			4,259	6,388	8,518	10,648
6				6,102	9,153	12,204	15,254
8				10,689	16,034	21,379	26,704
10				17,478	26,216	34,955	43,694
12				25,383	38,075	50,767	62,838
14				31,071	46,607	62,142	77,763

Notes: Velocity governs with 41 367 62 051 82 734 10

Pipe Size	Pressure Drop psig/100 ft.	governs pipe	with sizes	41,307 53,134 66,371	82,051 79,700 99,557	82,754 106,267 132,742	10 10 10
22	0.125	0.25	0.5	81,079 (23)	3,000 (34)	4,000 (45)	30
24				97,258	145,888	194,517	24
26				114,908	172,363	229,817	28
28				134,029	201,044	268,058	30
30				154,621	231,931	309,241	38
32				176,683	265,025	353,366	44
34				200,216	300,325	400,433	50
36				225,220	337,831	450,441	50
42				309,058	463,586	618,115	70
48				406,132	609,198	812,264	1,000
54				516,444	774,666	1,032,889	1,000
60				639,994	959,991	1,279,988	1,000
72				926,805	1,390,208	1,853,610	2,000
84				1,266,566	1,899,849	2,533,132	3,000
96				1,659,277	2,488,916	3,318,554	4,000

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	28	39	56	248	Pressure with these	drop pipe	governs pipe
3/4	68	96	136				
1	143	202	285				
1-	328	464	657	443	915	2,039	
1/4	519	734	1,038	610	1,530		
1-	1,076	1,522	2,152	1,020			
1/2							
2-	1,789	2,530	3,578	1,464	2,195	2,927	5,000
1/2	3,323	4,699		2,281	3,422	4,562	9,000
3	7,138			3,970	5,956	7,941	
4							
5	13,351	governs pipe	with sizes	6,283	9,425	12,566	10,000
6	21,706			9,002	13,503	18,004	20,000
8				15,769	23,654	31,539	30,000
Notes:	Velocity			25,784	38,676	51,568	60,000

12 Pipe 14 Size	these Pressure Drop psig/100 ft.			37,447 45,838	56,170 68,757	74,893 91,676	9: 1:
16	0.125	0.25	0.5	61,027	91,540	122,053	1:
18				78,385 (23)	117,578 3,000 (34)	156,771 4,000 (45)	5:
20				97,914	146,871	195,828	2:
22				119,612	179,419	239,225	2:
24				143,481	215,221	286,961	3:
26				169,519	254,278	339,037	4:
28				197,727	296,590	395,453	4:
30				228,104	342,156	456,209	5:
32				260,652	390,978	521,304	6:
34				295,369	443,054	590,739	7:
36				332,257	498,385	664,513	8:
42				455,937	683,906	911,875	1,
48				599,147	898,720	1,198,293	1,
54				761,885	1,142,827	1,523,769	1,
60				944,151	1,416,226	1,888,302	2,
72				1,367,270	2,050,904	2,734,539	3,
84				1,868,502	2,802,753	3,737,004	4,
96				2,447,849	3,671,774	4,895,698	6,

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	30	43	61	284	Pressure with these	drop pipe	go si
3/4	74	105	149				
1	156	221	312				
1-	359	508	718	507	1,047	2,333	
1/4	568	803	1,135	698	1,750		
1-	1,177	1,664	2,353	1,167			
1/2							
2							
2-	1,956	2,767	3,913	1,675	2,512	3,349	6,
1/2	3,634	5,139		2,610	3,915	5,220	1:
3	7,806	11,040		4,543	6,814	9,085	
4							
Notes:	14,600	governs	with	7,189	10,783	14,377	1:
6	23,737	pipe	sizes	10,299	15,449	20,598	2:

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			4'
	0.125	0.25	0.5	2,800	3,000 (34)	4,000 (45)	
10				18,042	27,063	36,084	4'
12	Velocity			29,500	44,249	58,999	7'
14	these			42,800	64,265	85,687	10'
16				52,491	78,666	104,888	12'
18				69,822	104,733	139,643	14'
20				89,682	134,523	179,364	16'
22				112,025	168,038	224,050	18'
24				136,851	205,276	273,701	20'
26				164,159	246,238	328,317	22'
28				193,949	290,924	387,898	24'
30				226,222	339,333	452,445	26'
32				260,978	391,467	521,956	28'
34				298,216	447,324	596,432	30'
36				337,937	506,905	675,874	32'
42				380,140	570,210	760,281	34'
48				521,646	782,468	1,043,291	36'
54				685,494	1,028,241	1,370,988	38'
60				871,685	1,307,527	1,743,370	40'
72				1,080,219	1,620,329	2,160,438	42'
84				1,564,316	2,346,474	3,128,632	44'
96				2,137,785	3,206,677	4,275,570	46'
				2,800,625	4,200,938	5,601,251	48'

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	34	49	69	342	Pressure with these	drop pipe	go
3/4	84	119	169				
1	176	250	353				
1-	406	574	812	609	1,259		
1/4	642	908	1,285	840	2,104		
1-	1,331	1,883	2,663	1,403			
1/2							
2							
Notes:	2,214	3,131	4,428	2,014	3,020	4,027	7,
1/2	4,112	5,815		3,138	4,707	6,276	1:
3	8,834	12,493		5,462	8,193	10,924	5,00
4							

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

4 Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
6	16,522	governs	with	8,644	12,966	17,288	20,000
8	26,861	pipe	sizes	12,384	18,576	24,769	30,000
	0.125	0.25	0.5	21,695 (23)	32,542 (34)	43,390 (45)	54,238 (57)
10	Velocity			35,472	53,208	70,944	88,680
12	these			51,517	77,276	103,034	128,792
14				63,061	94,592	126,123	157,504
16				83,957	125,936	167,915	209,894
18				107,839	161,758	215,677	267,240
20				134,705	202,058	269,410	336,760
22				164,557	246,835	329,113	411,440
24				197,393	296,090	394,787	493,472
26				233,215	349,823	466,430	582,912
28				272,022	408,033	544,044	685,056
30				313,814	470,721	627,629	784,544
32				358,592	537,887	717,183	895,424
34				406,354	609,531	812,708	1,010,208
36				457,102	685,652	914,203	1,132,896
42				627,255	940,883	1,254,511	1,568,016
48				824,276	1,236,413	1,648,551	2,060,160
54				1,048,162	1,572,243	2,096,324	2,620,800
60				1,298,915	1,948,372	2,597,830	3,251,200
72				1,881,020	2,821,530	3,762,040	4,642,560
84				2,570,590	3,855,886	5,141,181	6,326,400
96				3,367,626	5,051,440	6,735,253	8,319,040

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	37	53	74		Pressure	drop pipe	go
3/4	91	129	182		with these		si
1	191	270	382				
1-	439	621	878	683	2,359		
1/4	694	982	1,389	941			
1-	1,439	2,035	2,878	1,573			
1/2							
2							
Notes:	2,393	3,384	4,786	2,257	3,386	4,514	8,319

Pipe Size	Pressure	Drop	psig/100 ft	3,518	5,277	7,036	11,000
4	4,744	6,283		6,123	9,185	12,246	18,000
	0.125	0.25	0.5	2,000	3,000 (34)	4,000 (45)	5,000 (55)
5	17,859	governs	with	9,600	14,534	19,379	28,000
6	29,034	pipe	sizes	13,883	20,824	27,765	40,000
8				24,320	36,479	48,639	60,000
10	Velocity			39,764	59,645	79,527	90,000
12	these			57,750	86,625	115,500	140,000
14				70,691	106,036	141,382	170,000
16				94,115	141,173	188,230	230,000
18				120,886	181,328	241,771	300,000
20				151,002	226,504	302,005	370,000
22				184,466	276,698	368,931	450,000
24				221,275	331,912	442,550	540,000
26				261,431	392,146	522,861	640,000
28				304,933	457,399	609,866	760,000
30				351,781	527,672	703,562	880,000
32				401,976	602,964	803,952	1,000,000
34				455,517	683,275	911,034	1,150,000
36				512,404	768,606	1,024,808	1,300,000
42				703,144	1,054,716	1,406,288	1,700,000
48				924,001	1,386,001	1,848,001	2,200,000
54				1,174,974	1,762,461	2,349,948	2,800,000
60				1,456,065	2,184,097	2,912,129	3,500,000
72				2,108,596	3,162,893	4,217,191	5,000,000
84				2,881,594	4,322,391	5,763,188	7,000,000
96				3,775,060	5,662,589	7,550,119	9,000,000

Steam Condensate Flow lbs./h 15 psig Back Pressure

1/2	41	59	83		Pressure	drop pipe	go
3/4	102	144	203		with these		si
1	213	301	426				
Notes:	490	694	981	802	2,770		
1/4	776	1,097	1,551	1,105			
1-	1,608	2,273	3,215	1,847			
1 1/2							

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

1/2 Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
2-	2,673	3,780	5,346	2,650	3,975	5,301	17
1/2	4,012 4,125	7,025 7,025	9,929 9,929	2,000 4,130 (23)	8,000 (34)	8,000 (45)	5,
3	10,666	15,084		7,189	10,784	14,379	
4							
5	19,948	28,211	with	11,377	17,066	22,754	28
6	32,432		sizes	16,300	24,451	32,601	40
8	68,670			28,555	42,832	57,110	70
10	Velocity	governs		46,689	70,033	93,377	110
12	these	pipe		67,807	101,711	135,615	160
14				83,002	124,503	166,004	200
16				110,505	165,758	221,011	270
18				141,938	212,907	283,876	350
20				177,300	265,950	354,600	440
22				216,591	324,886	433,182	540
24				259,811	389,716	519,621	640
26				306,960	460,440	613,919	760
28				358,038	537,057	716,076	890
30				413,045	619,567	826,090	1,050
32				471,981	707,972	943,962	1,220
34				534,847	802,270	1,069,693	1,400
36				601,641	902,462	1,203,282	1,590
42				825,599	1,238,398	1,651,198	2,100
48				1,084,918	1,627,378	2,169,837	2,730
54				1,379,600	2,069,400	2,759,199	3,480
60				1,709,643	2,564,464	3,419,285	4,350
72				2,475,814	3,713,721	4,951,628	6,000
84				3,383,433	5,075,149	6,766,865	8,100
96				4,432,498	6,648,747	8,864,996	11,100

Steam Condensate Flow lbs./h 20 psig Back Pressure

1/2	49	70	99		Pressure	drop pipe	go
3/4	121	171	242		with these		si
1	253	358	507				
Notes:	583	825	1 166	1 026	3 543		

Pipe Size	Pressure Drop psig/100 ft	Velocity FPM (mph)						
		0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5,000 (56)
1/4	922	1,304	1,845	1,413				
1/2	1,912	2,703	3,823	2,362				
2-	3,179	4,495	6,357	3,390	5,085	10,566	20,132	
1/2	5,904	8,349	11,807	5,283	7,925	18,392		
3	12,683	17,937		9,196	13,794			
4								
5	23,722	33,548	with sizes	14,552	21,828	29,105	30,000	
6	38,567			20,849	31,274	41,699	50,000	
8	81,659			36,524	54,786	73,048	90,000	
10	Velocity governs these pipe			59,718	89,578	119,437	140,000	
12				86,731	130,097	173,462	200,000	
14				106,166	159,249	212,332	250,000	
16				141,345	212,018	282,691	300,000	
18				181,550	272,325	363,100	400,000	
20				226,781	340,171	453,561	500,000	
22				277,037	415,555	554,074	600,000	
24				332,318	498,478	664,637	800,000	
26				392,626	588,939	785,252	900,000	
28				457,959	686,938	915,918	1,000,000	
30				528,317	792,476	1,056,635	1,100,000	
32				603,701	905,552	1,207,403	1,200,000	
34				684,111	1,026,167	1,368,222	1,300,000	
36				769,547	1,154,320	1,539,093	1,400,000	
42				1,056,006	1,584,010	2,112,013	2,000,000	
48				1,387,697	2,081,545	2,775,393	3,000,000	
54				1,764,618	2,646,926	3,529,235	4,000,000	
60				2,186,769	3,280,153	4,373,538	5,000,000	
72				3,166,763	4,750,144	6,333,526	7,000,000	
84				4,327,679	6,491,518	8,655,358	10,000,000	
96				5,669,517	8,504,275	11,339,034	14,000,000	
Steam Condensate Flow lbs./h 25 psig Back Pressure								
Notes:	58	82	116		Pressure	drop pipe	go	

3/4 Pipe 1 Size	142 Pressure 298	201 Drop 422 ft.	285 psig/100 596		with these Velocity FPM (mph)		si
1- 1/4 1- 1/2 2	686 1,015 2,250	971 1,335 3,182	1,373 2,071 4,500	1,286 2,000 1,772 (23) 2,961	4,441 3,000 (34)	4,000 (45)	5,
2- 1/2 3 4	3,741 6,948 14,928	5,291 9,827 21,112	7,483 13,897	4,250 6,623 11,527	6,374 9,934 17,291	13,246 23,055	28
5 6 8	27,920 45,392 96,112	39,486 64,195		18,242 26,136 45,785	27,363 39,204 68,677	36,484 52,272 91,570	4! 6! 1:
10 12 14	184,257			74,860 108,722 133,085	112,291 163,084 199,628	149,721 217,445 266,171	18 2: 3:
16 18 20	Velocity these	governs pipe	with sizes	177,185 227,584 284,283	265,777 341,376 426,424	354,369 455,168 568,566	44 50 7:
22 24 26				347,282 416,581 492,179	520,923 624,871 738,269	694,564 833,161 984,359	80 1, 1,
28 30 32				574,078 662,277 756,775	861,117 993,415 1,135,163	1,148,156 1,324,553 1,513,550	1, 1, 1,
34 36 42				857,573 964,672 1,323,766	1,286,360 1,447,008 1,985,649	1,715,147 1,929,343 2,647,532	2, 2, 3,
48 54 60				1,739,559 2,212,051 2,741,243	2,609,338 3,318,077 4,111,864	3,479,118 4,424,102 5,482,485	4, 5, 6,
72 84 96				3,969,722 5,424,999 7,107,071	5,954,584 8,137,498 10,660,606	7,939,445 10,849,997 14,214,142	9, 1: 1:

Pipe Pressure Drop (psi/100 ft) Back Pressure

Velocity FPM (mph)

Size	68	96	136		Pressure	drop pipe	go
	167	236	333	2,000	with these	4,000 (45)	si
	0.125	0.25	0.5	(23)	3,000 (34)		5,
	349	493	698				
1-	803	1,135	1,606	1,590			
1/4	1,269	1,795	2,539	2,191			
1-	2,631	3,721	5,262	3,661			
1/2							
2							
2-	4,375	6,188	8,751	5,254	7,881	28,505	
1/2	8,126	11,492	16,252	8,188	12,282		
3	17,458	24,689	34,916	14,252	21,379		
4							
5	32,652	46,177	with	22,554	33,832	45,109	50
6	53,085	75,073	sizes	32,314	48,471	64,628	80
8	112,400			56,608	84,912	113,216	140
10	215,482	governs		92,557	138,835	185,113	240
12		pipe		134,423	201,635	268,846	360
14				164,545	246,818	329,090	480
16	Velocity			219,069	328,603	438,138	560
18	these			281,382	422,073	562,764	720
20				351,484	527,226	702,968	900
22				429,375	644,063	858,750	1,100
24				515,055	772,583	1,030,111	1,360
26				608,525	912,787	1,217,050	1,580
28				709,783	1,064,675	1,419,567	1,840
30				818,831	1,228,247	1,637,662	2,160
32				935,668	1,403,502	1,871,336	2,480
34				1,060,294	1,590,441	2,120,587	2,800
36				1,192,709	1,789,063	2,385,418	3,120
42				1,636,689	2,455,033	3,273,377	4,240
48				2,150,770	3,226,155	4,301,541	5,600
54				2,734,954	4,102,431	5,469,908	7,200
60				3,389,240	5,083,860	6,778,480	8,800
Notes:				4 908 118	7 362 177	9 816 236	12 800

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	20	28	39	92	131	171
3/4	48	68	96	153	214	286
1	101	143	202	273	376	500
1-1/4	232	328	464	273	376	500
1-1/2	367	519	734	376	500	661
2	761	1,076	1,521	629	863	1,134
2-1/2	1,265	1,789	2,503	903	1,244	1,634
3	2,349	3,322	4,644	1,407	1,926	2,541
4	5,047	7,066	9,724	2,448	3,363	4,441
5	9,439	13,113	18,243	3,874	5,298	7,011
6	14,881	20,817	28,863	5,551	7,566	10,001
8	28,863	40,797	56,487	9,724	13,298	17,541
Notes:	Velocity with these			15,899	23,848	31,798
12				23,090	34,636	46,181



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22.05. High-Pressure Steam Condensate System Pipe Sizing Tables (120-300 psig)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	20	28	39	92	131	171
3/4	48	68	96	153	214	286
1	101	143	202	273	376	500
1-1/4	232	328	464	273	376	500
1-1/2	367	519	734	376	500	661
2	761	1,076	1,521	629	863	1,134
2-1/2	1,265	1,789	2,503	903	1,244	1,634
3	2,349	3,322	4,644	1,407	1,926	2,541
4	5,047	7,066	9,724	2,448	3,363	4,441
5	9,439	13,113	18,243	3,874	5,298	7,011
6	14,881	20,817	28,863	5,551	7,566	10,001
8	28,863	40,797	56,487	9,724	13,298	17,541
Notes:	Velocity with these			15,899	23,848	31,798
12				23,090	34,636	46,181

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5			
16				28,265	42,397	56,529
18				37,630	56,445	75,261
20				48,004 (23)	37,000 (34)	46,000 (45)
22				60,376	90,564	120,751
24				73,755	110,633	147,511
26				88,473	132,709	176,946
28				104,529	156,793	209,057
30				121,922	182,883	243,844
32				140,654	210,980	281,307
34				160,723	241,085	321,446
36				182,130	273,196	364,261
42				204,876	307,314	409,752
48				281,140	421,710	562,280
54				369,446	554,168	738,891
60				469,793	704,689	939,586
66				582,182	873,273	1,164,364
72				843,085	1,264,628	1,686,170
84				1,152,155	1,728,233	2,304,310
96				1,509,392	2,264,088	3,018,784

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	25	35	50	223	Pressure with these	drop pipe
3/4	61	87	122			
1	128	181	256			
1-	295	417	590	398	823	1,833
1/4	467	660	933	549	1,375	
1-	967	1,368	1,934	917		
1/2						
2						
2-	1,608	2,274	3,216	1,316	1,973	2,631
1/2	2,986	4,223		2,050	3,075	4,100
3	6,416			3,569	5,353	7,137
4						
Notes:	12,000	governs	with	5,647	8,471	11,295
6	19,509	pipe	sizes	8,091	12,137	16,182
1				12,172	17,261	22,348
8				17,261	22,348	28,435

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)	27,177	21,201	20,370
10	these		23,175	34,762	46,350
12	0.125	0.25	33,658	50,486	67,315
14		0.5	41,200 (23)	61,800 (34)	82,399 (45)
16			54,852	82,278	109,703
18			70,454	105,681	140,908
20			88,006	132,010	176,013
22			107,509	161,264	215,019
24			128,962	193,444	257,925
26			152,366	228,549	304,732
28			177,719	266,579	355,439
30			205,023	307,535	410,047
32			234,278	351,416	468,555
34			265,482	398,223	530,964
36			298,637	447,955	597,274
42			409,803	614,704	819,606
48			538,522	807,782	1,077,043
54			684,793	1,027,189	1,369,585
60			848,616	1,272,925	1,697,233
72			1,228,921	1,843,382	2,457,843
84			1,679,436	2,519,155	3,358,873
96			2,200,162	3,300,242	4,400,323

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	27	38	54	254	Pressure	drop pipe
3/4	67	94	133		with these	
1	139	197	279			
1-	321	454	642	453	937	2,087
1/4	508	718	1,015	624	1,565	
1-	1,052	1,488	2,105	1,043		
1/2						
2						
Notes:	1,750	2,475	3,500	1,498	2,247	2,995
1/2	3,250	4,596		2,334	3,501	4,668
3	6,982	9,874		4,063	6,094	8,126
4						

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

2. Table based on heavy weight steel pipe using steam equations in Part

Pipe Size	Pressure	Drop	psig/100	6,429 9,211 16,137 2,000 (23)	9,644 13,817 24,205 3,000 (34)	Velocity FPM (mph)	12,859 18,423 32,273 4,000 (45)
	10 psig	pipe	sizes				
8	21,230 0.125						
10	Velocity			26,384	39,576		52,768
12	these			38,319	57,478		76,637
14				46,905	70,358		93,810
16				62,448	93,672		124,896
18				80,211	120,316		160,421
20				100,194	150,291		200,388
22				122,398	183,596		244,795
24				146,822	220,232		293,643
26				173,466	260,199		346,932
28				202,331	303,496		404,662
30				233,416	350,124		466,832
32				266,721	400,082		533,443
34				302,247	453,371		604,494
36				339,993	509,990		679,987
42				466,554	699,831		933,109
48				613,098	919,648		1,226,197
54				779,626	1,169,439		1,559,252
60				966,137	1,449,205		1,932,273
72				1,399,108	2,098,662		2,798,216
84				1,912,012	2,868,018		3,824,024
96				2,504,850	3,757,275		5,009,700

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	31	43	61	303	Pressure with these	drop pipe
3/4	75	106	150			
1	157	222	313			
1-	361	510	721	541	1,118	
1/4	570	807	1,141	745	1,868	
1-	1,182	1,672	2,364	1,246		
1/2						
2						
Notes:	1,966	2,780	3,931	1,788	2,682	3,575
1/2	2,651	5,162		2,706	4,170	5,572

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/2	3,051	3,103
3/4	7,843	11,091
4	2,700	4,179
5	4,849	7,274
6	7,674	9,688
8	14,669	23,848
10	23,848	31,493
12	31,493	47,239
14	45,738	68,607
16	55,987	83,981
18	74,539	111,808
20	95,741	143,612
22	119,594	179,390
24	146,096	219,144
26	175,249	262,874
28	207,053	310,579
30	241,506	362,259
32	278,610	417,915
34	318,364	477,546
36	360,768	541,152
42	405,823	608,734
48	556,888	835,333
54	731,806	1,097,710
60	930,577	1,395,865
72	1,153,200	1,729,800
84	1,670,003	2,505,004
96	2,282,216	3,423,324
	2,989,838	4,484,758

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	33	46	66	Pressure	drop pipe
3/4	80	114	161	with these	
1	168	238	337		
Notes:	388	549	776	603	2,084
1/4	613	867	1,227	831	
1-	1,271	1,798	2,542	1,389	

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

2. Table based on heavy weight steel pipe using steam equations in Part

Pipe Size	Pressure Drop psig/100 ft			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	3,926	5,552	8,434	3,107	4,661	6,215
3/4	8,434	11,928		5,409	8,113	10,817
1	15,775	governs	with	8,559	12,839	17,118
1 1/2	25,646	pipe	sizes	12,263	18,394	24,526
2				21,482	32,223	42,964
3	Velocity			35,124	52,686	70,248
4	these			51,012	76,517	102,023
6				62,443	93,664	124,885
8				83,134	124,700	166,267
10				106,780	160,171	213,561
12				133,383	200,075	266,766
14				162,942	244,413	325,883
16				195,456	293,184	390,912
18				230,926	346,390	461,853
20				269,353	404,029	538,705
22				310,735	466,102	621,469
24				355,073	532,609	710,145
26				402,366	603,549	804,733
28				452,616	678,924	905,232
30				621,100	931,650	1,242,200
32				816,187	1,224,280	1,632,373
34				1,037,876	1,556,814	2,075,752
36				1,286,168	1,929,252	2,572,336
38				1,862,561	2,793,841	3,725,122
40				2,545,364	3,818,046	5,090,729
42				3,334,579	5,001,868	6,669,157

Steam Condensate Flow lbs./h 15 psig Back Pressure

1/2	36	51	73		Pressure	drop pipe
3/4	89	126	178		with these	
1	187	264	373			
Notes:	430	608	860	703	2,428	

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2	1,409	1,992	2,818	1,618		
2-1/2	2,343	3,313	4,686	2,323	3,484	4,646
3	4,351	6,153	8,702	3,620	5,430	7,240
4	9,348	13,220		6,301	9,452	12,602
5	17,484	24,726	with sizes	9,971	14,957	19,943
6	28,425			14,286	21,430	28,573
8	60,185			25,027	37,540	50,054
10	Velocity governs these pipe			40,920	61,380	81,840
12				59,430	89,144	118,859
14				72,747	109,120	145,494
16				96,852	145,278	193,705
18				124,401	186,602	248,803
20				155,394	233,091	310,788
22				189,831	284,746	379,661
24				227,711	341,566	455,421
26				269,034	403,551	538,068
28				313,801	470,702	627,603
30				362,012	543,019	724,025
32				413,667	620,500	827,334
34				468,765	703,148	937,530
36				527,307	790,960	1,054,614
42				723,594	1,085,391	1,447,189
48				950,874	1,426,312	1,901,749
54				1,209,147	1,813,721	2,418,294
60				1,498,413	2,247,619	2,996,825
72				2,169,922	3,254,883	4,339,844
84				2,965,402	4,448,103	5,930,805
96				3,884,854	5,827,280	7,769,707

Steam Condensate Flow lbs./h 20 psig Back Pressure

Notes:	43	60	85		Pressure drop pipe	
3/4	105	148	209		with these	

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/4	504	3,062
1/2	1,652	3,000 (34)
3/4	2,748	3,000 (34)
1	5,103	3,000 (34)
1 1/2	10,964	3,000 (34)
2	20,505	3,000 (34)
2 1/2	33,337	3,000 (34)
3	70,587	3,000 (34)
4	125,505	3,000 (34)
5	210,505	3,000 (34)
6	310,505	3,000 (34)
8	438,505	3,000 (34)
10	504,505	3,000 (34)
12	570,505	3,000 (34)
14	636,505	3,000 (34)
16	702,505	3,000 (34)
18	768,505	3,000 (34)
20	834,505	3,000 (34)
22	900,505	3,000 (34)
24	966,505	3,000 (34)
26	1,032,505	3,000 (34)
28	1,098,505	3,000 (34)
30	1,164,505	3,000 (34)
32	1,230,505	3,000 (34)
34	1,296,505	3,000 (34)
36	1,362,505	3,000 (34)
42	1,494,505	3,000 (34)
48	1,626,505	3,000 (34)
54	1,758,505	3,000 (34)
60	1,890,505	3,000 (34)
72	2,378,505	3,000 (34)
84	2,866,505	3,000 (34)
96	3,354,505	3,000 (34)

Notes: Condensate Flow lbs./h 25 psia Back Pressure

Streamline condensate flow requires low pipe back pressure

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
1/2	49	70	99			
3/4	121	171	243			
1	234	359	508	2,000 (23)	3,000 (34)	4,000 (45)
1-1/4	585	827	1,169	1,095	3,782	
1-1/2	924	1,307	1,849	1,509		
2	1,916	2,709	3,832	2,521		
2-1/2	3,186	4,505	6,372	3,619	5,428	11,279
3	5,917	8,367	11,833	5,639	8,459	19,631
4	12,712	17,977		9,816	14,724	
5	23,775	33,622	With Sizes	15,533	23,300	31,067
6	38,652	54,662		22,255	33,383	44,510
8	81,840			38,986	58,479	77,973
10	156,896	governs pipe		63,744	95,616	127,489
12				92,578	138,867	185,156
14				113,323	169,985	226,646
16	Velocity these			150,874	226,311	301,748
18				193,789	290,684	387,579
20				242,069	363,104	484,138
22				295,713	443,570	591,427
24				354,722	532,083	709,444
26				419,095	628,642	838,190
28				488,832	733,248	977,664
30				563,934	845,901	1,127,868
32				644,400	966,600	1,288,800
34				730,231	1,095,346	1,460,461
36				821,426	1,232,139	1,642,852
42				1,127,197	1,690,796	2,254,395
48				1,481,249	2,221,873	2,962,497
54				1,883,580	2,825,369	3,767,159
60				2,334,190	3,501,285	4,668,381
Notes:				3,380,251	5,070,376	6,760,502

84 Pipe 96 Size	Pressure Drop psig/100 ft.			4,619,430 6,051,729	6,929,146 9,259,593	9,238,861 12,117,417
Steam Condensate Flow lbs./h 30 psig Back Pressure						
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	57	80	114		Pressure	drop pipe
3/4	139	197	279		with these	
1	292	413	584			
1-	672	951	1,345	1,332		
1/4	1,063	1,504	2,127	1,835		
1-	2,204	3,117	4,408	3,066		
1/2						
2						
2-	3,665	5,183	7,329	4,401	6,601	23,875
1/2	6,806	9,625	13,612	6,858	10,287	
3	14,622	20,679	29,244	11,937	17,906	
4						
5	27,348	38,676	with	18,891	28,336	37,781
6	44,462	62,879	sizes	27,065	40,598	54,130
8	94,142			47,413	71,119	94,826
10	180,480	governs		77,522	116,283	155,044
12		pipe		112,588	168,882	225,176
14				137,817	206,725	275,634
16	Velocity			183,484	275,226	366,968
18	these			235,675	353,513	471,350
20				294,390	441,585	588,780
22				359,629	539,443	719,258
24				431,392	647,087	862,783
26				509,678	764,517	1,019,356
28				594,489	891,733	1,188,977
30				685,823	1,028,734	1,371,646
32				783,681	1,175,522	1,567,362
34				888,063	1,332,095	1,776,127
36				998,969	1,498,454	1,997,939
42				1,370,830	2,056,246	2,741,661
Notes:				1,801,407	2,702,110	3,602,813
54				2,290,698	3,436,047	4,581,395

Pipe Size	Pressure Drop psig/100 ft.	2,838,704	4,258,056	5,677,407
72		4,110,860	6,166,291	8,221,721
84	0.125	2,000 (23)	3,000 (34)	4,000 (45)
96	0.25	7,359,753	11,039,630	14,719,506

Steam Condensate Flow lbs./h 40 psig Back Pressure

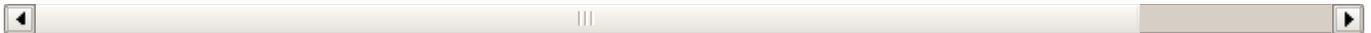
Pipe Size	Pressure Drop psig/100 ft.	2,838,704	4,258,056	5,677,407
1/2	74	105	148	
3/4	182	257	363	
1	381	538	761	
1-	876	1,239	1,752	2,626
1/4	1,385	1,959	2,770	4,387
1-	2,871	4,060	5,742	
1/2				
2-	4,774	6,751	9,548	6,297
1/2	8,866	12,539	17,733	9,814
3	19,048	26,939	38,097	17,081
4				
5	35,627	50,384	with	27,031
6	57,921	81,913	sizes	38,729
8	122,639			67,845
10	235,113	governs		110,929
12	383,762	pipe		161,106
14				197,207
16	Velocity			262,554
18	these			337,236
20				421,253
22				514,605
24				617,293
26				729,316
28				850,674
30				981,367
32				1,121,396
Notes:				1,270,760
36				1,429,459
42				1,961,568

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48				2,577,693	3,866,540	5,155,187
54				3,277,837	4,916,755	6,555,673
60				4,061,997	6,092,995	8,123,994
72				5,882,369	8,823,553	11,764,738
84				8,038,810	12,058,214	16,077,619
96				10,531,319	15,796,979	21,062,638

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM (55 mph)
2. Table based on heavy weight steel pipe using steam equations in Part 1



125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2	19	27	38	90	Pressure drop pipe with these	
3/4	47	67	94	150		
1	99	140	197			
1-1/4	227	321	455	267	401	1,232
1-1/2	359	508	719	369	553	
2	745	1,053	1,490	616	924	
2-1/2	1,239	1,752	with sizes	884	1,326	1,768
3	2,300	3,253		1,377	2,066	2,755
4	4,942			2,397	3,596	4,795
5	9,243	governs pipe		3,794	5,691	7,588
6				5,436	8,153	10,871
8				9,522	14,283	19,044
Notes:	Velocity			15,569	23,354	31,138

12 Pipe 14 Size	these Pressure Drop psig/100 ft.			22,612 27,679	33,917 41,518	45,223 55,551
					Velocity FPM (mph)	
16	0.125	0.25	0.5	36,850 2,000 (23)	55,275 3,000 (34)	73,700 4,000 (45)
18				47,332	70,998	94,664
20				59,124	88,686	118,248
22				72,226	108,339	144,452
24				86,639	129,958	173,277
26				102,361	153,542	204,723
28				119,394	179,091	238,789
30				137,737	206,606	275,475
32				157,391	236,086	314,782
34				178,354	267,532	356,709
36				200,628	300,942	401,257
42				275,311	412,967	550,622
48				361,786	542,679	723,572
54				460,053	690,079	920,106
60				570,112	855,168	1,140,224
72				825,606	1,238,409	1,651,212
84				1,128,268	1,692,402	2,256,536
96				1,478,098	2,217,147	2,956,197

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	24	34	49	218	Pressure with these	drop pipe
3/4	60	85	120			
1	125	177	250			
1-	288	408	576	389	804	1,791
1/4	456	645	911	536	1,343	
1-	945	1,336	1,889	895		
1/2						
2						
2-	1,571	2,221	3,142	1,285	1,928	2,570
1/2	2,917	4,126		2,003	3,004	4,005
3	6,267			3,486	5,229	6,972
4						
Notes:	11,722	governs	with	5,516	8,275	11,033
6	19,057	pipe	sizes	7,904	11,855	15,807

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	13,845	20,768	27,691
10				22,638	33,957	45,276
12				22,638 (23)	33,957 (34)	45,276 (45)
14				40,245	60,368	80,491
16				53,581	80,371	107,162
18				68,822	103,233	137,644
20				85,968	128,952	171,935
22				105,019	157,528	210,037
24				125,975	188,962	251,950
26				148,836	223,254	297,672
28				173,602	260,404	347,205
30				200,274	300,411	400,548
32				228,850	343,275	457,701
34				259,332	388,998	518,664
36				291,719	437,578	583,437
42				400,309	600,464	800,619
48				526,046	789,069	1,052,092
54				668,929	1,003,393	1,337,858
60				828,957	1,243,436	1,657,915
72				1,200,452	1,800,678	2,400,904
84				1,640,531	2,460,796	3,281,061
96				2,149,193	3,223,789	4,298,385

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	27	37	53	248	Pressure with these	drop pipe
3/4	65	92	130			
1	136	192	272			
1-	313	443	627	442	914	2,037
1/4	495	701	991	609	1,527	
1-	1,027	1,452	2,054	1,018		
1/2						
2						
Notes:	1,708	2,415	3,415	1,462	2,192	2,923
1/2	3,171	4,485		2,278	3,417	4,556
3	6,813	9,635		3,965	5,947	7,929
4						

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

4 Pipe Size	Pressure	Drop	psig/100 ft.	governs with pipe sizes	Velocity	FPM (mph)
6	12,743	0.125	0.25	0.5	6,274	9,411
8	20,717	0.23	0.34	0.45	8,989	13,483
					15,747	23,620
10	Velocity				25,747	38,620
12	these				37,393	56,090
14					45,772	68,658
16					60,939	91,409
18					78,273	117,410
20					97,774	146,661
22					119,441	179,162
24					143,275	214,913
26					169,276	253,914
28					197,444	296,165
30					227,778	341,667
32					260,279	390,418
34					294,947	442,420
36					331,781	497,672
42					455,285	682,927
48					598,289	897,434
54					760,794	1,141,191
60					942,800	1,414,200
72					1,365,313	2,047,969
84					1,865,828	2,798,743
96					2,444,346	3,666,519

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	30	42	59	296	Pressure with these	drop pipe
3/4	73	103	146			
1	153	216	305			
1-	351	497	703	527	1,089	
1/4	556	786	1,111	726	1,820	
1-	1,152	1,629	2,304	1,214		
1/2						
2						
Notes:	1,915	2,709	3,830	1,742	2,613	3,484

Pipe Size	Pressure psig	Drop ft/100	Velocity FPM (mph)
4	0.125	0.25	0.5
5	14,293		
6	23,237		
8			
10			
12			
14			
16	Velocity	governs	with
18	these	pipe	sizes
20			
22			
24			
26			
28			
30			
32			
34			
36			
42			
48			
54			
60			
72			
84			
96			

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	32	45	64		Pressure	drop pipe
3/4	78	111	157		with these	
1	164	232	328			
Notes:	378	534	755	587	2,028	
1/4	597	844	1,194	809		
1-	1,237	1,750	2,475	1,352		
1 1/2						

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

1/2 Pipe 2 Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
2- 1/2	2,058 0.125 3,821	2,910 0.25 5,404	4,115 0.5	1,941 2,000 (23) 3,025	2,911 3,000 (34) 4,537	3,882 4,000 (45) 6,049
3 4	8,210	11,610		5,265	7,897	10,529
5 6 8	15,355 24,963	governs pipe	with sizes	8,331 11,936 20,910	12,497 17,905 31,365	16,662 23,873 41,820
10 12 14	Velocity these			34,189 49,654 60,780	51,283 74,481 91,171	68,378 99,308 121,561
16 18 20				80,921 103,938 129,833	121,381 155,907 194,749	161,841 207,876 259,665
22 24 26				158,604 190,253 224,779	237,907 285,380 337,169	317,209 380,507 449,559
28 30 32				262,183 302,463 345,621	393,274 453,695 518,431	524,365 604,926 691,242
34 36 42				391,656 440,568 604,567	587,483 660,851 906,850	783,311 881,135 1,209,133
48 54 60				794,460 1,010,248 1,251,931	1,191,690 1,515,373 1,877,897	1,588,921 2,020,497 2,503,863
72 84 96				1,812,981 2,477,608 3,245,814	2,719,471 3,716,412 4,868,722	3,625,961 4,955,217 6,491,629

Steam Condensate Flow lbs./h 15 psig Back Pressure

1/2	35	50	71		Pressure	drop pipe
3/4	87	123	173		with these	
1	181	257	363			
Notes:	418	591	836	683	2 359	

Pipe Size	Pressure Drop psig/100 ft	Velocity FPM (mph)
1/4	1,369	941
1/2	0.125	2,000 (23)
2		3,000 (34)
		4,000 (45)
2-1/2	2,277	2,258
3	4,229	3,518
4	9,085	6,124
5	16,992	9,691
6	27,625	13,884
8	58,492	24,323
10	Velocity governs these pipe	39,769
12		57,757
14		70,700
16		94,127
18		120,900
20		151,021
22		184,488
24		221,302
26		261,463
28		304,970
30		351,824
32		402,025
34		455,573
36		512,467
42		703,231
48		924,114
54		1,175,119
60		1,456,244
72		2,108,855
84		2,881,948
96		3,775,524

Steam Condensate Flow lbs./h 20 psig Back Pressure

Notes: 41 58 83 Pressure drop pipe

3/4 Pipe 1 Size	101	143	203	with these		
	Pressure 212	Drop 300 ft.	psig/100	Velocity FPM (mph)		
1- 1/4	489 0.125 773	691 0.25 1,093	977 0.5 1,545	860 2,000 (23) 1,184	2,968 3,000 (34)	4,000 (45)
1- 1/2	1,602	2,265	3,203	1,979		
2- 1/2	2,663	3,766	5,326	2,840	4,260	8,852
3	4,946	6,995	9,892	4,426	6,639	15,408
4	10,626	15,027		7,704	11,556	
5	19,874	28,106	with	12,192	18,287	24,383
6	32,310		sizes	17,467	26,201	34,935
8	68,413			30,599	45,899	61,198
10	Velocity	governs		50,031	75,047	100,062
12	these	pipe		72,662	108,993	145,323
14				88,944	133,416	177,888
16				118,417	177,625	236,833
18				152,100	228,149	304,199
20				189,993	284,989	379,986
22				232,097	348,145	464,193
24				278,411	417,616	556,821
26				328,935	493,402	657,870
28				383,670	575,505	767,340
30				442,615	663,922	885,230
32				505,770	758,656	1,011,541
34				573,136	859,704	1,146,273
36				644,713	967,069	1,289,425
42				884,704	1,327,055	1,769,407
48				1,162,588	1,743,882	2,325,176
54				1,478,365	2,217,548	2,956,731
60				1,832,036	2,748,054	3,664,073
72				2,653,058	3,979,587	5,306,116
84				3,625,653	5,438,479	7,251,306
96				4,749,821	7,124,732	9,499,642

Pipe Pressure Drop (psi/100 ft) Back Pressure

Velocity FPM (mph)

Size	48	68	96		Pressure	drop pipe
1/2	10,125	16,625	23,045	2,000 (23)	3,000 (34)	4,000 (45)
3/4	245	347	491			
1-	565	799	1,130	1,058	3,654	
1/4	893	1,263	1,786	1,458		
1-	1,851	2,618	3,703	2,436		
1/2						
2-	3,079	4,354	6,157	3,497	5,245	10,899
1/2	5,718	8,086	11,435	5,450	8,175	18,971
3	12,284	17,372		9,486	14,228	
4						
5	22,975	32,491	with	15,011	22,516	30,022
6	37,352	52,824	sizes	21,507	32,260	43,013
8	79,088			37,675	56,513	75,350
10	151,620	governs		61,600	92,401	123,201
12		pipe		89,464	134,197	178,929
14				109,512	164,268	219,024
16	Velocity			145,800	218,700	291,600
18	these			187,272	280,908	374,544
20				233,928	350,892	467,856
22				285,768	428,652	571,536
24				342,792	514,188	685,583
26				405,000	607,500	809,999
28				472,392	708,587	944,783
30				544,968	817,451	1,089,935
32				622,727	934,091	1,245,455
34				705,671	1,058,507	1,411,343
36				793,799	1,190,699	1,587,599
42				1,089,287	1,633,931	2,178,574
48				1,431,431	2,147,146	2,862,862
54				1,820,231	2,730,346	3,640,461
60				2,255,686	3,383,529	4,511,372
Notes:				3 266 565	4 800 848	6 533 131

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)	5,200,500	7,000,040	8,500,101	
84			4,464,068	6,696,102	8,928,137	
96			5,848,195	8,772,293	11,696,390	
Steam Condensate Flow lbs./h 30 psig Back Pressure						
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	55	77	110		Pressure	drop pipe
3/4	134	190	269		with these	
1	281	398	563			
1-	648	916	1,295	1,283		
1/4	1,024	1,449	2,049	1,768		
1-	2,123	3,002	4,246	2,954		
1/2						
2						
2-	3,530	4,993	7,061	4,239	6,359	22,999
1/2	6,556	9,272	13,113	6,607	9,910	
3	14,086	19,921	28,172	11,499	17,249	
4						
5	26,345	37,258	with	18,198	27,297	36,396
6	42,831	60,573	sizes	26,073	39,109	52,145
8	90,689			45,674	68,511	91,348
10	173,861	governs		74,679	112,018	149,358
12		pipe		108,459	162,688	216,918
14				132,763	199,144	265,525
16	Velocity			176,755	265,132	353,510
18	these			227,032	340,548	454,064
20				283,593	425,390	567,187
22				346,440	519,659	692,879
24				415,570	623,356	831,141
26				490,986	736,479	981,972
28				572,686	859,029	1,145,372
30				660,671	991,006	1,321,341
32				754,940	1,132,410	1,509,880
34				855,494	1,283,241	1,710,987
36				962,332	1,443,498	1,924,665
42				1,320,556	1,980,833	2,641,111
Notes:				1,735,340	2,603,011	3,470,681

54 Pipe 60 Size	Pressure	Drop	psig/100 ft.	2,206,687 2,734,595	3,310,030 4,117,892	4,413,374 5,469,119
72 84 96	0.125	0.25	0.5	3,960,095 2,000 (23) 5,411,842 7,089,836	5,940,143 3,000 (34) 8,117,764 10,634,753	7,920,191 4,000 (45) 10,823,685 14,179,671

Steam Condensate Flow lbs./h 40 psig Back Pressure

1/2 3/4 1	71 174 364	100 246 515	142 348 728		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	838 1,325 2,746	1,185 1,873 3,883	1,675 2,649 5,491	2,511 4,196		
2- 1/2 3 4	4,566 8,480 18,218	6,457 11,992 25,764	9,132 16,959 36,436	6,022 9,386 16,337	9,034 14,079 24,505	32,673
5 6 8	34,073 55,395 117,291	48,187 78,341	with sizes	25,853 37,040 64,886	38,779 55,560 97,329	51,705 74,080 129,773
10 12 14	224,861 367,028	governs pipe		106,092 154,081 188,608	159,138 231,121 282,912	212,184 308,162 377,216
16 18 20	Velocity these			251,105 322,531 402,884	376,658 483,796 604,326	502,210 645,061 805,768
22 24 26				492,166 590,376 697,514	738,249 885,564 1,046,271	984,332 1,180,752 1,395,028
28 30 32				813,581 938,575 1,072,498	1,220,371 1,407,863 1,608,747	1,627,161 1,877,150 2,144,996
Notes: 36				1,215,349 1,367,128	1,823,023 2,050,692	2,430,697 2,734,256

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48				1,876,034	2,814,051	3,752,068
54				2,465,294	3,697,941	4,930,588
60				3,884,875	5,827,312	7,769,750
72				5,625,870	8,438,805	11,251,740
84				7,688,280	11,532,420	15,376,560
96				10,072,105	15,108,157	20,144,209

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	18	25	35	137	Pressure with these	drop pipe
3/4	43	61	86	82		
1	90	128	180			
1-	208	294	415	244	367	1,125
1/4	328	464	657	337	505	
1-	680	962	1,361	563	844	
1/2						
2-	1,131	1,600	with	807	1,211	1,615
1/2	2,101	2,972	sizes	1,258	1,887	
3	4,515			2,190	3,285	
4						
5	8,444	governs pipe		3,466	5,199	6,932
6			4,966	7,448	9,931	
8			8,699	13,048	17,397	
10				14,222	21,224	28,445

10 Pipe Size	velocity these	Pressure Drop ft.	psig/100	14,225 20,656 25,285	21,554 30,984 37,927	28,445 37,927 50,569
16 18 20	0.125	0.25	0.5	2,000 (23) 33,663 43,238 54,010	3,000 (34) 50,494 64,857 81,015	4,000 (45) 67,326 86,476 108,021
22 24 26				65,979 79,145 93,508	98,969 118,718 140,262	131,959 158,291 187,016
28 30 32				109,068 125,825 143,778	163,602 188,737 215,667	218,136 251,649 287,556
34 36 42				162,929 183,276 251,500	244,393 274,914 377,249	325,857 366,552 502,999
48 54 60				330,495 420,263 520,803	495,743 630,395 781,204	660,990 840,526 1,041,606
72 84 96				754,199 1,030,684 1,350,258	1,131,299 1,546,026 2,025,387	1,508,399 2,061,368 2,700,515

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2 3/4 1	22 54 113	31 76 160	44 108 226	197	Pressure with these	drop pipe
1- 1/4 1- 1/2 2	261 412 854	369 583 1,208	521 824 1,708	352 485 810	727 1,215	1,619
2- 1/2 3 4	1,420 2,638 5,668	2,009 3,731	2,841	1,162 1,811 3,152	1,743 2,717 4,729	2,324 3,622 6,305
Notes:	10,601	governs	with	4,989	7,483	9,977

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
10	17,234	20,472	29,732	7,147	10,721	14,295
12	20,472	29,732	36,395	12,521	18,781	25,042
14						
16				48,455	72,682	96,910
18				62,238	93,356	124,475
20				77,743	116,615	155,486
22				94,972	142,457	189,943
24				113,923	170,884	227,846
26				134,597	201,895	269,194
28				156,994	235,491	313,988
30				181,114	271,670	362,227
32				206,956	310,434	413,912
34				234,522	351,782	469,043
36				263,810	395,715	527,620
42				362,012	543,018	724,023
48				475,719	713,579	951,438
54				604,932	907,398	1,209,864
60				749,651	1,124,476	1,499,301
72				1,085,604	1,628,407	2,171,209
84				1,483,580	2,225,370	2,967,161
96				1,943,579	2,915,368	3,887,157

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	24	34	48	223	Pressure with these	drop pipe
3/4	59	83	117			
1	123	173	245			
1-	282	399	564	398	823	1,834
1/4	446	631	892	549		
1-	925	1,308	1,850	917		
1/2						
2						
Notes:	1,538	2,175	3,076	1,316	1,975	2,633
1/2	2,856	4,039		2,051	3,077	4,103
3	6,136	8,678		3,571	5,356	7,142

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	governs pipe	with sizes				
5	11,477			5,651	8,476	11,301
6	18,659 10,125	0.25 0.25	0.5 0.5	8,098 2,000 (23)	12,144 3,000 (34)	16,192 4,000 (45)
8				14,182	21,274	28,365
10	Velocity these			23,189	34,784	46,378
12				33,678	50,517	67,356
14				41,225	61,837	82,450
16				54,885	82,328	109,770
18				70,497	105,746	140,994
20				88,060	132,090	176,121
22				107,575	161,363	215,150
24				129,041	193,562	258,082
26				152,459	228,688	304,918
28				177,828	266,742	355,656
30				205,149	307,723	410,297
32				234,421	351,631	468,842
34				265,644	398,467	531,289
36				298,819	448,229	597,639
42				410,054	615,080	820,107
48				538,851	808,276	1,077,702
54				685,211	1,027,817	1,370,423
60				849,135	1,273,703	1,698,270
72				1,229,673	1,844,509	2,459,345
84				1,680,463	2,520,695	3,360,926
96				2,201,507	3,302,260	4,403,014

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	27	38	53	265	Pressure drop pipe with these
3/4	65	92	131		
1	137	193	273		
1-	315	445	629	472	975 1,630
1/4	497	704	995	650	
1-	1,031	1,458	2,062	1,087	
1/2					
2					

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)				
1/2	1,715	2,425	3,100	1,559	2,339	3,119
3/4	3,184	4,503		2,430	3,646	4,861
1	6,841	9,675		4,230	6,345	8,461
2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
3	12,796	governs	with	6,694	10,042	13,389
4	20,803	pipe	sizes	9,591	14,387	19,182
6				16,802	25,203	33,604
8	Velocity			27,472	41,208	54,944
10	these			39,898	59,847	79,797
12				48,839	73,258	97,678
14						
16				65,022	97,533	130,044
18				83,517	125,276	167,035
20				104,324	156,486	208,649
22				127,443	191,165	254,887
24				152,874	229,311	305,748
26				180,617	270,925	361,234
28				210,672	316,007	421,343
30				243,038	364,557	486,076
32				277,717	416,575	555,433
34				314,707	472,060	629,414
36				354,009	531,014	708,018
42				485,787	728,681	971,575
48				638,372	957,559	1,276,745
54				811,765	1,217,647	1,623,529
60				1,005,964	1,508,946	2,011,928
72				1,456,784	2,185,176	2,913,568
84				1,990,832	2,986,248	3,981,664
96				2,608,108	3,912,162	5,216,217

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	28	40	57		Pressure	drop pipe
3/4	70	99	140		with these	
1	146	207	292			
Notes:	337	476	673	524	1,808	
1/4	532	753	1,065	721		

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

1-1103 1-560 2-206 1-206

1 Pipe Size	1,100 Pressure Drop psig/100 ft.	1,500	2,200	1,200	Velocity FPM (mph)	
2- 1/2 3 4	0.125 1,835 3,407 7,320	0.25 2,394 4,818 10,352	0.5 3,669	2,000 (23) 1,730 2,697 4,694	3,000 (34) 2,596 4,045 7,041	4,000 (45) 3,461 5,394 9,388
5 6 8	13,691 22,258	governs pipe	with sizes	7,428 10,643 18,644	11,142 15,964 27,966	14,856 21,285 37,287
10 12 14	Velocity these			30,483 44,272 54,193	45,725 66,408 81,289	60,967 88,544 108,385
16 18 20				72,150 92,673 115,761	108,225 139,009 173,641	144,300 185,345 231,521
22 24 26				141,414 169,632 200,416	212,121 254,449 300,625	282,828 339,265 400,833
28 30 32				233,766 269,680 308,160	350,649 404,521 462,240	467,531 539,361 616,321
34 36 42				349,206 392,816 539,040	523,808 589,224 808,560	698,411 785,632 1,078,080
48 54 60				708,352 900,752 1,116,239	1,062,528 1,351,127 1,674,359	1,416,704 1,801,503 2,232,479
72 84 96				1,616,479 2,209,070 2,894,013	2,424,718 3,313,605 4,341,020	3,232,958 4,418,140 5,788,027

Steam Condensate Flow lbs./h 15 psig Back Pressure

Notes:	31	44	63		Pressure	drop pipe
3/4	77	109	154		with these	
1	161	227	322			

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop	Drop	psi/100 ft.	605	2,091	Velocity FPM (mph)
	585	828	1,171	834		
1-1/2	1,213	1,716	2,427	1,394		
2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2-1/2	2,018	2,853	4,035	2,000	3,001	4,001
3	3,747	5,299	7,494	3,118	4,676	6,235
4	8,050	11,385		5,426	8,140	10,853
5	15,057	21,293		8,587	12,881	17,174
6	24,479			12,303	18,455	24,606
8	51,830			21,553	32,329	43,105
10				35,240	52,859	70,479
12				51,180	76,769	102,359
14				62,648	93,972	125,296
16	Velocity	governs	with	83,407	125,111	166,815
18	these	pipe	sizes	107,132	160,698	214,264
20				133,822	200,734	267,645
22				163,478	245,217	326,957
24				196,100	294,150	392,200
26				231,687	347,530	463,374
28				270,240	405,359	540,479
30				311,758	467,637	623,516
32				356,242	534,363	712,484
34				403,691	605,537	807,383
36				454,106	681,160	908,213
42				623,145	934,718	1,246,290
48				818,874	1,228,312	1,637,749
54				1,041,294	1,561,941	2,082,588
60				1,290,404	1,935,605	2,580,807
72				1,868,694	2,803,041	3,737,389
84				2,553,746	3,830,619	5,107,493
96				3,345,560	5,018,339	6,691,119

Steam Condensate Flow lbs./h 20 psi Back Pressure

Water	26	51	72		Pressure	drop	pipe
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1/2 Pipe Size	50 Pressure 89	51 Drop 126 ft.	72 psig/100 178		Pressure with these Velocity	drop pipe FPM (mph)
1-	0.125 428	0.25 606	0.5 857	2,000 (23) 754	3,000 (34) 2,602	4,000 (45)
1/4	677	958	1,355	1,038		
1-	1,404	1,986	2,808	1,735		
1/2						
2-	2,335	3,302	4,669	2,490	3,735	7,761
1/2	4,336	6,132	8,672	3,880	5,821	13,508
3	9,316	13,174		6,754	10,131	
4						
5	17,423	24,640	with	10,688	16,032	21,377
6	28,326		sizes	15,313	22,970	30,627
8	59,977			26,826	40,239	53,652
10	Velocity	governs		43,862	65,792	87,723
12	these	pipe		63,702	95,552	127,403
14				77,976	116,964	155,952
16				103,814	155,722	207,629
18				133,344	200,016	266,688
20				166,564	249,847	333,129
22				203,476	305,214	406,952
24				244,079	366,119	488,158
26				288,373	432,560	576,746
28				336,359	504,538	672,717
30				388,035	582,053	776,070
32				443,403	665,104	886,805
34				502,462	753,692	1,004,923
36				565,212	847,817	1,130,423
42				775,609	1,163,413	1,551,217
48				1,019,226	1,528,840	2,038,453
54				1,296,065	1,944,097	2,592,129
60				1,606,124	2,409,185	3,212,247
Notes:				2,325,903	3,488,855	4,651,806
84				3,178,565	4,767,848	6,357,130
96				4,164,410	6,326,164	8,378,510

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.	Steam Condensate Flow lbs./h	25 psig Back Pressure	Velocity FPM (mph)		
1/2	41	59	83	2,000 (23)	3,000 (34)	4,000 (45)
3/4	102	144	203		with these	
1	213	301	425			
1-	490	692	979	917	3,168	
1/4	774	1,095	1,549	1,264		
1-	1,605	2,270	3,210	2,112		
1/2						
2						
2-	2,669	3,774	9,913	3,031	4,547	16,445
1/2	4,956	7,009	5,338	4,724	7,086	9,448
3	10,649	15,059		8,223	12,334	
4						
5	19,916	28,166	with	13,012	19,519	26,025
6	32,379	45,791	sizes	18,643	27,965	37,286
8	68,558			32,659	48,989	65,318
10	131,433	governs		53,399	80,099	106,798
12		pipe		77,553	116,330	155,106
14				94,932	142,397	189,863
16	Velocity			126,388	189,582	252,776
18	these			162,339	243,508	324,677
20				202,783	304,174	405,566
22				247,721	371,581	495,442
24				297,153	445,729	594,306
26				351,078	526,618	702,157
28				409,498	614,247	818,996
30				472,411	708,617	944,822
32				539,818	809,727	1,079,636
34				611,719	917,579	1,223,438
36				688,114	1,032,171	1,376,227
42				944,261	1,416,391	1,888,521
Notes:				1,240,852	1,861,277	2,481,703
54				1,577,887	2,366,830	3,155,774
60				1,955,366	2,933,050	3,910,733

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)	
96	0.125	0.25	0.5	2,831,658 3,869,727 5,069,573 2,000 (23)	4,247,487 5,804,590 7,604,359 3,000 (34)	5,663,316 7,739,454 10,139,145 4,000 (45)

Steam Condensate Flow lbs./h 30 psig Back Pressure

1/2	47	66	94		Pressure with these	drop pipe
3/4	115	163	230			
1	241	341	482			
1-	555	785	1,110	1,099		
1/4	877	1,241	1,755	1,514		
1-	1,818	2,572	3,637	2,530		
1/2						
2						
2-	3,024	4,276	6,048	3,631	5,447	19,700
1/2	5,616	7,942	11,232	5,659	8,488	
3	12,065	17,063	24,131	9,850	14,775	
4						
5	22,566	31,913	with	15,587	23,381	31,175
6	36,687	51,883	sizes	22,332	33,499	44,665
8	77,679			39,122	58,683	78,244
10	148,920	governs		63,966	95,949	127,932
12		pipe		92,900	139,350	185,800
14				113,717	170,576	227,434
16	Velocity			151,398	227,098	302,797
18	these			194,463	291,694	388,926
20				242,910	364,366	485,821
22				296,741	445,111	593,482
24				355,955	533,932	711,909
26				420,551	630,827	841,102
28				490,531	735,796	981,062
30				565,894	848,841	1,131,787
32				646,640	969,959	1,293,279
34				732,768	1,099,153	1,465,537
36				824,280	1,236,421	1,648,561
42				1,131,115	1,696,672	2,262,229
48				1,486,306	2,320,504	3,073,703

48 Pipe Size	Pressure Drop psig/100 ft.	0.125	0.25	0.5	1,480,590	2,229,594	2,912,192
54					1,890,125	2,925,188	3,780,251
60					2,342,302	3,513,453	4,684,604
72					2,000 (23)	3,000 (34)	4,000 (45)
84				3,391,998	5,087,997	6,783,996	
96				4,635,484	6,953,226	9,270,968	
				6,072,760	9,109,140	12,145,519	

Steam Condensate Flow lbs./h 40 psig Back Pressure

1/2	59	84	118		Pressure	drop pipe
3/4	145	205	290		with these	
1	304	429	607			
1-	699	988	1,397	2,094		
1/4	1,105	1,562	2,209	3,499		
1-	2,290	3,238	4,580			
1/2						
2						
2-	3,808	5,385	7,615	5,022	7,534	27,248
1/2	7,072	10,001	14,143	7,827	11,741	
3	15,193	21,486	30,385	13,624	20,436	
4						
5	28,415	40,185	with	21,560	32,339	43,119
6	46,196	65,331	sizes	30,889	46,333	61,778
8	97,814			54,111	81,167	108,222
10	187,520	governs		88,474	132,711	176,948
12	306,079	pipe		128,494	192,741	256,988
14				157,287	235,931	314,575
16	Velocity			209,406	314,110	418,813
18	these			268,971	403,456	537,942
20				335,981	503,971	671,962
22				410,437	615,655	820,873
24				492,338	738,507	984,676
26				581,685	872,527	1,163,369
28				678,477	1,017,715	1,356,954
30				782,715	1,174,072	1,565,429
32				894,398	1,341,597	1,788,796
Notes:				1,013,527	1,520,291	2,027,054

Pipe Size	Pressure	Drop	psig/100 ft.	1,140,102 1,564,499	1,710,153 2,346,748	2,280,203 3,128,997
48	0.125	0.25	0.5	2,055,906	3,083,859	4,111,812
54				2,614,323	3,921,484	5,228,646
60				3,239,750	4,859,625	6,479,500
72				4,691,635	7,037,452	9,383,270
84				6,411,560	9,617,339	12,823,119
96				8,399,525	12,599,287	16,799,049

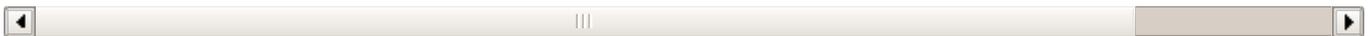
Steam Condensate Flow lbs./h 50 psig Back Pressure

1/2	74	104	147		Pressure	drop pipe
3/4	180	255	361		with these	
1	378	534	755			
1-	869	1,229	1,738	4,715		
1/4	1,374	1,944	2,749			
1-	2,849	4,029	5,697			
1/2						
2						
2-	4,737	6,699	9,474	6,767	15,819	36,713
1/2	8,797	12,441	17,595	10,546	27,535	
3	18,900	26,729	37,801	18,357		
4						
5	35,350	49,992	70,699	29,049	43,574	58,099
6	57,471	81,276		41,620	62,430	83,240
8	121,686	172,090		72,910	109,364	145,819
10	233,285	governs	with	119,210	178,816	238,421
12	380,779	pipe	sizes	173,133	259,700	346,266
14	495,895			211,930	317,894	423,859
16	Velocity			282,155	423,232	564,309
18	these			362,412	543,618	724,824
20				452,701	679,052	905,403
22				553,023	829,535	1,106,046
24				663,377	995,065	1,326,754
26				783,763	1,175,644	1,567,526
Notes:				914,181	1,371,272	1,828,362
30				1,054,631	1,581,947	2,109,263

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
34				1,205,114	1,807,671	2,410,228
36				1,365,629	2,048,443	2,731,257
42				2,108,009	3,162,013	4,216,018
48				2,770,132	4,155,198	5,540,264
54				3,522,544	5,283,816	7,045,089
60				4,365,246	6,547,869	8,730,493
72				6,321,519	9,482,278	12,643,037
84				8,638,949	12,958,423	17,277,898
96				11,317,537	16,976,306	22,635,075

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	16	23	33	76	Pressure drop pipe with these	g si
3/4	40	57	80	127		
1	84	118	167			
1-1/4	193	272	385	227	340	1,044
1-1/2	305	431	609	312	469	
2	631	893	1,263	522	783	
Notes:	1,050	1,485	with	749	1,124	1,498
1-1/2	1,950	2,758	sizes	1,168	1,751	2,335
3	4,189			2,032	3,048	4,065
4						

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1

Pipe Size	Pressure Drop psig/100 ft. pipe	governs	Velocity From (ft/min)	Velocity From (mph)		
5	7,835		3,216	4,824	8,412	8
6			4,608	6,912	9,215	1
8	0.125	0.25	8,472 (23)	12,108 3,000 (34)	16,144 4,000 (45)	5
10	Velocity		13,198	19,797	26,396	3
12	these		19,168	28,751	38,335	4
14			23,463	35,194	46,925	5
16			31,237	46,856	62,475	7
18			40,123	60,184	80,245	1
20			50,119	75,178	100,237	1
22			61,225	91,838	122,450	1
24			73,442	110,164	146,885	1
26			86,770	130,155	173,541	2
28			101,209	151,813	202,418	2
30			116,758	175,137	233,516	2
32			133,418	200,127	266,836	3
34			151,189	226,783	302,377	3
36			170,070	255,105	340,140	4
42			233,377	350,066	466,755	5
48			306,681	460,021	613,362	7
54			389,980	584,971	779,961	9
60			483,276	724,914	966,552	1
72			699,855	1,049,782	1,399,709	1
84			956,417	1,434,626	1,912,834	2
96			1,252,963	1,879,445	2,505,926	3

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	20	29	41	182	Pressure	drop pipe	g
3/4	50	70	100		with these		si
1	104	147	209				
1-	240	339	480	324	669	1,491	
1/4	380	537	759	446	1,118		
1-	787	1,113	1,573	746			
1/2							
2							
Notes:	1,308	1,850	2,616	1,070	1,605	2,140	4

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)					
4	2,428 5,219	3,436		1,668 2,903	2,502 4,355	3,336 5,806	7
5	0.125 9,762	0.25 governs	0.5 with	2,000 4,592	3,000 (34) 6,891	4,000 (45) 9,188	5 1
6	15,871	pipe	sizes	6,582	9,873	13,164	1
8				11,530	17,296	23,061	2
10	Velocity			18,853	28,279	37,706	4
12	these			27,381	41,071	54,761	6
14				33,516	50,274	67,032	8
16				44,622	66,933	89,244	1
18				57,315	85,972	114,629	1
20				71,594	107,391	143,187	1
22				87,459	131,189	174,919	2
24				104,912	157,367	209,823	2
26				123,950	185,925	247,901	3
28				144,576	216,863	289,151	3
30				166,787	250,181	333,575	4
32				190,586	285,879	381,172	4
34				215,971	323,956	431,942	5
36				242,943	364,414	485,885	6
42				333,377	500,065	666,753	8
48				438,090	657,135	876,180	1
54				557,082	835,623	1,114,164	1
60				690,353	1,035,530	1,380,707	1
72				999,733	1,499,600	1,999,467	2
84				1,366,230	2,049,344	2,732,459	3
96				1,789,842	2,684,763	3,579,684	4

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	22	31	44	205	Pressure	drop pipe	g
3/4	54	76	107		with these		si
1	113	159	225				
Notes:	259	366	518	366	756	1,684	
1/4	410	579	819	504	1,263		
1-	849	1,201	1,698	842			
1-1/2							

1- Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	2-	1,412	1,997	2,824	1,209	1,813	2,417
1/2	2,622	3,709	5,000	1,883	2,825	3,767	5
3	5,634	7,968	10,537	3,278	4,918	6,557	8
4							
5	10,537	governs	with	5,188	7,782	10,376	1
6	17,131	pipe	sizes	7,433	11,149	14,866	1
8				13,021	19,532	26,042	3
10	Velocity			21,290	31,935	42,580	5
12	these			30,920	46,380	61,840	7
14				37,849	56,773	75,698	9
16				50,391	75,586	100,781	1
18				64,724	97,086	129,448	1
20				80,849	121,273	161,698	2
22				98,766	148,148	197,531	2
24				118,474	177,711	236,948	2
26				139,974	209,961	279,948	3
28				163,266	244,898	326,531	4
30				188,349	282,523	376,698	4
32				215,224	322,836	430,448	5
34				243,891	365,836	487,781	6
36				274,349	411,523	548,698	6
42				376,474	564,711	752,948	9
48				494,724	742,086	989,448	1
54				629,099	943,648	1,258,198	1
60				779,599	1,169,398	1,559,198	1
72				1,128,974	1,693,461	2,257,948	2
84				1,542,849	2,314,273	3,085,697	3
96				2,021,224	3,031,835	4,042,447	5
Steam Condensate Flow lbs./h 10 psig Back Pressure							
1/2	24	34	49	242	Pressure	drop pipe	g
3/4	60	84	119		with these		si
1	125	177	250				
Notes:	288	407	575	431	891		

Pipe Size	Pressure	Drop	psig	100	594	1,490	Velocity FPM (mph)	
	942	1,183	1,885	993				
1/2	0.125	0.25	0.5	2,000	3,000 (34)	4,000 (45)	5	
2								
2-1/2	1,567	2,216	3,135	1,425	2,138	2,851	5	
3	2,911	4,116		2,221	3,332	4,443	9	
4	6,253	8,844		3,867	5,800	7,733		
5	11,696	governs pipe	with sizes	6,119	9,178	12,238	1	
6	19,015			8,767	13,150	17,534	2	
8				15,358	23,037	30,715	3	
10	Velocity these			25,111	37,666	50,221	6	
12				36,469	54,703	72,938	9	
14				44,641	66,961	89,282	1	
16				59,433	89,150	118,866	1	
18				76,339	114,508	152,677	1	
20				95,357	143,036	190,715	2	
22				116,489	174,734	232,978	2	
24				139,734	209,601	279,468	3	
26				165,092	247,638	330,184	4	
28				192,564	288,845	385,127	4	
30				222,148	333,222	444,296	5	
32				253,846	380,769	507,692	6	
34				287,657	431,485	575,313	7	
36				323,581	485,371	647,161	8	
42				444,032	666,048	888,064	1	
48				583,502	875,253	1,167,004	1	
54				741,990	1,112,986	1,483,981	1	
60				919,497	1,379,246	1,838,995	2	
72				1,331,568	1,997,351	2,663,135	3	
84				1,819,712	2,729,568	3,639,424	4	
96				2,383,931	3,575,897	4,767,863	5	

Steam Condensate Flow lbs./h 12 psig Back Pressure

Notes:	26	37	52		Pressure	drop pipe	g
2/4	61	90	127		with these		ci

Pipe Size	Pressure Drop psig/100 ft.				Velocity FPM (mph)		SI
	04 133	50 188	127 267		with these		
1-	307	434	614	477	1,648		
1/4	465 (125)	686 (225)	970.5	658 (23)	3,000 (34)	4,000 (45)	5
1-	1,005	1,422	2,011	1,099			
1/2							
2-	1,672	2,364	3,344	1,577	2,365	3,154	6
1/2	3,105	4,391		2,458	3,686	4,915	1
3	6,671	9,434		4,278	6,417	8,555	
4							
5	12,476	governs	with	6,769	10,154	13,539	1
6	20,284	pipe	sizes	9,699	14,548	19,398	2
8				16,990	25,486	33,981	4
10	Velocity			27,780	41,670	55,560	6
12	these			40,346	60,519	80,692	1
14				49,387	74,080	98,774	1
16				65,752	98,627	131,503	1
18				84,454	126,681	168,909	2
20				105,495	158,242	210,990	2
22				128,873	193,310	257,746	3
24				154,589	231,884	309,179	3
26				182,643	273,965	365,287	4
28				213,035	319,553	426,070	5
30				245,765	368,647	491,530	6
32				280,832	421,249	561,665	7
34				318,238	477,357	636,476	7
36				357,981	536,972	715,962	8
42				491,238	736,856	982,475	1
48				645,535	968,302	1,291,070	1
54				820,872	1,231,309	1,641,745	2
60				1,017,251	1,525,876	2,034,501	2
72				1,473,128	2,209,693	2,946,257	3
84				2,013,168	3,019,753	4,026,337	5
96				2,637,370	3,956,056	5,274,741	6

Steam Condensate Flow lbs./h 15 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.			2,000 (23)	Velocity FPM (mph)		
	0.125	0.25	0.5		Pressure with these	drop pipe	g si
3/4	70	99	139				
1	146	206	292		3,000 (34)	4,000 (45)	5
1-1/4	336	475	672	549	1,897		
1-1/2	531	751	1,062	757			
2	1,101	1,557	2,202	1,264			
2-1/2	1,830	2,589	3,661	1,815	2,722	3,630	1
3	3,400	4,808	6,799	2,828	4,243	5,657	
4	7,304	10,329		4,923	7,385	9,846	
5	13,660	19,318	with sizes	7,791	11,686	15,581	1
6	22,208			11,162	16,743	22,324	2
8	47,023			19,553	29,330	39,107	4
10	Velocity governs these pipe			31,971	47,956	63,942	7
12				46,432	69,648	92,864	1
14				56,837	85,255	113,674	1
16				75,670	113,506	151,341	1
18				97,194	145,792	194,389	2
20				121,409	182,113	242,818	3
22				148,314	222,471	296,628	3
24				177,910	266,864	355,819	4
26				210,196	315,293	420,391	5
28				245,172	367,758	490,344	6
30				282,839	424,259	565,678	7
32				323,197	484,795	646,394	8
34				366,245	549,367	732,490	9
36				411,983	617,975	823,967	1
42				565,342	848,013	1,130,684	1
48				742,915	1,114,373	1,485,831	1
54				944,703	1,417,055	1,889,406	2
60				1,170,706	1,756,058	2,341,411	2
Notes:				1,695,354	2,543,031	3,390,708	4

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			5 7
	2,316,860 3,035,225			3,475,290 4,552,837	4,633,721 6,070,450		
Steam Condensate Flow, lbs./h 20 psig Back Pressure							
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	5
1/2	33	46	65		Pressure	drop pipe	g
3/4	80	113	160		with these		si
1	168	237	335				
1-1/4	386	545	771	678	2,343		
1-1/2	610	862	1,220	935			
2	1,264	1,788	2,528	1,562			
2-1/2	2,102	2,973	4,204	2,242	3,363	6,987	1
3	3,904	5,521	7,808	3,494	5,240	12,162	
4	8,387	11,861		6,081	9,121		
5	15,687	22,184		9,623	14,434	19,246	2
6	25,503			13,787	20,680	27,574	3
8	53,998			24,152	36,228	48,304	6
10				39,490	59,234	78,979	9
12				57,352	86,028	114,704	1
14				70,204	105,306	140,408	1
16	Velocity	governs	with	93,467	140,200	186,933	2
18	these	pipe	sizes	120,053	180,079	240,105	3
20				149,962	224,943	299,924	3
22				183,195	274,792	366,389	4
24				219,750	329,625	439,501	5
26				259,629	389,444	519,259	6
28				302,832	454,248	605,663	7
30				349,357	524,036	698,715	8
32				399,206	598,809	798,412	9
34				452,378	678,567	904,757	1
36				508,874	763,310	1,017,747	1
42				698,299	1,047,449	1,396,598	1
Notes:				917,634	1,376,451	1,835,268	2
54				1,166,878	1,750,318	2,322,757	2

54				1,100,878	1,750,518	2,555,157	2
60				1,446,032	2,169,048	2,892,064	3
72				2,094,067	3,141,100	4,188,134	5
84	0.125	0.25	0.5	2,861,739 2,000 (23)	3,000 (34)	4,000 (45)	5
96				3,749,048	5,623,573	7,498,097	9

Steam Condensate Flow lbs./h 25 psig Back Pressure

1/2	37	52	74		Pressure	drop pipe	g
3/4	91	128	181		with these		si
1	190	269	380				
1-	437	619	875	819	2,830		
1/4	692	978	1,383	1,129			
1-	1,434	2,027	2,867	1,886			
1/2							
2							
2-	2,384	3,371	4,768	2,708	4,061	8,439	1
1/2	4,427	6,261	8,854	4,220	6,330	14,689	
3	9,512	13,451		7,345	11,017		
4							
5	17,790	25,158	with	11,623	17,435	23,246	2
6	28,922	40,902	sizes	16,653	24,979	33,305	4
8	61,238			29,172	43,758	58,344	7
10	117,400	governs		47,698	71,546	95,395	1
12		pipe		69,273	103,909	138,546	1
14				84,796	127,194	169,591	2
16	Velocity			112,894	169,340	225,787	2
18	these			145,006	217,508	290,011	3
20				181,132	271,697	362,263	4
22				221,272	331,907	442,543	5
24				265,426	398,138	530,851	6
26				313,593	470,390	627,187	7
28				365,775	548,663	731,551	9
30				421,971	632,957	843,943	1
32				482,181	723,272	964,363	1
Notes:				546,405	819,608	1,092,811	1
36				614,643	921,965	1,229,286	1

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft. / 5.0 ft/s

42	Pressure Drop psig/100 ft.	0.125	0.25	0.5	843,441	1,265,162	1,686,882	2
48					1,108,365	1,662,547	2,216,730	2
54					1,409,415	2,114,122	2,818,829	3
60					1,746,590 (23)	2,619,885 (34)	3,493,181 (45)	4
72					2,529,320	3,793,980	5,058,639	6
84					3,456,553	5,184,829	6,913,106	8
96					4,528,290	6,792,435	9,056,580	1

Steam Condensate Flow lbs./h 30 psig Back Pressure

1/2	42	59	83		Pressure with these	drop pipe	g si
3/4	102	144	204				
1	214	302	427				
1-	492	695	983	974			
1/4	777	1,099	1,554	1,341			
1-	1,611	2,278	3,222	2,241			
1/2							
2							
2-	2,679	3,788	5,358	3,217	4,825	17,452	
1/2	4,975	7,036	9,950	5,013	7,520		
3	10,689	15,116	21,377	8,726	13,089		
4							
5	19,991	28,272	with	13,809	20,713	27,618	3
6	32,501	45,963	sizes	19,784	29,676	39,568	4
8	68,816			34,658	51,987	69,316	8
10	131,928	governs pipe		56,667	85,001	113,335	1
12				82,300	123,450	164,600	2
14				100,742	151,113	201,484	2
16	Velocity these			134,124	201,186	268,248	3
18				172,275	258,412	344,549	4
20				215,194	322,791	430,389	5
22				262,883	394,324	525,765	6
24				315,340	473,010	630,680	7
26				372,566	558,849	745,133	9
Notes:				434,561	651,842	869,123	1
30				501,325	751,988	1,002,650	1
32				572,858	859,287	1,145,716	1

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Flow Rate (gpm)	Velocity (ft/min)	Flow Rate (gpm)	Velocity (ft/min)
34				649,159	977	977	1
36				730,230	1,095,345	1,460,460	1
42	0.125	0.25	0.5	1,202,954 (23)	1,503,081 3,000 (34)	2,004,108 4,000 (45)	5
48				1,316,798	1,975,197	2,633,596	3
54				1,674,462	2,511,693	3,348,924	4
60				2,075,045	3,112,567	4,150,090	5
72				3,004,970	4,507,456	6,009,941	7
84				4,106,574	6,159,861	8,213,148	1
96				5,379,857	8,069,785	10,759,713	1

Steam Condensate Flow lbs./h 40 psig Back Pressure

Pipe Size	51	73	103		Pressure with these	drop pipe	g si
1/2	51	73	103				
3/4	126	178	252				
1	264	374	528				
1-	608	860	1,216	1,822			
1/4	961	1,360	1,923	3,045			
1-	1,993	2,818	3,985				
1/2							
2							
2-	3,314	4,686	6,627	4,371	6,556	23,712	
1/2	6,154	8,703	12,308	6,812	10,217		
3	13,221	18,698	26,443	11,856	17,784		
4							
5	24,728	34,971	with	18,762	28,143	37,524	4
6	40,202	56,855	sizes	26,881	40,322	53,762	6
8	85,123			47,090	70,636	94,181	1
10	163,190	governs		76,995	115,492	153,990	1
12	266,367	pipe		111,822	167,734	223,645	2
14				136,880	205,320	273,760	3
16	Velocity			182,237	273,355	364,473	4
18	these			234,073	351,109	468,146	5
20				292,389	438,583	584,777	7
22				357,184	535,776	714,368	8
24				428,459	642,688	856,917	1
26				506,213	759,319	1,012,426	1

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000	3,000 (34)	4,000 (45)	
28				590,447	885,670	1,180,893	1
30				681,160	1,021,740	1,362,520	1
32				778,353	1,167,529	1,556,706	1
34	0.125	0.25	0.5	882,225	3,000 (34)	4,000 (45)	5
36				992,177	1,488,266	1,984,354	2
42				1,361,510	2,042,265	2,723,020	3
48				1,789,159	2,683,738	3,578,317	4
54				2,275,123	3,412,684	4,550,246	5
60				2,819,403	4,229,104	5,638,806	7
72				4,082,910	6,124,365	8,165,820	1
84				5,579,680	8,369,520	11,159,360	1
96				7,309,713	10,964,569	14,619,426	1

Steam Condensate Flow lbs./h 50 psig Back Pressure

Pipe Size	63	89	125		Pressure with these	drop pipe	g si
1/2	63	89	125				
3/4	154	217	307				
1	322	455	644				
1-	741	1,048	1,482	4,020			
1/4	1,172	1,657	2,344				
1-	2,429	3,435	4,858				
1/2							
2							
2-	4,039	5,712	8,078	5,770	13,489	31,305	
1/2	7,501	10,609	15,003	8,993	23,479		
3	16,116	22,792	32,233	15,653			
4							
5	30,143	42,628	60,285	24,770	37,155	49,540	8
6	49,005	69,303		35,489	53,234	70,978	1
8	103,761	146,740		62,170	93,254	124,339	
10	198,921	governs	with	101,650	152,475	203,300	2
12	324,688	pipe	sizes	147,630	221,445	295,260	3
14	422,847			180,711	271,067	361,422	4
16	Velocity			240,592	360,888	481,184	6
18	these			309,027	463,540	618,054	7
20				386,016	579,024	772,032	9
Notes:				471,560	707,340	943,120	1

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)	
24				565,658	848,487	1,131,316	1
26				668,310	1,002,466	1,336,621	1
28	0.125	0.25	0.5	779,517	1,169,276	1,559,035	1
30				899,279	1,348,918	1,798,557	2
32				1,027,594	1,541,391	2,055,188	2
34				1,164,464	1,746,696	2,328,928	2
36				1,309,889	1,964,833	2,619,777	3
42				1,797,488	2,696,232	3,594,976	4
48				2,362,077	3,543,115	4,724,153	5
54				3,003,655	4,505,482	6,007,309	7
60				3,722,222	5,583,333	7,444,444	9
72				5,390,325	8,085,487	10,780,650	1
84				7,366,385	11,049,578	14,732,771	1
96				9,650,403	14,475,605	19,300,806	2

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2	15	22	31	72	Pressure drop pipe with these	
3/4	38	53	75	119		
1	79	111	157			
1-	181	256	362	213	319	980
1/4	286	404	572	293	440	
1-	593	838	1,185	490	735	
1/2						
2						

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
2	985	703
1/2	1,830	1,055
3	3,931	1,406
4	0.125	0.25
		0.5
		2,000 (23)
		3,000 (34)
		4,000 (45)
5	7,353	3,018
6		4,324
8		7,575
10		12,385
12		17,987
14		22,018
16	Velocity	governs
18	these	pipe
20		with
		sizes
		29,314
		43,971
		58,628
22		37,652
24		56,478
26		70,549
		94,065
28		57,455
30		86,183
32		114,911
		137,841
		162,855
34		94,977
36		142,466
42		189,954
		219,138
		250,406
48		141,880
54		212,819
60		283,759
		319,196
		438,016
72		287,798
84		431,697
96		575,596
		731,937
		907,039
		1,313,526
		1,795,056
		2,351,631

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	19	27	38	169	Pressure	drop pipe
3/4	46	66	93		with these	
1	97	138	195			
Notes:	224	317	448	302	624	1,391
1/4	354	501	708	416	1,043	
1-	734	1,038	1,468	696		

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
2-1/2	1,025 2,266	1,025 3,205	2,045	2,980 (23) 1,556	3,000 (34) 2,334	4,900 (45) 3,112
3	4,869			2,708	4,062	5,416
4						
5	9,106	governs	with	4,285	6,428	8,571
6	14,805	pipe	sizes	6,140	9,210	12,280
8				10,756	16,134	21,512
10	Velocity			17,586	26,379	35,172
12	these			25,541	38,312	51,082
14				31,264	46,896	62,529
16				41,624	62,436	83,248
18				53,464	80,196	106,928
20				66,784	100,175	133,567
22				81,583	122,375	163,166
24				97,863	146,794	195,726
26				115,622	173,434	231,245
28				134,862	202,293	269,724
30				155,582	233,372	311,163
32				177,781	266,672	355,562
34				201,461	302,191	402,921
36				226,620	339,930	453,240
42				310,978	466,467	621,956
48				408,656	612,984	817,312
54				519,654	779,481	1,039,307
60				643,971	965,957	1,287,942
72				932,565	1,398,847	1,865,129
84				1,274,437	1,911,656	2,548,875
96				1,669,589	2,504,383	3,339,177

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	20	29	41	191	Pressure with these	drop pipe
3/4	50	71	100			
1	105	148	209			

Pipe Size	Pressure Drop psig/100 ft.	341	482	340	703	1,567
		530	762	469	1,175	
1-1/2	790	1,118	1,580	784		
2	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
2-1/2	1,314	1,858	2,628	1,125	1,687	2,249
3	2,440	3,451		1,753	2,629	3,506
4	5,243	7,415		3,051	4,576	6,102
5	9,806	governs	with	4,828	7,242	9,656
6	15,942	pipe	sizes	6,917	10,376	13,834
8				12,118	18,176	24,235
10	Velocity			19,813	29,719	39,625
12	these			28,775	43,162	57,549
14				35,223	52,834	70,445
16				46,894	70,341	93,788
18				60,233	90,349	120,465
20				75,239	112,858	150,477
22				91,912	137,868	183,824
24				110,253	165,379	220,505
26				130,261	195,391	260,522
28				151,936	227,904	303,872
30				175,279	262,918	350,558
32				200,289	300,433	400,578
34				226,966	340,450	453,933
36				255,311	382,967	510,622
42				350,349	525,524	700,699
48				460,394	690,590	920,787
54				585,444	878,166	1,170,888
60				725,500	1,088,250	1,451,001
72				1,050,631	1,575,947	2,101,262
84				1,435,786	2,153,679	2,871,572
96				1,880,965	2,821,448	3,761,931

Steam Condensate Flow lbs./h 10 psig Back Pressure

Notes: 23

32

45

224

Pressure

drop pipe

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)	with these	Velocity FPM (mph)	with these	Velocity FPM (mph)
1-1/4	207	307	533	2,000 (23)	3,200 (34)	4,000 (45)
1-1/2	422	596	843	551	1,382	
2	874	1,236	1,748	921		
2-1/2	1,453	2,056	2,907	1,322	1,983	2,644
3	2,699	3,818		2,060	3,090	4,120
4	5,800	8,202		3,586	5,379	7,172
5	10,847	governs	with	5,675	8,512	11,350
6	17,635	pipe	sizes	8,130	12,196	16,261
8				14,243	21,364	28,486
10	Velocity			23,288	34,932	46,576
12	these			33,822	50,733	67,643
14				41,401	62,101	82,801
16				55,119	82,679	110,238
18				70,798	106,196	141,595
20				88,436	132,653	176,871
22				108,034	162,050	216,067
24				129,591	194,387	259,183
26				153,109	229,663	306,218
28				178,586	267,879	357,172
30				206,023	309,035	412,046
32				235,420	353,130	470,840
34				266,777	400,165	533,554
36				300,093	450,140	600,187
42				411,802	617,702	823,603
48				541,148	811,722	1,082,296
54				688,132	1,032,199	1,376,265
60				852,755	1,279,132	1,705,510
Notes:				1,234,915	1,852,372	2,469,829
84				1,687,627	2,531,440	3,375,254
96				2,210,892	3,316,337	4,421,783

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.			Back Pressure	Velocity FPM (mph)	
	0.125	0.25	0.5		3,000 (34) with these	4,000 (45)
1/2	24	34	48	2,000 (23)	3,000 (34) with these	4,000 (45)
3/4	59	83	118			
1	123	174	247			
1-1/4	284	401	568	442	1,525	
1-1/2	449	635	898	608		
2	930	1,316	1,861	1,017		
2-1/2	1,547	2,188	3,094	1,459		
3	2,873	4,063		2,274	2,189	2,918
4	6,172	8,729		3,958	3,411	4,548
5	11,544	governs pipe	with sizes	6,264	5,937	7,916
6	18,768			8,974	9,396	12,527
8				15,721	13,461	17,948
10	Velocity these			25,704	23,581	31,442
12				37,331	38,557	51,409
14				45,697	55,997	74,663
16				60,839	68,545	91,394
18				78,144	91,258	121,678
20				97,613	117,216	156,288
22				119,244	146,419	195,225
24				143,039	178,866	238,488
26				168,997	214,558	286,078
28				197,118	253,495	337,994
30				227,402	295,677	394,236
32				259,850	341,103	454,804
34				294,460	389,774	519,699
36				331,234	441,690	588,920
42				454,534	496,851	662,468
48				597,303	681,801	909,068
54				759,540	895,954	1,194,605
60				941,245	1,139,310	1,519,079
					1,411,868	1,882,490

72 84 96 Pipe Size	Pressure Drop psig/100 ft.			1,363,061	2,044,592	2,726,123
				1,862,752	2,794,127	3,725,503
	0.125	0.25	0.5	2,440,315	3,660,473	4,880,631
				2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 15 psig Back Pressure

1/2	26	37	52		Pressure	drop pipe
3/4	64	91	128		with these	
1	135	190	269			
1-	310	438	619	507	1,749	
1/4	490	693	979	698		
1-	1,015	1,435	2,030	1,166		
1/2						
2						
2-	1,688	2,387	3,376	1,674	2,510	3,347
1/2	3,135	4,433	6,269	2,608	3,912	5,216
3	6,735	9,524		4,540	6,809	9,079
4						
5	12,596	17,814	with	7,184	10,776	14,368
6	20,478		sizes	10,293	15,439	20,585
8	43,360			18,031	27,046	36,061
10	Velocity	governs		29,481	44,221	58,961
12	these	pipe		42,816	64,224	85,632
14				52,410	78,615	104,820
16				69,777	104,665	139,554
18				89,624	134,437	179,249
20				111,953	167,929	223,906
22				136,762	205,144	273,525
24				164,053	246,079	328,106
26				193,824	290,737	387,649
28				226,077	339,115	452,153
30				260,810	391,215	521,620
32				298,024	447,036	596,049
34				337,720	506,579	675,439
36				379,896	569,844	759,791
42				521,310	781,965	1,042,620
Notes:				685.053	1.027.579	1.370.106

Pipe Size	Pressure Drop psig/100 ft.	871,124	1,306,686	1,742,248
60		1,079,524	1,619,286	2,159,048
72	0.125	0.25	0.5	2,000 (23)
84				3,000 (34)
96				4,000 (45)

Steam Condensate Flow lbs./h 20 psig Back Pressure

Pipe Size	Pressure Drop psig/100 ft.	871,124	1,306,686	1,742,248
1/2	30	42	60	Pressure drop pipe
3/4	73	104	147	with these
1	154	217	307	
1-	354	500	707	622
1/4	559	791	1,118	857
1-	1,159	1,639	2,318	1,432
1/2				
2				
2-	1,927	2,725	3,854	2,055
1/2	3,579	5,061	7,158	3,203
3	7,689	10,874		5,575
4				
5	14,381	20,338	with	8,822
6	23,381		sizes	12,640
8	49,505			22,142
10	Velocity	governs		36,204
12	these	pipe		52,580
14				64,362
16				85,689
18				110,063
20				137,484
22				167,951
24				201,465
26				238,026
28				277,633
30				320,287
32				365,988
Notes:				414,736

36 Pipe 42 Size	Pressure Drop psig/100 ft.			466,530 640,194	699,796 960,200	933,061 1,200,000
48 54 60	0.125	0.25	0.5	841,278 2,000 (23) 1,069,783	1,261,917 3,000 (34) 1,604,674	1,682,556 4,000 (45) 2,139,566
72 84 96				1,325,708 1,919,821 2,623,615 3,437,092	1,988,562 2,879,731 3,935,423 5,155,638	2,651,417 3,839,641 5,247,230 6,874,184

Steam Condensate Flow lbs./h 25 psig Back Pressure

1/2 3/4 1	34 83 173	48 117 245	67 165 346		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	399 630 1,307	564 891 1,848	797 1,261 2,613	747 1,029 1,719	2,579	
2- 1/2 3 4	2,173 4,035 8,669	3,072 5,706 12,259	4,345 8,070	2,468 3,846 6,694	3,702 5,769 10,041	7,692 13,388
5 6 8	16,213 26,359 55,812	22,929 37,278		10,593 15,177 26,587	15,890 22,766 39,881	21,186 30,354 53,174
10 12 14	106,997			43,471 63,135 77,282	65,207 94,702 115,923	86,942 126,269 154,564
16 18 20	Velocity these	governs pipe	with sizes	102,890 132,157 165,082	154,336 198,236 247,623	205,781 264,314 330,164
22 24 26				201,665 241,907 285,807	302,498 362,860 428,710	403,330 483,814 571,613
Notes: 30				333,365 384,582	500,047 576,872	666,730 769,163

Pipe Size	Pressure Drop psig/100 ft.			439,456	659,185	878,913
				Velocity FPM (mph)		
36	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
42				560,181	840,272	1,120,363
48				768,706	1,153,059	1,537,412
54				1,010,155	1,515,233	2,020,311
60				1,284,530	1,926,795	2,569,060
66				1,591,829	2,387,744	3,183,658
72				2,305,203	3,457,804	4,610,405
84				3,150,276	4,725,414	6,300,552
96				4,127,049	6,190,574	8,254,098

Steam Condensate Flow lbs./h 30 psig Back Pressure

1/2	38	53	75		Pressure	drop pipe
3/4	92	131	185		with these	
1	193	274	387			
1-	445	630	891	882		
1/4	704	996	1,408	1,215		
1-	1,459	2,064	2,919	2,030		
1/2						
2						
2-	2,427	3,432	4,853	2,914	4,371	15,809
1/2	4,507	6,374	9,014	4,541	6,812	
3	9,683	13,693	19,365	7,905	11,857	
4						
5	18,110	25,611	with	12,509	18,764	25,018
6	29,442	41,637	sizes	17,922	26,883	35,844
8	62,339			31,396	47,094	62,792
10	119,511	governs		51,334	77,001	102,668
12		pipe		74,554	111,831	149,108
14				91,260	136,890	182,521
16	Velocity			121,500	182,251	243,001
18	these			156,061	234,091	312,121
20				194,941	292,411	389,881
Notes:				238,141	357,211	476,282
24				285,661	428,492	571,322
26				337,501	506,252	675,002

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
28				393,661	590,492	781,923
30				454,142	681,212	908,283
32				518,942	778,415	1,037,884
34				588,062	882,093	1,176,124
36				661,502	992,254	1,323,005
42				907,743	1,361,615	1,815,486
48				1,192,864	1,789,296	2,385,728
54				1,516,865	2,275,298	3,033,731
60				1,879,747	2,819,620	3,759,493
72				2,722,150	4,083,224	5,444,299
84				3,720,073	5,580,110	7,440,146
96				4,873,517	7,310,276	9,747,034

Steam Condensate Flow lbs./h 40 psig Back Pressure

Pipe Size	46	65	92		Pressure with these	drop pipe
1/2	46	65	92			
3/4	113	160	226			
1	236	334	472			
1-	544	769	1,087	1,630		
1/4	860	1,216	1,720	2,723		
1-	1,782	2,520	3,564			
1/2						
2						
2-	2,963	4,191	5,927	3,909	5,863	21,207
1/2	5,504	7,784	11,008	6,092	9,138	
3	11,824	16,722	23,649	10,603	15,905	
4						
5	22,115	31,276	with	16,780	25,170	33,560
6	35,955	50,848	sizes	24,041	36,061	48,082
8	76,129			42,115	63,172	84,230
10	145,947	governs		68,860	103,289	137,719
12	238,222	pipe		100,007	150,011	200,014
14				122,417	183,626	244,834
16	Velocity			162,981	244,472	325,963
18	these			209,341	314,011	418,681
20				261,495	392,242	522,989

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
26				319,444 383,187 452,726	479,165 574,781 679,089	638,887 766,375 905,452
28				528,060	792,090	1,056,120
30				609,188	913,783	1,218,377
32				696,112	1,044,168	1,392,224
34				788,830	1,183,245	1,577,660
36				887,343	1,331,015	1,774,687
42				1,217,652	1,826,478	2,435,305
48				1,600,115	2,400,173	3,200,231
54				2,034,733	3,052,099	4,069,465
60				2,521,504	3,782,256	5,043,007
72				3,651,508	5,477,262	7,303,016
84				4,990,129	7,485,193	9,980,258
96				6,537,366	9,806,049	13,074,732

Steam Condensate Flow lbs./h 50 psig Back Pressure

					Pressure with these	drop pipe
1/2	55	78	111			
3/4	136	192	271			
1	284	401	568			
1-	653	924	1,307	3,545		
1/4	1,033	1,461	2,067			
1-	2,142	3,029	4,283			
1/2						
2						
2-	3,561	5,037	7,123	5,088	11,894	27,603
1/2	6,614	9,354	13,229	7,929	20,702	
3	14,210	20,096	28,420	13,801		
4						
5	26,578	37,586	53,155	21,841	32,761	43,681
6	43,209	61,107		31,292	46,938	62,584
8	91,489	129,385		54,817	82,225	109,634
10	175,395	governs	with	89,628	134,442	179,256
12	286,288	pipe	sizes	130,170	195,255	260,340
14	372,838			159,339	239,008	318,678
Notes:	Velocity			212 137	318 206	424 275

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
10		212,137
12		272,479
14		340,363
16		415,789
18		498,759
20		589,271
22	0.125	2,000 (23)
24	0.25	3,000 (34)
26	0.5	4,000 (45)
28		687,325
30		792,922
32		906,062
34		1,026,745
36		1,154,970
42		1,584,902
48		2,082,718
54		2,648,418
60		3,282,001
72		4,752,821
84		6,495,176
96		8,509,067

Steam Condensate Flow lbs./h 60 psig Back Pressure

1/2	66	93	131		Pressure	drop pipe
3/4	161	227	321		with these	
1	337	476	673			
1-	775	1,096	1,549	4,497		
1/4	1,225	1,733	2,450			
1-	2,539	3,591	5,078			
1/2						
2						
2-	4,222	5,971	8,445	6,454	15,088	
1/2	7,842	11,090	15,684	10,059	26,262	
3	16,848	23,826	33,695	17,508		
4						
5	31,510	44,562	63,021	27,706	41,560	55,413
6	51,229	72,448		39,696	59,544	79,392
8	108,469	153,399		69,539	104,308	139,078
Notes:	207,948	governs	with	113,699	170,549	227,399

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
12	339,422			165,129	247,694	330,259
14	442,035			202,132	305,199	404,264
16	Velocity these	0.25	0.5	269,111	403,666	538,221
18				345,658	518,487	691,316
20				431,773	647,660	863,546
22				527,457	791,186	1,054,914
24				632,709	949,064	1,265,419
26				747,530	1,121,295	1,495,060
28				871,919	1,307,878	1,743,838
30				1,005,876	1,508,814	2,011,752
32				1,149,402	1,724,103	2,298,804
34				1,302,496	1,953,744	2,604,992
36				1,465,158	2,197,738	2,930,317
42				2,010,556	3,015,834	4,021,113
48				2,642,069	3,963,104	5,284,139
54				3,359,698	5,039,547	6,719,396
60				4,163,442	6,245,163	8,326,884
72				6,029,277	9,043,915	12,058,553
84				8,239,573	12,359,359	16,479,146
96				10,794,331	16,191,496	21,588,662

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/4	14	20	29	68	104	138
3/8	36	50	71	113	170	230
1/2	74	105	149	230	345	465

Steam Condensate Flow lbs./h 0 psig Back

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.	201	302	Velocity FPM (mph)		
1-1/4	271	383	541	201	302	416
1-1/2	501	793	1,122	2,000 (23)	3,000 (34)	4,000 (45)
2						
2-1/2	933	1,319		666	999	1,331
3	1,733	2,450		1,038	1,556	2,075
4	3,723			1,806	2,709	3,612
5	6,962			2,858	4,287	5,716
6				4,094	6,142	8,189
8				7,173	10,759	14,345
10				11,728	17,591	23,455
12				17,032	25,548	34,065
14				20,849	31,273	41,698
16	Velocity	governs	with	27,757	41,636	55,515
18	these	pipe	sizes	35,653	53,479	71,306
20				44,535	66,803	89,071
22				54,405	81,607	108,809
24				65,261	97,891	130,522
26				77,104	115,656	154,208
28				89,934	134,901	179,868
30				103,751	155,627	207,502
32				118,555	177,833	237,110
34				134,346	201,519	268,692
36				151,124	226,686	302,248
42				207,379	311,069	414,758
48				272,517	408,775	545,033
54				346,537	519,805	693,073
60				429,439	644,158	858,878
72				621,891	932,836	1,243,781
84				849,872	1,274,808	1,699,744
96				1,113,383	1,670,074	2,226,765

Steam Condensate Flow lbs./h 5 psig Back Pressure

Pipe Size	18 Pressure Drop psig/100 ft.	25 Pressure Drop psig/100 ft.	36 Pressure Drop psig/100 ft.	160 Pressure Drop psig/100 ft.	Pressure Velocity FPM (mph) with these	drop pipe Velocity FPM (mph)
1	92 0.125	130 0.25	183 0.5	2,000 (23)	3,000 (34)	4,000 (45)
1-1/4	211	298	422	285	588	1,311
1-1/2	334	472	667	392	983	
2	691	978	1,383	655		
2-1/2	1,150	1,626	2,300	941	1,411	1,881
3	2,136	3,020		1,466	2,199	2,932
4	4,588			2,552	3,828	5,104
5	8,581	governs	with	4,038	6,057	8,077
6	13,951	pipe	sizes	5,786	8,679	11,572
8				10,136	15,203	20,271
10	Velocity			16,572	24,858	33,144
12	these			24,068	36,102	48,137
14				29,462	44,192	58,923
16				39,224	58,836	78,448
18				50,381	75,572	100,762
20				62,933	94,399	125,866
22				76,879	115,319	153,758
24				92,220	138,330	184,440
26				108,956	163,434	217,911
28				127,086	190,629	254,172
30				146,611	219,916	293,222
32				167,530	251,295	335,061
34				189,844	284,767	379,689
36				213,553	320,330	427,106
42				293,047	439,571	586,095
48				385,093	577,640	770,186
54				489,691	734,536	979,381
60				606,840	910,260	1,213,680
Notes:				878,793	1,318,190	1,757,587
84				1,200,954	1,801,430	2,401,907

1. Maximum recommended drop velocity is 0.25 psi/100 ft. (15 ft/sec)

Pipe Size	Pressure Drop psig/100 ft.			1,573,321	2,359,981	3,146,642
	0.125	0.25	0.5	Velocity FPM (mph)		
1/2	19	27	38	180	Pressure	drop pipe
3/4	47	67	94		with these	
1	99	139	197			
1-	227	321	454	320	662	1,474
1/4	359	507	717	441	1,106	
1-	743	1,051	1,486	737		
1/2						
2						
2-	1,236	1,748	2,472	1,058	1,587	2,116
1/2	2,295	3,246		1,649	2,473	3,297
3	4,931	6,974		2,870	4,304	5,739
4						
5	9,223	governs	with	4,541	6,812	9,082
6	14,995	pipe	sizes	6,506	9,759	13,012
8				11,397	17,096	22,794
10	Velocity			18,635	27,952	37,270
12	these			27,064	40,596	54,128
14				33,129	49,693	66,258
16				44,106	66,160	88,213
18				56,652	84,978	113,305
20				70,766	106,150	141,533
22				86,449	129,673	172,897
24				103,699	155,549	207,398
26				122,518	183,777	245,036
28				142,905	214,357	285,810
30				164,860	247,290	329,720
32				188,384	282,575	376,767
34				213,475	320,213	426,951
36				240,135	360,203	480,270
42				329,524	494,287	659,049
Notes:				433,028	649,541	866,055
54				550,645	825,967	1,101,290
60				682,376	1,023,564	1,364,752

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	0.125	0.25	0.5	1	2	3
72				988,181	1,451,262	1,906,362
84				1,350,442	2,025,663	2,700,884
96	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	21	30	42	210	Pressure with these	drop pipe
3/4	52	73	104			
1	109	154	217			
1-	250	354	500	375	776	
1/4	396	559	791	517	1,296	
1-	820	1,159	1,640	864		
1/2						
2						
2-	1,363	1,928	2,727	1,240	1,860	2,480
1/2	2,532	3,581		1,932	2,899	3,865
3	5,440	7,693		3,364	5,045	6,727
4						
5	10,174	governs	with	5,323	7,984	10,646
6	16,541	pipe	sizes	7,626	11,440	15,253
8				13,360	20,040	26,720
10	Velocity			21,844	32,766	43,688
12	these			31,725	47,587	63,449
14				38,834	58,250	77,667
16				51,701	77,552	103,403
18				66,408	99,611	132,815
20				82,952	124,428	165,904
22				101,335	152,002	202,670
24				121,556	182,334	243,112
26				143,615	215,423	287,230
28				167,513	251,269	335,025
30				193,249	289,873	386,497
32				220,823	331,234	441,645
34				250,235	375,353	500,470
36				281,486	422,229	562,971
42				386,267	579,401	772,535

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
60				507,593 645,464 799,879	761,390 968,196 1,199,818	1,015,187 1,290,928 1,599,758
72				1,158,342	1,737,514	2,316,685
84				1,582,984	2,374,476	3,165,967
96				2,073,803	3,110,704	4,147,606

Steam Condensate Flow lbs./h 12 psig Back Pressure

Pipe Size	22	32	45		Pressure with these	drop pipe
3/4	55	78	110			
1	115	163	231			
1-	266	376	532	413	1,428	
1/4	420	594	840	570		
1-	871	1,232	1,742	952		
1/2						
2						
2-	1,448	2,048	2,897	1,366	2,049	2,732
1/2	2,690	3,804		2,129	3,194	4,258
3	5,779	8,173		3,706	5,559	7,412
4						
5	10,809	governs	with	5,865	8,797	11,729
6	17,573	pipe	sizes	8,402	12,604	16,805
8				14,719	22,079	29,439
10	Velocity			24,067	36,100	48,134
12	these			34,953	52,430	69,906
14				42,785	64,178	85,571
16				56,963	85,444	113,926
18				73,166	109,748	146,331
20				91,394	137,091	182,787
22				111,647	167,471	223,294
24				133,926	200,889	267,852
26				158,230	237,345	316,460
28				184,560	276,839	369,119
30				212,914	319,372	425,829
32				243,295	364,942	486,589
Notes:				275,700	413,550	551,400

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
36				273,700	413,550	551,400
42				310,131	465,196	620,263
48				425,576	638,363	851,151
54				559,248	838,875	1,118,497
60				711,149	1,066,724	1,422,299
72				881,278	1,321,917	1,762,557
84				1,276,221	1,914,331	2,552,441
96				1,744,075	2,616,113	3,488,151
				2,284,842	3,427,264	4,569,685

Steam Condensate Flow lbs./h 15 psig Back Pressure

1/2	24	35	49		Pressure with these	drop pipe
3/4	60	85	120			
1	126	178	251			
1-	289	409	578	473	1,633	
1/4	457	647	915	652		
1-	948	1,340	1,896	1,089		
1/2						
2						
2-	1,576	2,229	3,152	1,563	2,344	3,125
1/2	2,927	4,140	5,854	2,435	3,653	4,871
3	6,289	8,894		4,239	6,358	8,478
4						
5	11,762	16,634	with sizes	6,708	10,062	13,416
6	19,122			9,611	14,416	19,222
8	40,488			16,836	25,254	33,673
10	Velocity these	governs pipe		27,528	41,292	55,056
12				39,980	59,970	79,960
14				48,939	73,408	97,878
16				65,155	97,733	130,310
18				83,688	125,532	167,376
20				104,538	156,807	209,076
22				127,704	191,556	255,408
24				153,187	229,781	306,374
26				180,987	271,480	361,973
Notes:				211,103	316,654	422,206

30 Pipe 32 Size	Pressure Drop psig/100 ft.			243,536	365,303	487,071
				278,285	417,426	556,990
34 36 42	0.125	0.25	0.5	315,351 2,000 (23) 354,734 486,782	473,027 3,000 (34) 532,101 730,172	630,702 4,000 (45) 709,468 973,563
48 54 60				639,679 813,426 1,008,023	959,519 1,220,139 1,512,035	1,279,358 1,626,853 2,016,046
72 84 96				1,459,766 1,994,907 2,613,447	2,189,649 2,992,361 3,920,170	2,919,531 3,989,814 5,226,894

Steam Condensate Flow lbs./h 20 psig Back Pressure

1/2 3/4 1	28 68 143	39 96 202	56 136 286		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	329 520 1,077	465 735 1,523	657 1,039 2,155	578 797 1,331	1,996	
2- 1/2 3 4	1,791 3,327 7,148	2,533 4,705 10,108	3,583 6,654	1,910 2,977 5,182	2,866 4,466 7,773	5,955 10,364
5 6 8	13,368 21,734 46,018	18,905	with sizes	8,201 11,749 20,583	12,301 17,624 30,874	16,401 23,499 41,165
10 12 14	Velocity these	governs pipe		33,653 48,876 59,828	50,480 73,314 89,743	67,307 97,752 119,657
16 18 20				79,653 102,310 127,799	119,480 153,465 191,699	159,306 204,620 255,598
Notes: 24				156,120 187,273	234,180 280,910	312,240 374,547

Pipe Size	Pressure Drop psig/100 ft.			221,259	331,888	442,518
	0.125	0.25	0.5	Velocity FPM (mph)		
28				258,076	387,114	516,152
30				290,002 (23)	346,008 (34)	450,005 (45)
32				340,207	510,311	680,415
34				385,521	578,282	771,043
36				433,667	650,501	867,334
42				595,098	892,646	1,190,195
48				782,017	1,173,025	1,564,034
54				994,425	1,491,638	1,988,851
60				1,232,323	1,848,484	2,464,645
72				1,784,585	2,676,877	3,569,169
84				2,438,802	3,658,204	4,877,605
96				3,194,976	4,792,465	6,389,953

Steam Condensate Flow lbs./h 25 psig Back Pressure

1/2	31	44	62		Pressure with these	drop pipe
3/4	77	108	153			
1	160	227	320			
1-	369	522	738	691	2,386	
1/4	583	825	1,167	952		
1-	1,209	1,710	2,418	1,591		
1/2						
2-	2,010	2,843	4,021	2,283	3,425	7,117
1/2	3,734	5,280	7,467	3,559		
3	8,021	11,344		6,194		
4						
5	15,003	21,217		9,802	14,703	19,604
6	24,391	34,494		14,044		
8	51,644			24,602		
10	99,008			40,225	60,338	80,450
12				58,420		
14				71,511		
Notes:				95,208	142,811	190,415
18				122,289		
20				155,455		

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 lbs./h

20				152,755	229,155	305,510
Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
22				186,607	279,910	373,214
24				223,843	335,765	447,687
26	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
				264,465	396,698	528,931
28	Velocity	governs	with	308,472	462,709	616,945
30	these	pipe	sizes	355,865	533,797	711,729
32				406,642	609,963	813,284
34				460,804	691,207	921,609
36				518,352	777,528	1,036,704
42				711,306	1,066,959	1,422,612
48				934,726	1,402,090	1,869,453
54				1,188,613	1,782,920	2,377,226
60				1,472,966	2,209,450	2,945,933
72				2,133,072	3,199,608	4,266,144
84				2,915,043	4,372,565	5,830,086
96				3,818,880	5,728,320	7,637,760

Steam Condensate Flow lbs./h 30 psig Back Pressure

1/2	35	49	69		Pressure	drop pipe
3/4	85	120	170		with these	
1	178	252	356			
1-	410	580	820	812		
1/4	648	917	1,297	1,119		
1-	1,344	1,901	2,688	1,870		
1/2						
2						
2-	2,235	3,161	4,470	2,684	4,026	14,561
1/2	4,151	5,870	8,302	4,183	6,274	
3	8,918	12,612	17,836	7,281	10,921	
4						
5	16,680	23,589	with	11,522	17,282	23,043
6	27,118	38,350	sizes	16,507	24,761	33,015
8	57,418			28,917	43,376	57,835
Notes:	110,076	governs		47,281	70,922	94,563
12		pipe		68,668	103,002	137,336
1	Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000			84,056	126,083	168,111
14						

Pipe Size	Velocity	Pressure Drop psig/100 ft.			Velocity FPM (mph)	
	these					
20	0.125	0.25	0.5	111,908 143,740 179,551 2,000 (23)	167,862 215,610 269,326 3,000 (34)	223,817 287,480 359,101 4,000 (45)
22				219,340	329,010	438,680
24				263,109	394,663	526,218
26				310,856	466,285	621,713
28				362,583	543,874	725,166
30				418,288	627,432	836,577
32				477,973	716,959	955,945
34				541,636	812,454	1,083,272
36				609,278	913,918	1,218,557
42				836,079	1,254,119	1,672,159
48				1,098,691	1,648,036	2,197,381
54				1,397,113	2,095,669	2,794,226
60				1,731,346	2,597,018	3,462,691
72				2,507,243	3,760,865	5,014,486
84				3,426,383	5,139,575	6,852,766
96				4,488,766	6,733,149	8,977,532

Steam Condensate Flow lbs./h 40 psig Back Pressure

Pipe Size	42	59	84		Pressure with these	drop pipe
1/2	42	59	84			
3/4	103	146	206			
1	215	305	431			
1-	496	701	992	1,487		
1/4	784	1,109	1,569	2,484		
1-	1,626	2,299	3,251			
1/2						
2						
2-	2,703	3,823	5,407	3,566	5,349	19,345
1/2	5,021	7,100	10,041	5,557	8,336	
3	10,786	15,254	21,573	9,673	14,509	
4						
5	20,174	28,531		15,307	22,960	30,614
6	32,799	46,384		21,931	32,896	43,861
8	69,446			38,418	57,627	76,836
10	122,126			62,815	84,222	125,628

10 Pipe Size	133,136 Pressure Drop psig/100 ft.			62,815 91,229 111,671	94,223 136,842 167,507	125,630 182,457 223,343
16 18 20	0.125 Velocity these	0.25 governs pipe	0.5 with sizes	2,000 (23) 148,675 190,965 238,541	3,000 (34) 223,012 286,447 357,811	4,000 (45) 297,350 381,929 477,081
22 24 26				291,403 349,551 412,986	437,104 524,327 619,479	582,806 699,103 825,972
28 30 32				481,707 555,714 635,007	722,560 833,571 952,511	963,414 1,111,428 1,270,015
34 36 42				719,587 809,453 1,110,767	1,079,380 1,214,179 1,666,151	1,439,174 1,618,905 2,221,534
48 54 60				1,459,658 1,856,124 2,300,167	2,189,487 2,784,186 3,450,250	2,919,316 3,712,249 4,600,334
72 84 96				3,330,980 4,552,097 5,963,518	4,996,470 6,828,145 8,945,277	6,661,960 9,104,194 11,927,036

Steam Condensate Flow lbs./h 50 psig Back Pressure

1/2 3/4 1	50 122 256	71 173 362	100 245 513		Pressure with these	drop pipe
1- 1/4 1- 1/2 2	590 933 1,933	834 1,319 2,734	1,180 1,866 3,867	3,200		
2- 1/2 3 4	3,215 5,971 12,828	4,547 8,444 18,142	6,430 11,942 25,657	4,593 7,158 12,459	10,737 18,689	24,919
Notes:	23,993	33,932	47,987	19,717	29,576	39,434

Pipe Size	39,008 82,593	55,165 118,805	Pressure Drop, psig/100 ft.	28,249 49,487	42,374 74,230	56,498 98,975
10	158,340	governs pipe	with 0.5 sizes	80,813	121,370	161,826
12	258,451			2,000 (23)	3,000 (34)	4,000 (45)
14	336,585					
16	Velocity			191,510	287,265	383,020
18	these			245,984	368,976	491,968
20				307,267	460,901	614,535
22				375,360	563,040	750,720
24				450,262	675,392	900,523
26				531,973	797,959	1,063,945
28				620,493	930,739	1,240,986
30				715,822	1,073,733	1,431,645
32				817,961	1,226,942	1,635,922
34				926,909	1,390,364	1,853,818
36				1,042,666	1,563,999	2,085,333
42				1,430,793	2,146,190	2,861,587
48				1,880,204	2,820,306	3,760,408
54				2,390,898	3,586,346	4,781,795
60				2,962,874	4,444,312	5,925,749
72				4,290,678	6,436,017	8,581,356
84				5,863,615	8,795,422	11,727,229
96				7,681,684	11,522,526	15,363,368

Steam Condensate Flow lbs./h 60 psig Back Pressure

1/2	58	83	117		Pressure	drop pipe
3/4	143	203	287		with these	
1	300	425	601			
1-	692	978	1,383	4,014		
1/4	1,094	1,547	2,187			
1-	2,267	3,205	4,533			
1/2						
2						
Notes:	3,769	5,330	7,538	5,761	13,468	
1/2	7,000	9,899	14,000	8,979	23,442	
3	15,039	21,268	30,077	15,628		

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
5	28,127	39,778	56,254	24,732	37,097	49,463
6	49,728 9,125	64,670 0,25	0.5	35,434 2,000 (23)	52,131 3,000 (34)	70,987 4,000 (45)
8	96,823	136,929		62,073	93,109	124,145
10	185,621	governs pipe	with sizes	101,492	152,237	202,983
12	302,979			147,400	221,099	294,799
14	394,575			180,429	270,644	360,859
16	572,625			240,217	360,325	480,433
18				308,545	462,818	617,090
20				385,414	578,122	770,829
22	Velocity these			470,825	706,237	941,650
24				564,776	847,164	1,129,553
26				667,269	1,000,903	1,334,537
28				778,302	1,167,453	1,556,605
30				897,877	1,346,815	1,795,754
32				1,025,992	1,538,989	2,051,985
34				1,162,649	1,743,974	2,325,298
36				1,307,847	1,961,770	2,615,693
42				1,794,686	2,692,029	3,589,372
48				2,358,395	3,537,592	4,716,789
54				2,998,973	4,498,459	5,997,945
60				3,716,420	5,574,630	7,432,840
72				5,381,923	8,072,884	10,763,845
84				7,354,903	11,032,354	14,709,806
96				9,635,361	14,453,041	19,270,721

Steam Condensate Flow lbs./h 75 psig Back Pressure

1/2	73	104	147		Pressure with these	drop pipe
3/4	180	254	359			
1	376	532	753			
1-	866	1,225	1,732	5,481		
1/4	1,370	1,937	2,739			
1-	2,839	4,015	5,678			
1/2						
2						

Pipe Size	4,721 8,767	6,676 12,399	9,441 17,535	7,867 12,260	32,009	Velocity FPM (mph)
3	18,836	26,638	37,672	21,339	2,000 (23)	3,000 (34)
4	0.125	0.25	0.5			4,000 (45)
5	35,229	49,822	70,459	33,769	50,654	67,538
6	57,275	80,999	114,550	48,382	72,573	96,764
8	121,271	171,504		84,756	127,133	169,511
10	232,491	328,792	with sizes	138,579	207,869	277,158
12	379,483			201,263	301,895	402,527
14	494,206			246,363	369,544	492,726
16	717,216	governs pipe		327,998	491,997	655,996
18	992,077			421,295	631,943	842,591
20				526,255	789,382	1,052,509
22	Velocity these			642,876	964,314	1,285,752
24				771,160	1,156,740	1,542,320
26				911,106	1,366,659	1,822,211
28				1,062,714	1,594,071	2,125,427
30				1,225,984	1,838,976	2,451,968
32				1,400,916	2,101,374	2,801,832
34				1,587,511	2,381,266	3,175,021
36				1,785,767	2,678,651	3,571,534
42				2,450,510	3,675,765	4,901,020
48				3,220,212	4,830,318	6,440,424
54				4,094,874	6,142,310	8,189,747
60				5,074,495	7,611,742	10,148,989
72				7,348,614	11,022,922	14,697,229
84				10,042,572	15,063,858	20,085,144
96				13,156,367	19,734,550	26,312,734

Notes:

- 1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM**
- 2. Table based on heavy weight steel pipe using steam equations in Part 1**

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 0 psig Back Pressure						
1/2	14	20	28	65	Pressure with these	drop pipe
3/4	34	48	68	108		
1	71	100	142			
1-1/4	163	231	326	192	288	884
1-1/2	258	365	516	265	397	
2	535	756	1,070	442	663	
2-1/2	889	1,258	with sizes	635	952	1,269
3	1,652	2,336		989	1,484	1,978
4	3,549			1,722	2,582	3,443
5	6,638	governs pipe		2,724	4,087	5,449
6				3,903	5,855	7,807
8				6,838	10,257	13,676
10	Velocity these			11,180	16,771	22,361
12				16,238	24,357	32,475
14				19,876	29,815	39,753
16				26,463	39,694	52,925
18				33,990	50,985	67,979
20				42,458	63,687	84,915
22				51,867	77,800	103,733
24				62,216	93,325	124,433
26				73,507	110,261	147,014
28				85,739	128,608	171,477
30				98,911	148,367	197,822
32				113,025	169,537	226,049
Notes:				128,079	192,118	256,158
36				144,074	216,111	288,148

Pipe Size	Pressure Drop psig/100 ft.			197,705	296,557	395,410
	0.125	0.25	0.5	Velocity FPM (mph)		
48				259,804	389,706	519,607
54				2,300 (23)	3,500 (34)	4,600 (45)
60				409,405	614,108	818,811
72				592,879	889,319	1,185,759
84				810,225	1,215,338	1,620,450
96				1,061,443	1,592,165	2,122,887

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	17	24	34	152	Pressure with these	drop pipe
3/4	42	59	83			
1	87	123	174			
1-	200	283	401	270	559	1,245
1/4	317	448	634	372	934	
1-	657	929	1,313	622		
1/2						
2-	1,092	1,544	2,184	893	1,340	1,787
1/2	2,028	2,868		1,392	2,088	2,784
3	4,357			2,423	3,635	4,846
4						
5	8,148	governs pipe	with sizes	3,835	5,752	7,669
6	13,247			5,494	8,241	10,988
8				9,624	14,436	19,248
10	Velocity these			15,736	23,604	31,472
12				22,854	34,281	45,708
14				27,975	41,963	55,950
16				37,245	55,867	74,490
18				47,839	71,759	95,678
20				59,757	89,636	119,515
22				73,000	109,500	146,000
24				87,567	131,351	175,134
26				103,458	155,187	206,916
Notes:				120,674	181,011	241,347
30				139,213	208,820	278,427
32				159,177	238,616	318,155

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

32				155,877	238,818	318,155
Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
34				180,266	270,398	360,531
36				202,778	304,167	405,556
42	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
				278,261	417,392	556,525
48				365,663	548,494	731,326
54				464,983	697,474	929,965
60				576,221	864,331	1,152,442
72				834,453	1,251,679	1,668,905
84				1,140,358	1,710,537	2,280,716
96				1,493,937	2,240,905	2,987,874

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	18	26	36	170	Pressure with these	drop pipe
3/4	45	63	89			
1	93	132	187			
1-	215	304	430	304	627	1,397
1/4	340	481	680	418	1,048	
1-	705	996	1,409	699		
1/2						
2						
2-	1,172	1,657	2,343	1,003	1,504	2,006
1/2	2,176	3,077		1,563	2,344	3,126
3	4,675	6,612		2,720	4,081	5,441
4						
5	8,744	governs	with	4,305	6,458	8,610
6	14,216	pipe	sizes	6,168	9,252	12,336
8				10,805	16,208	21,611
10	Velocity			17,667	26,501	35,334
12	these			25,659	38,488	51,317
14				31,408	47,113	62,817
16				41,816	62,724	83,632
18				53,710	80,565	107,420
20				67,091	100,637	134,182
Notes:				81,959	122,939	163,918
24				98,314	147,471	196,627
26				116,155	174,233	232,310

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
32				135,483 156,298 178,600	203,225 234,448 267,900	270,967 312,597 357,200
34				202,389	303,583	404,778
36				227,664	341,496	455,328
42				312,411	468,616	624,822
48				410,539	615,808	821,078
54				522,048	783,072	1,044,096
60				646,938	970,407	1,293,876
72				936,861	1,405,292	1,873,722
84				1,280,309	1,920,463	2,560,617
96				1,677,281	2,515,921	3,354,561

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2	20	28	40	199	Pressure with these	drop pipe
3/4	49	69	98			
1	103	145	206			
1-	237	335	473	355	734	
1/4	374	529	748	489	1,226	
1-	776	1,097	1,551	817		
1/2						
2						
2-	1,290	1,824	2,579	1,173	1,759	2,346
1/2	2,395	3,387		1,828	2,742	3,656
3	5,146	7,277		3,182	4,773	6,364
4						
5	9,624	governs	with	5,035	7,553	10,070
6	15,647	pipe	sizes	7,214	10,821	14,428
8				12,638	18,956	25,275
10	Velocity			20,663	30,995	41,326
12	these			30,010	45,015	60,019
14				36,734	55,102	73,469
16				48,907	73,360	97,814
18				62,818	94,227	125,636
20				78,468	117,702	156,936
24				125,057	187,706	251,715

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
22				95,857	145,780	191,715
24				114,985	172,478	229,971
26				135,852	203,778	271,704
28				158,458	237,687	316,916
30				182,803	274,204	365,605
32				208,886	313,329	417,773
34				236,709	355,063	473,418
36				266,270	399,405	532,541
42				365,388	548,082	730,776
48				480,156	720,234	960,312
54				610,574	915,861	1,221,148
60				756,642	1,134,963	1,513,285
72				1,095,729	1,643,594	2,191,459
84				1,497,417	2,246,125	2,994,834
96				1,961,705	2,942,558	3,923,411

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	21	30	42		Pressure with these	drop pipe
3/4	52	74	104			
1	109	154	218			
1-	251	355	502	391	1,349	
1/4	397	561	794	538		
1-	823	1,163	1,645	899		
1/2						
2						
2-	1,368	1,935	2,736	1,290	1,936	2,581
1/2	2,541	3,593		2,011		
3	5,459	7,720		3,500		
4						
5	10,209	governs pipe	with sizes	5,539	8,309	11,079
6	16,598			7,936	11,905	15,873
8				13,903	20,855	27,806
10	Velocity these			22,732	34,098	45,464
12				33,015	49,522	66,029
14				40,413	60,619	80,825
Notes:				53,804	80,706	107,608

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
18				69,108	103,662	138,216
20				86,325	129,488	172,851
22				105,456	158,183	210,911
24				126,499	189,748	252,998
26				149,455	224,183	298,910
28				174,324	261,487	348,649
30				201,107	301,660	402,214
32				229,802	344,703	459,604
34				260,411	390,616	520,821
36				292,932	439,398	585,864
42				401,974	602,962	803,949
48				528,234	792,351	1,056,468
54				671,711	1,007,566	1,343,422
60				832,405	1,248,608	1,664,810
72				1,205,445	1,808,167	2,410,890
84				1,647,354	2,471,031	3,294,707
96				2,158,131	3,237,197	4,316,263

Steam Condensate Flow lbs./h 15 psig Back Pressure

Pipe Size	23	33	46		Pressure with these	drop pipe
1/2	23	33	46			
3/4	57	80	113			
1	118	167	237			
1-	273	385	545	446	1,539	
1/4	431	610	862	614		
1-	893	1,263	1,787	1,026		
1/2						
2						
2-	1,485	2,101	2,971	1,473	2,209	2,946
1/2	2,759	3,901	5,517	2,295	3,443	4,591
3	5,927	8,382		3,995	5,993	7,990
4						
5	11,085	15,677	With	6,322	9,483	12,644
6	18,022		Sizes	9,058	13,587	18,116
8	38,159			15,868	23,802	31,735
Notes:	Velocity	governs		25,944	38,917	51,889
12	these	pipe		37,680	56,520	75,360

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,500 (45)
16				46,123	69,185	92,247
18				61,407	92,110	122,814
20				78,904	118,911	157,048
22				98,524	147,786	197,048
24				120,358	180,536	240,715
26				144,375	216,562	288,749
28				170,575	255,862	341,150
30				198,959	298,438	397,917
32				229,526	344,288	459,051
34				262,276	393,414	524,552
36				297,210	445,815	594,419
42				334,327	501,490	668,654
48				458,778	688,167	917,557
54				602,880	904,320	1,205,760
60				766,632	1,149,948	1,533,264
72				950,034	1,425,051	1,900,068
84				1,375,789	2,063,684	2,751,578
96				1,880,145	2,820,217	3,760,290
96				2,463,102	3,694,653	4,926,203

Steam Condensate Flow lbs./h 20 psig Back Pressure

1/2	26	37	52		Pressure	drop pipe
3/4	64	91	128		with these	
1	134	190	268			
1-	309	436	617	543	1,875	
1/4	488	690	976	748		
1-	1,012	1,431	2,023	1,250		
1/2						
2						
2-	1,682	2,379	3,364	1,794	2,691	5,592
1/2	3,124	4,418	6,248	2,796	4,194	9,733
3	6,712	9,492		4,866	7,299	
4						

Notes: 12,553 17,753 with 7,701 11,551 15,402
6 20,409 sizes 11,033 16,550 22,066
1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

8 Pipe Size	45,215			19,528	28,992	38,050
10	Pressure Drop psig/100 ft.	Velocity governs		31,602	47,403	63,204
12	these	pipe		45,897	68,845	91,793
14	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
				56,181	84,272	112,362
16				74,798	112,196	149,595
18				96,073	144,110	192,146
20				120,008	180,013	240,017
22				146,603	219,905	293,206
24				175,857	263,786	351,715
26				207,771	311,656	415,542
28				242,344	363,516	484,688
30				279,576	419,365	559,153
32				319,468	479,203	638,937
34				362,020	543,030	724,040
36				407,231	610,846	814,462
42				558,821	838,231	1,117,641
48				734,345	1,101,518	1,468,691
54				933,805	1,400,708	1,867,611
60				1,157,201	1,735,801	2,314,401
72				1,675,797	2,513,695	3,351,593
84				2,290,134	3,435,200	4,580,267
96				3,000,211	4,500,317	6,000,423

Steam Condensate Flow lbs./h 25 psig Back Pressure

1/2	29	41	58		Pressure	drop pipe
3/4	72	101	143		with these	
1	150	212	300			
1-	345	488	690	647	2,233	
1/4	546	772	1,091	891		
1-	1,131	1,600	2,262	1,488		
1/2						
2						
Notes:	1,881	2,660	3,762	2,136	3,205	6,659
1/2	3,493	4,940	6,987	3,330	4,994	11,591
1:	Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000					
3	7,505	10,614		5,795	8,693	
2:	Table based on heavy weight steel pipe using steam equations in Part					

Pipe Size	Pressure Drop psig/100 ft.	with sizes	Velocity FPM (mph)			
8	14,037 22,821 48,319 0.125	19,851 32,273 0.25	with sizes 0.5	9,171 13,140 23,018 2,000 (23)	13,757 19,709 34,527 3,000 (34)	18,342 26,279 46,036 4,000 (45)
10	92,633	governs pipe		37,635	56,453	75,271
12				54,659	81,989	109,318
14				66,907	100,361	133,815
16	Velocity these			89,078	133,617	178,155
18				114,415	171,623	228,831
20				142,920	214,380	285,841
22				174,592	261,889	349,185
24				209,432	314,147	418,863
26				247,438	371,157	494,876
28				288,612	432,918	577,224
30				332,953	499,429	665,906
32				380,461	570,691	760,922
34				431,136	646,704	862,272
36				484,979	727,468	969,958
42				665,510	998,264	1,331,019
48				874,545	1,311,818	1,749,091
54				1,112,086	1,668,129	2,224,172
60				1,378,132	2,067,197	2,756,263
72				1,995,737	2,993,606	3,991,474
84				2,727,362	4,091,043	5,454,725
96				3,573,007	5,359,510	7,146,014

Steam Condensate Flow lbs./h 30 psig Back Pressure

1/2	32	46	65		Pressure with these	drop pipe
3/4	79	112	159			
1	166	235	332			
1-	382	541	765	757		
1/4	605	855	1,209	1,043		
1-	1,253	1,772	2,506	1,743		
1/2						
2						
Notes:	2,084	2,947	4,167	2,502	3,753	13,574

1/2 Pipe 3 Size 4	3,870 Pressure	5,472 Drop psig/100ft.	7,739 100ft.	3,899 6,787	5,849 10,180	Velocity FPM (mph)
5	0.125 15,549	0.25 21,989	0.5 with	2,000 (23) 10,740	3,000 (34) 16,110	4,000 (45) 21,480
6	25,279	35,749	sizes	15,388	23,082	30,775
8	53,524			26,956	40,434	53,912
10	102,611	governs		44,075	66,112	88,149
12	167,486	pipe		64,011	96,017	128,022
14				78,355	117,532	156,710
16	Velocity			104,319	156,478	208,637
18	these			133,991	200,987	267,983
20				167,373	251,060	334,747
22				204,464	306,697	408,929
24				245,265	367,897	490,529
26				289,774	434,661	579,548
28				337,992	506,988	675,984
30				389,920	584,879	779,839
32				445,556	668,334	891,112
34				504,902	757,353	1,009,804
36				567,957	851,935	1,135,913
42				779,375	1,169,063	1,558,751
48				1,024,176	1,536,265	2,048,353
54				1,302,359	1,953,539	2,604,718
60				1,613,924	2,420,886	3,227,848
72				2,337,199	3,505,799	4,674,398
84				3,194,002	4,791,003	6,388,004
96				4,184,333	6,276,499	8,368,666

Steam Condensate Flow lbs./h 40 psig Back Pressure

1/2	39	55	78		Pressure	drop pipe
3/4	95	135	190		with these	
1	199	282	399			
Notes:	459	649	918	1,375		
1/4	726	1,026	1,451	2,298		
1-	1,504	2,127	3,008			
1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM						
2. Table based on heavy weight steel pipe using steam equations in Part 1						

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	2,501	3,537	5,002	3,299	4,948	17,897
1/2	4,615 4,125	6,569 6,025	9,209 8,095	5,100 2,000 (23)	7,710 3,000 (34)	17,897 4,000 (45)
3	9,979	14,113	19,958	8,949	13,423	
4						
5	18,664	26,395	with	14,161	21,242	28,323
6	30,344	42,913	sizes	20,289	30,434	40,579
8	64,249			35,543	53,314	71,086
10	123,172	governs pipe		58,114	87,171	116,228
12	201,047			84,401	126,601	168,802
14				103,314	154,971	206,628
16	Velocity these			137,548	206,322	275,096
18				176,673	265,009	353,346
20				220,688	331,032	441,376
22				269,594	404,391	539,188
24				323,391	485,086	646,781
26				382,078	573,117	764,156
28				445,656	668,483	891,311
30				514,124	771,186	1,028,248
32				587,483	881,224	1,174,966
34				665,732	998,599	1,331,465
36				748,873	1,123,309	1,497,745
42				1,027,637	1,541,455	2,055,273
48				1,350,416	2,025,624	2,700,832
54				1,717,211	2,575,816	3,434,421
60				2,128,021	3,192,031	4,256,041
72				3,081,687	4,622,530	6,163,374
84				4,211,415	6,317,122	8,422,829
96				5,517,204	8,275,806	11,034,407

Steam Condensate Flow lbs./h 50 psig Back Pressure

1/2	46	65	92		Pressure with these	drop pipe
3/4	112	159	225			
1	235	333	470			
Notes:	541	766	1,083	2,937		

Pipe Size	Pressure Drop psig/100ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/4	856	1,211	1,712			
1/2	2,951	4,173	5,901	4,215	9,854	22,870
3/4	5,480	7,750	10,960	6,570	17,152	
1	11,773	16,650	23,547	11,435		
2	22,020	31,141	44,040	18,095	27,143	36,191
3	35,800	50,629		25,926	38,889	51,852
4	75,801	107,199		45,417	68,125	90,834
6	145,319			74,259	111,388	148,518
8	237,196			107,849	161,773	215,697
10	308,904			132,016	198,023	264,031
12				175,760	263,641	351,521
14				225,754	338,632	451,509
16				281,998	422,997	563,996
18	Velocity	governs	with	344,490	516,736	688,981
20	these	pipe	sizes	413,232	619,848	826,464
22				488,223	732,335	976,447
24				569,464	854,195	1,138,927
26				656,953	985,430	1,313,907
28				750,692	1,126,038	1,501,384
30				850,680	1,276,020	1,701,361
32				956,918	1,435,377	1,913,835
34				1,313,125	1,969,688	2,626,251
36				1,725,576	2,588,365	3,451,153
42				2,194,271	3,291,406	4,388,542
48				2,719,209	4,078,813	5,438,417
54				3,937,814	5,906,721	7,875,628
60				5,381,393	8,072,089	10,762,785
72				7,049,945	10,574,917	14,099,889
84						
96						

Steam Condensate Flow lbs./h 60 psig Back Pressure

Notes:	53	75	106		Pressure	drop pipe
3/4	131	185	261		with these	

Pipe Size	273	387	547	Velocity FPM (mph)		
	Pressure	Drop	psig/100 ft.			
1-1/4	629	890	1,259	3,653		
1-1/2	951,25	1,025	1,925	2,000 (23)	3,000 (34)	4,000 (45)
2	2,063	2,917	4,125			
2-1/2	3,430	4,850	6,859	5,243	12,256	
3	6,370	9,008	12,739	8,170	21,332	
4	13,685	19,353	27,369	14,221		
5	25,595	36,196	51,189	22,505	33,757	45,010
6	41,611	58,847		32,243	48,365	64,487
8	88,105	124,600		56,484	84,726	112,968
10	168,908	governs pipe	with sizes	92,353	138,530	184,707
12	275,699			134,128	201,192	268,256
14	359,048			164,184	246,276	328,368
16	521,067			218,588	327,882	437,176
18				280,764	421,146	561,528
20				350,712	526,069	701,425
22	Velocity these			428,433	642,649	856,865
24				513,925	770,887	1,027,850
26				607,189	910,783	1,214,378
28				708,225	1,062,338	1,416,450
30				817,034	1,225,550	1,634,067
32				933,614	1,400,421	1,867,228
34				1,057,966	1,586,949	2,115,932
36				1,190,090	1,785,136	2,380,181
42				1,633,096	2,449,643	3,266,191
48				2,146,049	3,219,073	4,292,098
54				2,728,950	4,093,425	5,457,900
60				3,381,800	5,072,700	6,763,600
72				4,897,343	7,346,015	9,794,687
84				6,692,680	10,039,020	13,385,360
96				8,767,809	13,151,713	17,535,618

Notes: Condensate Flow lbs /h 75 psig Back Pressure

STEAM CONDENSATE FLOW 105.711 7.5 PSIG BACK PRESSURE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1/2	66	93	131			
3/4	161	228	322			
1	338	477	675			
1-	777	1,099	1,554	4,916		
1/4	1,229	1,737	2,457			
1-	2,546	3,601	5,093			
1/2						
2						
2-	4,234	5,988	8,468	7,056	28,710	
1/2	7,864	11,121	15,727	10,996		
3	16,895	23,893	33,789	19,140		
4						
5	31,598	44,687	63,196	30,289	45,433	60,577
6	51,372	72,650	102,743	43,395	65,093	86,791
8	108,772	153,827		76,020	114,030	152,040
10	208,528	294,903	with	124,296	186,444	248,592
12	340,369		sizes	180,519	270,779	361,038
14	443,268			220,970	331,455	441,941
16	643,292	governs		294,191	441,287	588,382
18	889,824	pipe		377,872	566,808	755,745
20				472,014	708,020	944,027
22	Velocity			576,615	864,922	1,153,230
24	these			691,676	1,037,514	1,383,353
26				817,198	1,225,797	1,634,396
28				953,180	1,429,769	1,906,359
30				1,099,622	1,649,432	2,199,243
32				1,256,524	1,884,785	2,513,047
34				1,423,886	2,135,828	2,847,771
36				1,601,708	2,402,562	3,203,416
42				2,197,935	3,296,903	4,395,871
48				2,888,304	4,332,456	5,776,609
54				3,672,814	5,509,221	7,345,629
60				4,551,465	6,827,198	9,102,931
Notes:				6,591,191	9,886,787	13,182,383

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
84				9,007,482	13,511,223	18,014,964
96				11,800,338	17,700,507	23,600,676

Notes: 0.125 0.25 0.5 2,000 (23) 3,000 (34) 4,000 (45)

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

2. Table based on heavy weight steel pipe using steam equations in Part



275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	13	19	26	62	Pressure with these	drop pipe
3/4	32	46	65	103		
1	68	96	136			
1-	156	221	313	184	276	847
1/4	247	350	494	253	380	
1-	512	724	1,025	423	635	
1/2						
2-	852	1,205	with sizes	608	912	1,216
1/2	1,582	2,237		947	1,421	1,895
3	3,399			1,649	2,473	3,298
4						
5	6,357	governs pipe		2,609	3,914	5,218
6				3,738	5,607	7,477
8				6,549	9,823	13,098
10	Velocity these			10,708	16,061	21,415
12				15,551	23,326	31,102
14				19,036	28,553	38,071
Notes:				25,343	38,015	50,686
18				32,552	48,828	65,104
20				40,662	60,993	81,324

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure	Drop psig	/100 ft.	Velocity FPM (mph)		
				49,673 59,585 70,398	74,509 89,377 105,597	99,345 119,169 140,796
26	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
28				82,112	123,168	164,224
30				94,727	142,091	189,454
32				108,244	162,365	216,487
34				122,661	183,992	245,322
36				137,980	206,969	275,959
42				189,342	284,013	378,684
48				248,814	373,221	497,628
54				316,396	474,594	632,791
60				392,087	588,131	784,175
72				567,800	851,700	1,135,601
84				775,952	1,163,929	1,551,905
96				1,016,544	1,524,816	2,033,088

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	16	23	32	145	Pressure with these	drop pipe
3/4	40	56	79			
1	83	117	166			
1-	191	270	382	258	533	1,188
1/4	302	428	605	355		
1-	627	886	1,253	594		
1/2						
2						
2-	1,042	1,474	2,084	853	1,279	1,705
1/2	1,935	2,737		1,329	1,993	2,657
3	4,158			2,313	3,469	4,625
4						
5	7,777	governs pipe	with sizes	3,660	5,490	7,319
6	12,643			5,243	7,865	10,487
8				9,185	13,778	18,371
10	Velocity these			15,019	22,528	30,037
12				21,812	32,718	43,624
14				26,700	40,049	53,399
15				35,547	52,320	71,004

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
16				35,547	53,320	71,094
18				45,658	68,487	91,811
20				57,033	85,549	114,066
22				69,672	104,508	139,343
24				83,574	125,362	167,149
26				98,741	148,112	197,482
28				115,172	172,757	230,343
30				132,866	199,299	265,732
32				151,824	227,737	303,649
34				172,047	258,070	344,093
36				193,533	290,299	387,065
42				265,574	398,361	531,148
48				348,991	523,486	697,981
54				443,782	665,673	887,564
60				549,949	824,923	1,099,897
72				796,406	1,194,610	1,592,813
84				1,088,364	1,632,546	2,176,728
96				1,425,822	2,138,733	2,851,644

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	17	25	35	162	Pressure with these	drop pipe
3/4	43	60	85			
1	89	126	178			
1-	205	290	410	289	598	1,332
1/4	324	458	648	399	999	
1-	672	950	1,343	666		
1/2						
2						
2-	1,117	1,579	2,234	956	1,434	1,912
1/2	2,074	2,933		1,490	2,235	2,979
3	4,456	6,302		2,593	3,889	5,186
4						
5	8,334			4,103	6,155	8,207
6	13,550			5,879	8,819	11,758
8				10,299	15,448	20,598
Notes:				16,839	25,259	33,678

12 14 Pipe Size	Pressure Drop psig/100 ft.			24,456 29,936	36,684 44,905 Velocity FPM (mph)	48,912 59,875
16 18 20	Velocity 0.125 these	governs 0.25 pipe	with 0.5 sizes	29,856 2,000 (23) 51,193 63,947	59,784 3,000 (34) 76,789 95,920	79,712 4,000 (45) 102,386 127,894
22 24 26				78,118 93,706 110,711	117,177 140,559 166,067	156,236 187,412 221,423
28 30 32				129,134 148,973 170,230	193,701 223,460 255,345	258,267 297,946 340,460
34 36 42				192,903 216,994 297,769	289,355 325,491 446,654	385,807 433,988 595,538
48 54 60				391,298 497,581 616,618	586,947 746,372 924,927	782,596 995,162 1,233,236
72 84 96				892,953 1,220,305 1,598,672	1,339,430 1,830,457 2,398,008	1,785,907 2,440,610 3,197,344

Steam Condensate Flow lbs./h 10 psig Back Pressure

1/2 3/4 1	19 47 98	27 66 138	38 93 196	189	Pressure with these	drop pipe
1- 1/4 1- 1/2 2	225 356 738	318 503 1,043	450 712 1,476	338 465 777	698 1,166	
2- 1/2 3 4	1,227 2,279 4,895	1,735 3,222 6,923	2,454	1,116 1,739 3,027	1,674 2,609 4,540	2,232 3,478 6,054
Notes: 6	9,156 14.885	governs pipe	with sizes	4,790 6.863	7,185 10.294	9,580 13.726

Pipe Size	Pipe			12,022	18,034	24,045
	Pressure	Drop psig	/100 ft.	Velocity FPM (mph)		
10	Velocity			19,657	29,486	39,314
12	these	0.125	0.25	2,000 (23)	3,000 (34)	4,000 (45)
14				28,949	42,823	57,097
16				34,946	52,419	69,892
18				46,526	69,788	93,051
20				59,760	89,639	119,519
22				74,648	111,972	149,296
24				91,190	136,785	182,381
26				109,387	164,080	218,774
28				129,238	193,857	258,476
30				150,743	226,115	301,486
32				173,903	260,854	347,805
34				198,716	298,074	397,432
36				225,184	337,776	450,368
42				253,306	379,960	506,613
48				347,598	521,397	695,197
54				456,779	685,168	913,557
60				580,847	871,270	1,161,694
66				719,804	1,079,705	1,439,607
72				1,042,381	1,563,572	2,084,763
84				1,424,512	2,136,768	2,849,024
96				1,866,196	2,799,293	3,732,391

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2	20	29	40		Pressure	drop pipe
3/4	49	70	99		with these	
1	104	147	207			
1-	238	337	477	371	1,281	
1/4	377	533	754	511		
1-	782	1,105	1,563	854		
1/2						
2						
Notes:	1,300	1,838	2,600	1,226	1,839	2,452
1/2	2,414	3,414		1,911	2,866	3,821
3	5,186	7,335		3,326	4,989	6,652

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

4 Pipe Size	Pressure 9,700	Drop psig/ governs pipe	/100 ft. with sizes	Velocity FPM (mph)		
				5,263	7,895	10,526
6	15,770	0.125	0.5	7,541	11,311	15,081
8		0.25		2,000 (23)	3,000 (34)	4,000 (45)
10	Velocity			13,209	19,814	26,419
12	these			21,598	32,397	43,196
14				31,368	47,051	62,735
16				38,397	57,595	76,793
18				51,120	76,680	102,239
20				65,660	98,491	131,321
22				82,019	123,028	164,037
24				100,195	150,292	200,389
26				120,188	180,282	240,376
28				141,999	212,999	283,998
30				165,628	248,442	331,255
32				191,074	286,611	382,148
34				218,338	327,507	436,676
36				247,419	371,129	494,838
42				278,318	417,477	556,636
48				381,921	572,881	763,841
54				501,882	752,822	1,003,763
60				638,201	957,301	1,276,401
72				790,878	1,186,317	1,581,756
84				1,145,308	1,717,962	2,290,616
96				1,565,171	2,347,756	3,130,341
				2,050,467	3,075,700	4,100,934

Steam Condensate Flow lbs./h 15 psig Back Pressure

1/2	22	31	44		Pressure with these	drop pipe
3/4	54	76	107			
1	112	159	225			
1-	258	366	517	423	1,460	
1/4	409	578	817	582		
1-	847	1,198	1,694	973		
1/2						
2						

Notes: 1 409 1 002 2 817 1 307 2 005 2 703

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1/2	2,616	4,353
3/4	5,621	7,577
4	0.125	0.25
5	10,513	14,867
6	17,091	with sizes
8	36,188	5,996
10	Velocity	governs
12	these	pipe
14		24,604
16		35,734
18		43,741
20		58,235
22		87,353
24		112,200
26		140,152
28		188,682
30		283,022
32		377,363
34		435,339
36		497,457
42		281,858
48		422,786
54		475,586
60		634,115
72		870,161
84		571,739
96		727,032
		900,961
		1,304,724
		1,957,086
		2,674,542
		3,566,055
		4,671,745

Steam Condensate Flow lbs./h 20 psig Back Pressure

1/2	25	35	49		Pressure	drop pipe
3/4	61	86	121		with these	
1	127	179	254			
Notes:	292	413	584	513	1,772	
1/4	461	653	923	707		
1-	956	1,353	1,913	1,182		

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

1/2 Pipe 2 Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
2- 1/2 3 4	1,590 0.125 2,954 6,346	2,249 0.25 4,177 8,974	3,181 0.5 5,907	1,696 2,000 (23) 2,643 4,601	2,544 3,000 (34) 3,965 6,901	5,286 4,000 (45) 9,201
5 6 8	11,868 19,295 40,855	16,784	with sizes	7,281 10,431 18,273	10,921 15,647 27,410	14,561 20,862 36,546
10 12 14	Velocity these	governs pipe		29,878 43,392 53,116	44,816 65,088 79,673	59,755 86,784 106,231
16 18 20				70,716 90,831 113,460	106,074 136,246 170,190	141,432 181,661 226,920
22 24 26				138,603 166,261 196,433	207,905 249,392 294,650	277,207 332,522 392,867
28 30 32				229,120 264,321 302,036	343,680 396,481 453,054	458,240 528,641 604,072
34 36 42				342,265 385,009 528,327	513,398 577,514 792,490	684,531 770,018 1,056,654
48 54 60				694,274 882,850 1,094,055	1,041,411 1,324,275 1,641,082	1,388,548 1,765,699 2,188,110
72 84 96				1,584,352 2,165,166 2,836,497	2,376,528 3,247,749 4,254,745	3,168,704 4,330,332 5,672,993

Steam Condensate Flow lbs./h 25 psig Back Pressure

1/2	28	39	55		Pressure	drop pipe
3/4	67	95	135		with these	
1	141	200	283			

Notes: 225

460

651

800

2,104

3/4 Pipe Size	75 Pressure Drop 156	105 Drop psig/100 ft. 221	149 312	with these Velocity FPM (mph)		
1- 1/4 1- 1/2 2	359 0.125 568 1,177	508 0.25 803 1,665	718 0.5 1,136 2,355	2,000 (23) 980 1,638	3,000 (34)	4,000 (45)
2- 1/2 3 4	1,958 3,636 7,812	2,769 5,142 11,047	3,916 7,272 15,623	2,351 3,664 6,377	3,526 5,496 9,566	12,755
5 6 8	14,610 23,753 50,294	20,662 33,592	with sizes	10,092 14,459 25,330	15,138 21,689 37,995	20,184 28,919 50,659
10 12 14	96,419	governs pipe		41,415 60,149 73,627	62,123 90,223 110,440	82,830 120,297 147,254
16 18 20	Velocity these			98,024 125,906 157,274	147,036 188,860 235,911	196,048 251,813 314,548
22 24 26				192,127 230,465 272,289	288,191 345,698 408,434	384,254 460,931 544,578
28 30 32				317,598 366,392 418,672	476,397 549,588 628,008	635,196 732,784 837,343
34 36 42				474,437 533,687 732,349	711,655 800,530 1,098,523	948,873 1,067,373 1,464,698
48 54 60				962,379 1,223,776 1,516,541	1,443,568 1,835,664 2,274,812	1,924,757 2,447,552 3,033,083
Notes: 84 96				2,196,175 3,001,279 3,931,855	3,294,262 4,501,919 5,897,782	4,392,350 6,002,559 7,863,709
1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5.00						

Pipe Size	Steam Condensate Flow lbs./h, 40 psig Back Pressure			Velocity FPM (mph)		
	Pressure Drop	10.125	16.25	20.5	2,000 (23)	3,000 (34)
1/2	36	51	72			
3/4	89	126	179			
1	186	263	372			
1-1/4	429	606	857	1,284		
1-1/2	678	958	1,355	2,146		
2	1,405	1,986	2,809			
2-1/2	2,336	3,303	4,671	3,081	4,621	16,713
3	4,338	6,134	8,675	4,801	7,202	
4	9,319	13,179	18,638	8,357	12,535	
5	17,429	24,649		13,224	19,836	26,448
6	28,336	40,073		18,947	28,420	37,894
8	59,997			33,191	49,786	66,382
10	115,022			54,269	81,403	108,537
12	187,744			78,816	118,224	157,632
14				96,477	144,716	192,955
16	Velocity	governs	with	128,446	192,669	256,893
18	these	pipe	sizes	164,982	247,473	329,964
20				206,085	309,127	412,170
22				251,755	377,632	503,510
24				301,992	452,987	603,983
26				356,795	535,193	713,591
28				416,166	624,249	832,332
30				480,104	720,156	960,208
32				548,609	822,913	1,097,217
34				621,680	932,520	1,243,360
36				699,319	1,048,978	1,398,638
42				959,637	1,439,455	1,919,274
48				1,261,057	1,891,586	2,522,115
54				1,603,581	2,405,372	3,207,162
60				1,987,207	2,980,811	3,974,415
72				2,877,760	4,316,652	5,755,537

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
Steam Condensate Flow lbs./h 50 psig Back Pressure						
1/2	42	60	85		Pressure	drop pipe
3/4	104	147	208		with these	
1	218	309	436			
1-	502	710	1,005	2,725		
1/4	794	1,123	1,589			
1-	1,646	2,328	3,293			
1/2						
2						
2-	2,738	3,871	5,475	3,911	9,142	21,217
1/2	5,084	7,190	10,168	6,095	15,913	
3	10,923	15,447	21,846	10,609		
4						
5	20,429	28,892	40,859	16,788	25,182	33,577
6	33,214	46,971		24,053	36,080	48,106
8	70,325	99,455		42,136	63,204	84,272
10	134,821	governs	with	68,894	103,341	137,789
12	220,061	pipe	sizes	100,058	150,086	200,115
14	286,589			122,479	183,718	244,957
16	Velocity			163,063	244,595	326,127
18	these			209,446	314,169	418,892
20				261,626	392,439	523,252
22				319,604	479,406	639,209
24				383,380	575,070	766,760
26				452,954	679,431	905,908
28				528,325	792,488	1,056,651
30				609,495	914,242	1,218,990
32				696,462	1,044,693	1,392,924
34				789,227	1,183,840	1,578,454
36				887,790	1,331,685	1,775,579
42				1,218,265	1,827,397	2,436,530
Notes:				1,600,920	2,401,381	3,201,841

54 Pipe Size	Pressure Drop	psig/100 ft.		2,035,756	3,053,634	4,071,512
60				2,522,772	3,784,158	5,045,544
72	0.125	0.25	0.5	2,653,345	5,480,018	7,306,690
84				2,000 (23)	3,000 (34)	4,000 (45)
96				4,992,639	7,488,959	9,985,279
				6,540,655	9,810,982	13,081,309

Steam Condensate Flow lbs./h 60 psig Back Pressure

1/2	49	69	98		Pressure with these	drop pipe
3/4	120	170	241			
1	252	356	504			
1-	580	820	1,160	3,366		
1/4	917	1,297	1,834			
1-	1,900	2,688	3,801			
1/2						
2						
2-	3,160	4,469	6,321	4,831	11,293	
1/2	5,869	8,300	11,739	7,529	19,656	
3	12,610	17,833	25,219	13,104		
4						
5	23,584	33,353	47,168	20,737	31,106	41,474
6	38,342	54,224		29,711	44,566	59,421
8	81,185	114,812		52,047	78,070	104,094
10	155,640	governs	with	85,099	127,648	170,198
12	254,042	pipe	sizes	123,592	185,388	247,184
14	330,844			151,287	226,930	302,574
16	480,136			201,417	302,126	402,835
18				258,709	388,064	517,419
20				323,163	484,745	646,326
22	Velocity			394,778	592,167	789,556
24	these			473,555	710,332	947,109
26				559,493	839,239	1,118,986
28				652,592	978,889	1,305,185
30				752,853	1,129,280	1,505,707
32				860,276	1,290,414	1,720,552
Notes:				974,860	1,462,290	1,949,720
36				1,096,606	1,644,909	2,193,212

Pipe Size	Pressure	Drop	psig/100 ft.	1,504,812	2,257,218	3,009,623
48	0.125	0.25	0.5	1,977,471	2,966,207	3,954,942
54				2,914,584	3,990,876	5,029,169
60				3,116,151	4,674,226	6,232,302
72				4,512,645	6,768,967	9,025,290
84				6,166,953	9,250,430	12,333,906
96				8,079,076	12,118,613	16,158,151

Steam Condensate Flow lbs./h 75 psig Back Pressure

1/2	60	85	120		Pressure with these	drop pipe
3/4	147	208	294			
1	308	435	615			
1-	708	1,001	1,416	4,479		
1/4	1,119	1,583	2,239			
1-	2,320	3,281	4,640			
1/2						
2						
2-	3,858	5,456	7,715	6,428	26,157	
1/2	7,165	10,132	14,329	10,019		
3	15,392	21,768	30,785	17,438		
4						
5	28,789	40,714	57,578	27,596	41,393	55,191
6	46,804	66,191	93,608	39,537	59,306	79,074
8	99,101	140,150		69,261	103,891	138,522
10	189,987	268,683	with sizes	113,245	169,867	226,489
12	310,107			164,469	246,703	328,938
14	403,857			201,324	301,985	402,647
16	586,096	governs pipe		268,034	402,052	536,069
18	810,709		344,275	516,413	688,551	
20			430,046	645,069	860,093	
22	Velocity these			525,347	788,021	1,050,695
24				630,179	945,268	1,260,357
26				744,540	1,116,810	1,489,080

Notes:

30				868,431	1,302,647	1,736,863
1				1,001,853	1,502,779	2,003,706

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5.00

32 Pipe Size				1,144,805	1,717,207	2,289,609
36	0.125	0.25	0.5	1,297,286	1,945,930	2,594,573
42				1,459,298	2,188,947	2,918,597
				2,000 (23)	3,000 (34)	4,000 (45)
				2,002,515	3,003,772	4,005,029
48				2,631,502	3,947,253	5,263,004
54				3,346,260	5,019,391	6,692,521
60				4,146,790	6,220,185	8,293,579
72				6,005,161	9,007,742	12,010,323
84				8,206,617	12,309,926	16,413,234
96				10,751,157	16,126,735	21,502,314

Steam Condensate Flow lbs./h 85 psig Back Pressure

1/2	68	96	136		Pressure with these	drop pipe
3/4	166	235	333			
1	349	493	697			
1-	802	1,135	1,605			
1/4	1,269	1,795	2,538			
1-	2,630	3,720	5,260			
1/2						
2						
2-	4,374	6,185	8,747	7,661	31,174	
1/2	8,123	11,487	16,246	11,940		
3	17,451	24,680	34,902	20,782		
4						
5	32,639	46,159	65,278	32,888	49,332	94,240
6	53,064	75,044	106,128	47,120	70,680	165,089
8	112,355	158,894		82,544	123,817	
10	215,397	304,618	with sizes	134,964	202,446	269,927
12	351,582			196,012	294,019	392,025
14	457,871			239,935	359,903	479,871
16	664,484	governs pipe		319,441	479,161	638,881
18	919,137		410,304	615,456	820,608	
20	1,225,107		512,525	768,787	1,025,050	
Notes:	Velocity			626,104	939,156	1,252,207
24	these			751,041	1,126,561	1,502,081
26				887,335	1,331,003	1,774,670

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5.00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
28				1,034,988	1,552,482	2,069,976
30				1,193,998	1,790,997	2,387,997
32				1,364,367	2,046,550	2,738,733
34				1,546,093	2,319,139	3,092,186
36				1,739,177	2,608,766	3,478,354
42				2,386,577	3,579,865	4,773,154
48				3,136,198	4,704,296	6,272,395
54				3,988,039	5,982,059	7,976,079
60				4,942,102	7,413,153	9,884,205
72				7,156,891	10,735,337	14,313,782
84				9,780,564	14,670,846	19,561,128
96				12,813,121	19,219,681	25,626,242

Notes:

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM
2. Table based on heavy weight steel pipe using steam equations in Part 1



300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)

Steam Condensate Flow lbs./h 0 psig Back Pressure

1/2	13	18	25	60	Pressure drop pipe with these	
3/4	31	44	62	99		
1	65	92	131			
1-	150	213	301	177	265	815
1/4	238	336	476	244	366	
1-	493	697	986	407	611	
1/2						
2						
Notes:	819	1,159		585	877	1,170
1/2	1,522	2,152		911	1,367	1,823

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
5	6,116	2,510
6	0.125	2,000 (23)
8	0.25	3,000 (34)
	0.5	4,000 (45)
10		6,300
12		10,301
14		14,961
16	Velocity	18,313
18	these	24,381
20	governs	31,317
	pipe	39,119
	with	47,788
22	sizes	57,323
24		67,726
26		78,996
28		91,132
30		104,136
32		118,006
34		132,743
36		148,156
42		177,009
48		199,115
54		239,371
60		304,388
72		377,207
84		546,251
96		746,504

Steam Condensate Flow lbs./h 5 psig Back Pressure

1/2	16	22	31	139	Pressure	drop pipe
3/4	38	54	76		with these	
1	80	113	159			
Notes:	183	259	367	248	511	1,140
1/4	290	410	580	341	855	
1-	601	850	1,202	570		
1/2						
2						

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM

2. Table based on heavy weight steel pipe using steam equations in Part 2

Pipe Size	1,000 Pressure Drop psig/100 ft.	1,414 Pressure Drop psig/100 ft.	1,999 Pressure Drop psig/100 ft.	818 Velocity FPM (mph)	1,227 Velocity FPM (mph)	1,636 Velocity FPM (mph)
3	1,856	2,625		1,274	1,912	2,549
4	3,988 0.125		0.5	2,218 2,000 (23)	3,327 3,000 (34)	4,437 4,000 (45)
5	7,459	governs	with	3,510	5,266	7,021
6	12,127	pipe	sizes	5,030	7,544	10,059
8				8,811	13,216	17,622
10	Velocity			14,406	21,609	28,812
12	these			20,922	31,383	41,845
14				25,611	38,416	51,221
16				34,097	51,145	68,194
18				43,796	65,694	87,591
20				54,707	82,060	109,413
22				66,830	100,245	133,660
24				80,166	120,249	160,332
26				94,714	142,071	189,428
28				110,474	165,711	220,948
30				127,447	191,170	254,894
32				145,632	218,448	291,264
34				165,029	247,544	330,059
36				185,639	278,459	371,278
42				254,742	382,114	509,485
48				334,757	502,135	669,513
54				425,682	638,523	851,364
60				527,518	791,277	1,055,037
72				763,924	1,145,886	1,527,848
84				1,043,974	1,565,961	2,087,948
96				1,367,668	2,051,502	2,735,336

Steam Condensate Flow lbs./h 7 psig Back Pressure

1/2	17	23	33	155	Pressure	drop pipe
3/4	41	58	81		with these	
1	85	121	171			
Notes:	196	278	393	277	573	1,276
1/4	310	439	621	382	957	

1, Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

1- Pipe 1/2 Size	045 Pressure	910 Drop psig/100 ft.	1,287	038	Velocity FPM (mph)	
2-	0.125 1,070	0.25 1,513	0.5 2,140	2,000 (23) 916	3,000 (34) 1,374	4,000 (45) 1,832
1/2	1,987	2,810		1,427	2,141	2,855
3	4,269	6,038		2,484	3,727	4,969
4						
5	7,985	governs	with	3,932	5,897	7,863
6	12,982	pipe	sizes	5,633	8,449	11,266
8				9,868	14,801	19,735
10	Velocity			16,134	24,201	32,268
12	these			23,432	35,148	46,864
14				28,683	43,024	57,365
16				38,187	57,281	76,374
18				49,049	73,574	98,098
20				61,269	91,903	122,538
22				74,847	112,270	149,693
24				89,782	134,673	179,564
26				106,075	159,113	212,150
28				123,726	185,589	247,452
30				142,735	214,102	285,469
32				163,101	244,652	326,202
34				184,825	277,238	369,651
36				207,907	311,861	415,814
42				285,300	427,949	570,599
48				374,912	562,368	749,824
54				476,744	715,116	953,488
60				590,796	886,194	1,181,592
72				855,559	1,283,339	1,711,119
84				1,169,202	1,753,803	2,338,404
96				1,531,724	2,297,587	3,063,449

Steam Condensate Flow lbs./h 10 psig Back Pressure

Notes: 18	26	36	181	Pressure	drop pipe
3/4	45	63	89	with these	
1	94	132	187	Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000	

Pipe Size	Pressure Drop psig/100 ft.	Velocity FPM (mph)
1-1/2	0.125	3,000 (34)
2	0.25	4,000 (45)
2-1/2	0.5	2,000 (23)
3	1.0	1,601
4	1.660	1,663
5	2,347	2,895
6	3,082	4,343
8	6,622	6,873
10	governs	9,847
12	pipe	17,250
14	with	18,803
16	sizes	27,309
18		33,428
20		44,505
22		57,164
24		71,406
26		87,230
28		104,636
30		123,625
32		144,196
34		166,349
36		190,085
42		215,404
48		242,305
54		323,106
60		363,457
72		498,752
84		655,409
96		833,429
		1,032,811
		1,495,662
		1,994,216
		2,725,283
		3,570,283

Steam Condensate Flow lbs./h 12 psig Back Pressure

1/2 Pipe 3/4 Size	19 Pressure	27 Drop psig/100 ft.	39 Drop psig/100 ft.	Pressure with Velocity	drop pipe Velocity FPM (mph)	
1	99	140	198			
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
1-	228	322	456	355	1,224	
1/4	360	510	721	488		
1-	747	1,056	1,494	816		
1/2						
2						
2-	1,242	1,756	2,484	1,172	1,757	2,343
1/2	2,307	3,262		1,826	2,739	3,652
3	4,956	7,008		3,178	4,767	6,356
4						
5	9,269			5,029	7,544	10,058
6	15,069			7,205	10,808	14,411
8				12,622	18,933	25,244
10	Velocity	governs	with	20,638	30,957	41,276
12	these	pipe	sizes	29,973	44,960	59,946
14				36,690	55,034	73,379
16				48,847	73,271	97,694
18				62,741	94,112	125,483
20				78,372	117,559	156,745
22				95,740	143,610	191,481
24				114,845	172,267	229,690
26				135,686	203,529	271,373
28				158,265	237,397	316,529
30				182,580	273,869	365,159
32				208,631	312,947	417,263
34				236,420	354,630	472,840
36				265,945	398,918	531,890
42				364,942	547,413	729,884
48				479,570	719,355	959,139
54				609,829	914,743	1,219,657
60				755,719	1,133,578	1,511,437
Notes:				1,094,392	1,641,587	2,188,783
84				1,495,589	2,243,383	2,991,178

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5.00

96 Pipe Size	Condensate Flow lbs./hr	Pressure Drop psig/100 ft.	15 psig Back Pressure	1,959,311	2,938,966	3,918,621
1/2	210.125	290.25	420.5	2,000 (23)	3,000 (34)	4,000 (45)
3/4	51	72	102		with these	
1	107	152	214			
1-	247	349	493	403	1,393	
1/4	390	551	780	556		
1-	808	1,143	1,616	928		
1/2						
2						
2-	1,344	1,901	2,688	1,333	1,999	2,665
1/2	2,496	3,530	4,992	2,077	3,115	4,153
3	5,362	7,584		3,615	5,422	7,229
4						
5	10,029	14,184	with	5,720	8,580	11,440
6	16,306		sizes	8,195	12,293	16,391
8	34,525			14,357	21,535	28,713
10	Velocity	governs		23,474	35,210	46,947
12	these	pipe		34,091	51,137	68,183
14				41,731	62,596	83,461
16				55,559	83,338	111,117
18				71,362	107,043	142,724
20				89,141	133,711	178,282
22				108,895	163,343	217,790
24				130,625	195,937	261,249
26				154,330	231,495	308,659
28				180,010	270,015	360,020
30				207,666	311,499	415,332
32				237,297	355,946	474,595
34				268,904	403,356	537,808
36				302,486	453,729	604,972
42				415,085	622,628	830,170
Notes:				545,463	818,194	1,090,926
54				693,619	1,040,429	1,387,239
60				859,555	1,289,332	1,719,109

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
72				1,244,761	1,867,142	2,489,523
84				1,701,083	2,551,625	3,402,167
96				2,238,521	3,342,781	4,457,041
Steam Condensate Flow lbs./h 20 psig Back Pressure						
1/2	23	33	47		Pressure with these	drop pipe
3/4	58	81	115			
1	121	171	241			
1-	278	393	555	488	1,687	
1/4	439	621	878	673		
1-	910	1,287	1,820	1,124		
1/2						
2-	1,513	2,140	3,027	1,614	2,421	5,030
1/2	2,811	3,975	5,621	2,515	3,773	8,756
3	6,038	8,539		4,378	6,567	
4						
5	11,294	15,972	with sizes	6,928	10,392	13,856
6	18,361			9,926	14,889	19,852
8	38,876			17,388	26,082	34,777
10	Velocity these	governs pipe		28,431	42,646	56,861
12				41,291	61,936	82,582
14				50,543	75,815	101,087
16				67,292	100,937	134,583
18				86,432	129,648	172,865
20				107,966	161,948	215,931
22				131,891	197,837	263,783
24				158,210	237,315	316,420
26				186,921	280,382	373,842
28				218,025	327,037	436,049
30				251,521	377,281	503,042
32				287,410	431,115	574,820
34				325,691	488,537	651,382
36				366,365	549,548	732,731
42				502,743	754,114	1,005,486

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
48				660,654	990,981	1,321,307
54				840,098	1,260,147	1,680,196
60				1,041,075	1,561,613	2,082,151
72				1,507,630	2,261,446	3,015,261
84				2,060,319	3,090,478	4,120,637
96				2,699,140	4,048,710	5,398,280

Steam Condensate Flow lbs./h 25 psig Back Pressure

Pipe Size	26	37	52		Pressure with these	drop pipe
1/2	26	37	52			
3/4	64	91	128			
1	134	190	268			
1-	309	437	617	578	1,997	
1/4	488	690	976	797		
1-	1,012	1,431	2,024	1,332		
1/2						
2						
2-	1,683	2,380	3,365	1,911	2,867	5,957
1/2	3,125	4,420	6,250	2,979	4,468	10,369
3	6,714	9,495		5,185	7,777	
4						
5	12,557	17,759	with	8,204	12,307	16,409
6	20,415	28,872	sizes	11,755	17,632	23,510
8	43,227			20,592	30,888	41,184
10	82,870	governs		33,669	50,503	67,338
12		pipe		48,898	73,348	97,797
14				59,856	89,784	119,712
16	Velocity			79,690	119,534	159,379
18	these			102,357	153,535	204,714
20				127,858	191,786	255,715
22				156,192	234,288	312,383
24				187,359	281,039	374,718
26				221,360	332,040	442,720
28				258,194	387,292	516,389
30				297,862	446,793	595,724
32				340,363	510,545	680,727
Notes:				385,698	578,547	771,396

Pipe Size	Pressure	Drop psig/100 ft.		433,866 595,370	650,799 893,055	867,732 1,190,740
48	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
54				994,881	1,492,321	1,989,762
60				1,232,887	1,849,331	2,465,775
72				1,785,402	2,678,103	3,570,804
84				2,439,920	3,659,880	4,879,839
96				3,196,440	4,794,660	6,392,880

Steam Condensate Flow lbs./h 30 psig Back Pressure

1/2	29	41	58		Pressure	drop pipe
3/4	71	100	141		with these	
1	148	209	295			
1-	340	481	680	674		
1/4	538	761	1,076	928		
1-	1,115	1,576	2,229	1,551		
1/2						
2						
2-	1,853	2,621	3,707	2,226	3,339	12,075
1/2	3,442	4,868	6,885	3,469	5,203	
3	7,396	10,459	14,791	6,038	9,056	
4						
5	13,832	19,562		9,554	14,332	19,109
6	22,488	31,803		13,689	20,533	27,378
8	47,615			23,980	35,970	47,961
10	91,283	governs	with	39,209	58,813	78,418
12		pipe	sizes	56,944	85,417	113,889
14				69,705	104,557	139,409
16	Velocity			92,802	139,203	185,604
18	these			119,199	178,799	238,398
20				148,896	223,343	297,791
22				181,892	272,838	363,784
24				218,188	327,282	436,376
26				257,783	386,675	515,567
Notes:				300,678	451,018	601,357
30				346,873	520,310	693,746

Pipe Size	Pressure	Drop	psig/100 ft.	378,875 396,368	528,510 594,551	699,740 792,735
34	0.125	0.25	0.5	449,162	673,742	898,323
36				2,000 (23)	3,000 (34)	4,000 (45)
42				505,255	757,885	1,010,511
48				693,334	1,040,001	1,386,668
54				911,109	1,366,664	1,822,219
60				1,158,581	1,737,872	2,317,163
66				1,435,750	2,153,625	2,871,500
72				2,079,177	3,118,766	4,158,354
84				2,841,391	4,262,086	5,682,782
96				3,722,391	5,583,587	7,444,782

Steam Condensate Flow lbs./h 40 psig Back Pressure

1/2	34	48	68		Pressure with these	drop pipe
3/4	84	118	167			
1	175	248	351			
1-	404	571	807	1,210		
1/4	638	903	1,276	2,022		
1-	1,323	1,871	2,646			
1/2						
2						
2-	2,200	3,111	4,400	2,902	4,352	15,742
1/2	4,085	5,778	8,171	4,522	6,783	
3	8,777	12,413	17,554	7,871	11,806	
4						
5	16,416	23,216	with	12,456	18,683	24,911
6	26,689	37,744	sizes	17,846	26,768	35,691
8	56,510			31,262	46,893	62,523
10	108,336	governs		51,114	76,671	102,229
12	176,832	pipe		74,235	111,353	148,470
14				90,870	136,305	181,740
16	Velocity			120,981	181,471	241,961
18	these			155,393	233,089	310,786
20				194,107	291,160	388,213
Notes:				237,122	355,683	474,244
24				284,439	426,658	568,878

1. Maximum recommended pressure drop/velocity: 0.25 psia/100 ft./5.00

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
26				336,057	504,086	672,114
30				391,977	587,966	783,954
32				452,199	678,298	904,397
34				516,722	775,082	1,033,443
36				585,546	878,319	1,171,092
42				658,672	988,008	1,317,344
48				903,860	1,355,789	1,807,719
54				1,187,761	1,781,641	2,375,521
60				1,510,376	2,265,564	3,020,751
66				1,871,704	2,807,557	3,743,409
72				2,710,503	4,065,755	5,421,007
84				3,704,157	5,556,236	7,408,315
96				4,852,667	7,279,000	9,705,333

Steam Condensate Flow lbs./h 50 psig Back Pressure

Pipe Size	40	56	80		Pressure with these	drop pipe
1/2	40	56	80			
3/4	98	138	195			
1	204	289	409			
1-	471	666	941	2,553		
1/4	744	1,052	1,488			
1-	1,542	2,181	3,085			
1/2						
2						
2-	2,565	3,627	5,129	3,664	8,565	19,878
1/2	4,763	6,736	9,527	5,710	14,909	
3	10,234	14,472	20,467	9,939		
4						
5	19,140	27,068	38,280	15,729	23,593	31,457
6	31,117	44,006		22,535	33,802	45,070
8	65,886	93,177		39,477	59,215	78,953
10	126,311	governs	with	64,546	96,819	129,092
12	206,171	pipe	sizes	93,742	140,613	187,484
14	268,500			114,748	172,122	229,496
Notes:	Velocity			152,771	229,157	305,542
18	these			196,226	294,339	392,452
1	Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000			245,113	367,669	490,226
20						

Pipe Size	Pressure	Drop psig/100 ft.		Velocity FPM (mph)		
		0.125	0.25	0.5	23	34
22				299,432	449,147	598,863
24				359,182	538,773	718,364
26				420,006 (23)	636,004 (34)	848,002 (45)
28				494,979	742,468	989,957
30				571,025	856,537	1,142,050
32				652,503	978,754	1,305,006
34				739,413	1,109,119	1,478,825
36				831,754	1,247,631	1,663,509
42				1,141,371	1,712,056	2,282,741
48				1,499,874	2,249,811	2,999,747
54				1,907,264	2,860,895	3,814,527
60				2,363,540	3,545,310	4,727,080
72				3,422,754	5,134,131	6,845,508
84				4,677,515	7,016,272	9,355,029
96				6,127,822	9,191,734	12,255,645

Steam Condensate Flow lbs./h 60 psig Back Pressure

1/2	46	65	91		Pressure with these	drop pipe
3/4	112	158	224			
1	235	332	469			
1-	540	764	1,081	3,136		
1/4	854	1,208	1,709			
1-	1,771	2,504	3,542			
1/2						
2						
2-	2,945	4,164	5,889	4,501	10,522	
1/2	5,469	7,734	10,937	7,015	18,314	
3	11,749	16,616	23,498	12,210		
4						
5	21,974	31,076	43,949	19,322	28,982	38,643
6	35,725	50,523		27,683	41,524	55,365
8	75,643	106,976		48,494	72,741	96,989
10	145,016			79,290	118,935	158,581
12	236,702			115,156	172,734	230,312
14	308,261			140,961	211,441	281,921

16 Pipe 18 Size 20	447,364 Pressure Drop	governs pipe Drop psig	with pipe sizes /100 ft.	187,669 241,051 301,105 2,000 (23)	281,504 301,576 451,658 3,000 (34)	375,339 482,102 602,210 4,000 (45)
22	Velocity			367,832	551,748	735,664
24	these			441,231	661,847	882,463
26				521,304	781,956	1,042,607
28				608,049	912,073	1,216,097
30				701,466	1,052,199	1,402,933
32				801,557	1,202,335	1,603,113
34				908,320	1,362,479	1,816,639
36				1,021,755	1,532,633	2,043,511
42				1,402,098	2,103,148	2,804,197
48				1,842,496	2,763,744	3,684,992
54				2,342,947	3,514,421	4,685,895
60				2,903,453	4,355,180	5,806,906
72				4,204,627	6,306,941	8,409,254
84				5,746,018	8,619,027	11,492,036
96				7,527,625	11,291,438	15,055,251

Steam Condensate Flow lbs./h 75 psig Back Pressure

1/2	55	78	111		Pressure	drop pipe
3/4	136	192	271		with these	
1	284	402	568			
1-	654	924	1,307	4,136		
1/4	1,034	1,462	2,067			
1-	2,142	3,030	4,285			
1/2						
2						
2-	3,562	5,038	7,125	5,936	24,154	
1/2	6,616	9,356	13,232	9,251		
3	14,214	20,102	28,428	16,103		
4						
5	26,585	37,596	53,169	25,483	38,224	50,965
6	43,220	61,123	86,441	36,510	54,765	73,019
8	91,513	129,419		63,958	95,936	127,915
Notes:	175,440	248,110	with	104,574	156,860	209,147

Pipe Size	Pressure Drop psig	Drop psig/100 ft.	sizes		Velocity FPM (mph)	
	286,362 372,934			151,876 185,909	227,814 278,863	303,752 371,817
16	4,125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
18	541,225	governs		2,000 (23)	3,000 (34)	4,000 (45)
20	748,634	pipe		317,915	476,872	635,829
22				397,118	595,678	794,237
24	Velocity			485,122	727,684	970,245
26	these			581,927	872,890	1,163,854
28				687,532	1,031,298	1,375,064
30				801,937	1,202,906	1,603,874
32				925,143	1,387,714	1,850,286
34				1,057,149	1,585,723	2,114,298
36				1,197,955	1,796,933	2,395,911
42				1,347,562	2,021,344	2,695,125
48				1,849,186	2,773,778	3,698,371
54				2,430,012	3,645,019	4,860,025
60				3,090,043	4,635,065	6,180,086
66				3,829,277	5,743,916	7,658,554
72				5,545,357	8,318,035	11,090,713
84				7,578,251	11,367,376	15,156,501
96				9,927,959	14,891,939	19,855,919

Steam Condensate Flow lbs./h 85 psig Back Pressure

1/2	62	88	125		Pressure	drop pipe
3/4	153	216	305		with these	
1	320	452	640			
1-	736	1,041	1,472			
1/4	1,164	1,646	2,328			
1-	2,413	3,412	4,826			
1/2						
2						
2-	4,012	5,674	8,025	7,029	28,599	
1/2	7,452	10,539	14,904	10,954		
3	16,010	22,641	32,020	19,066		
4						
Notes:	29,944	42,347	59,887	30,172	45,258	86,457
6	48,682	68,846	97,362	43,328	64,842	151,455

Pipe Size	48,082 102,076 Pressure	88,840 145,772 Drop psig	97,505 /100 ft.	43,228 75,727	84,842 112,591 Velocity	131,433 FPM (mph)
10	197,608	279,460	with 0.5 sizes	123,817	185,726	247,635
12	322,546	0.25		179,824	269,736	359,649
14	420,057			220,120	330,180	440,240
16	609,606	governs pipe		293,059	439,589	586,118
18	843,229		376,418	564,627	752,836	
20	1,123,929		470,197	705,295	940,394	
22	Velocity these			574,396	861,594	1,148,791
24				689,014	1,033,521	1,378,029
26				814,053	1,221,079	1,628,106
28				949,511	1,424,267	1,899,022
30				1,095,389	1,643,084	2,190,779
32				1,251,688	1,877,531	2,503,375
34				1,418,406	2,127,608	2,836,811
36				1,595,544	2,393,315	3,191,087
42				2,189,476	3,284,215	4,378,953
48				2,877,188	4,315,782	5,754,377
54				3,658,679	5,488,019	7,317,358
60				4,533,949	6,800,923	9,067,897
72				6,565,824	9,848,737	13,131,649
84				8,972,816	13,459,224	17,945,632
96				11,754,923	17,632,384	23,509,846

Steam Condensate Flow lbs./h 100 psig Back Pressure

1/2	74	104	148		Pressure with these	drop pipe
3/4	181	256	362			
1	379	536	758			
1-	872	1,234	1,745			
1/4	1,380	1,951	2,759			
1-	2,859	4,044	5,719			
1/2						
2						
Notes:	4,755	6,724	9,509	8,900	36,215	
1/2	8,830	12,488	17,660	13,871		
3	18,971	26,829	37,942	24,144		

1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000

Pipe Size	Pressure Drop psig/100 ft.			Velocity FPM (mph)		
	0.125	0.25	0.5	2,000 (23)	3,000 (34)	4,000 (45)
4	35,482	50,179	70,964	38,207	57,310	109,480
6	57,686	81,580	115,371	54,740	82,110	191,788
8	122,141	172,733		95,894	143,841	
10	234,157	331,149	with	156,791	235,186	313,581
12	382,203	540,517	sizes	227,712	341,569	455,425
14	497,750			278,739	418,108	557,478
16	722,357	governs		371,102	556,653	742,204
18	999,190	pipe		476,660	714,990	953,320
20	1,331,807			595,413	893,119	1,190,825
22	1,723,555			727,360	1,091,040	1,454,720
24	2,177,597			872,502	1,308,753	1,745,004
26				1,030,839	1,546,259	2,061,678
28	Velocity			1,202,371	1,803,556	2,404,741
30	these			1,387,097	2,080,646	2,774,194
32				1,585,018	2,377,527	3,170,036
34				1,796,134	2,694,201	3,592,268
36				2,020,445	3,030,667	4,040,889
42				2,772,545	4,158,817	5,545,089
48				3,643,397	5,465,096	7,286,795
54				4,633,003	6,949,504	9,266,006
60				5,741,361	8,612,042	11,482,722
72				8,314,335	12,471,503	16,628,671
84				11,362,320	17,043,480	22,724,640
96				14,885,316	22,327,974	29,770,631

Notes:

- 1. Maximum recommended pressure drop/velocity: 0.25 psig/100 ft./5,000 FPM (60 mph)**
- 2. Table based on heavy weight steel pipe using steam equations in Part 21**

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 22: Steam Condensate Piping Systems, Chapter

EXPORT

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Part 23: AC Condensate Piping

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23.01. Air Conditioning (AC) Condensate Piping

A. AC Condensate Flow

1. Range:	0.02–0.08 GPM/ton.
2. Average:	0.04 GPM/ton.
3. Unitary packaged AC equipment:	0.006 GPM/ton.
4. Air handling units (100 percent outside air):	0.100 GPM/1000 CFM.
5. Air handling units (50 percent outdoor air):	0.065 GPM/1000 CFM.
6. Air handling units (25 percent outdoor air):	0.048 GPM/1000 CFM.
7. Air handling units (15 percent outdoor air):	0.041 GPM/1000 CFM.
8. Air handling units (0 percent outdoor air):	0.030 GPM/1000 CFM.

B. AC Condensate Pipe Sizing

1. Minimum pipe sizes are provided in the following table.

2. Pipe size shall not be smaller than the drain pan outlet. The minimum size below grade and below ground floor shall be 2-1/2" (4" Allegheny Co., PA). The drain shall have a slope of not less than 1/8" per foot.
3. Some localities require AC condensate to be discharged to storm sewers. Some require AC condensate to be discharged to sanitary sewers, while some permit AC condensate to be discharged to either storm or sanitary sewers. Verify pipe sizing and discharge requirements with local authorities and codes.

AC Tons

Minimum Drain Size

0-20	1"
21-40	1-1/4"
41-60	1-1/2"
61-100	2"
101-250	3"
251 and larger	4"

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 23: AC Condensate Piping, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 24: Refrigerant Piping Systems

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24.01. Refrigerant Systems and Piping

A. Refrigeration System Design Considerations

1. Refrigeration load and system size:
 - a. Conduction heat gains, sensible.
 - b. Radiation heat gains, sensible.
 - c. Convection/infiltration heat gains, sensible and latent.
 - d. Internal heat gains, lights, people, equipment.
 - e. Product load, sensible and latent.
2. Part load performance, minimum versus maximum load.
3. Piping layout and design:
 - a. Ensure proper refrigerant flow to feed evaporators.
 - b. Size piping to limit excessive pressure drop and temperature rise and to minimize first cost.
 - c. Ensure proper lubricating oil flow to compressors and protect compressors for loss of lubricating oil flow.
 - d. To prevent liquid (oil or refrigerant) from entering the compressors.
 - e. Maintain a clean and dry system.

- f. To prevent refrigeration system leaks.
4. Refrigerant type selection and refrigerant limitations.
5. System operation, partial year or year round regardless of ambient conditions.
6. Load variations during short time periods.
7. Evaporator frost control.
8. Oil management under varying load conditions.
9. Heat exchange method.
10. Secondary coolant selection.
11. Installed cost, operating costs, maintenance costs, system efficiency, and system simplicity.
12. Safe operation for building inhabitants.
13. Operating pressure and pressure ratios; single stage versus two stage versus multistaged.
14. Special electrical requirements.
15. Refrigerant system capacity estimate:
 - a. Packaged systems: 2.0 lbs. refrigerant per ton.
 - b. Split systems: 3.0 lbs. refrigerant per ton.

B. Refrigerant Pipe Design Criteria

1. Halocarbon refrigerants:
 - a. Liquid lines (condensers to receivers)—100 FPM or less.
 - b. Liquid lines (receivers to evaporator)—300 FPM or less.
 - c. Compressor suction line—900 to 4,000 FPM.
 - d. Compressor discharge line—2,000 to 3,500 FPM.
 - e. Defrost gas supply lines—1,000 to 2,000 FPM.
 - f. Condensate drop legs—150 FPM or less.
 - g. Condensate mains—100 FPM or less.

- h. Pressure loss due to refrigerant liquid risers is 0.5 psi per foot of lift.
 - i. Liquid lines should be sized to produce a pressure drop due to friction that corresponds to a 1°F to 2°F change in saturation temperature or less.
 - j. Discharge and suction lines should be sized to produce a pressure drop due to friction that corresponds to a 2°F change in saturation temperature or less.
 - k. Pump suction pipe sizing should be 2.5 fps maximum. Oversizing of pump suction piping should be limited to one pipe size.
2. Standard steel pipe sizes: 1/2", 3/4", 1", 1-1/4", 1-1/2", 2", 2-1/2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20".
 3. Standard copper pipe sizes: 3/8", 1/2", 5/8", 3/4", 7/8", 1", 1-1/8", 1-1/4", 1-3/8", 1-1/2", 1-5/8", 2", 2-1/8", 2-1/2", 2-5/8", 3", 3-1/8", 3-5/8", 4", 4-1/8", 6", 8", 10", 12".
 4. Ammonia refrigerant:
 - a. Liquid lines should be sized for 2.0 psi/100 ft. of equivalent pipe length or less. Liquid lines should be sized for a 3:1, 4:1, or 5:1 overfeed ratio (4:1 recommended).
 - b. Suction lines should be sized for 0.25, 0.5, or 1.0°F/100 ft. of equivalent pipe length.
 - c. Discharge lines should be sized for 1.0°F/100 ft. of equivalent pipe length.
 - d. Pump suction pipe sizing should be 3.0 fps maximum. Oversizing of pump suction piping should be limited to one pipe size.
 - e. Cooling water flow rate: 0.1 GPM/ton.

C. Halocarbon Refrigerant Pipe Materials

1. Pipe:	Type "L (ACR)" copper tubing, <i>ASTM B280</i> , hard drawn.
Fittings:	Wrought copper solder joint fittings, <i>ANSI/ASME B16.22</i> .
Joints:	Classification BAg-1 (silver) AWS A5.8 Brazed-Silver Alloy brazing. Brazing shall be conducted using a brazing flux. Do not use an acid flux.

D. Ammonia Refrigerant Pipe Materials

1. Liquid lines:

a. 1-1/2" and smaller:	Schedule 80 minimum.
b. 2" to 6":	Schedule 40 minimum.
c. 8" and larger:	Schedule 30 minimum.

2. Suction, discharge, and vapor lines:

a. 1-1/2" and smaller:	Schedule 80 minimum.
b. 2" to 6":	Schedule 40 minimum.
c. 8" and larger:	Schedule 30 minimum.

3. Fittings:

- a. Couplings, elbows, tees, and unions for threaded piping systems must be constructed of forged steel with a pressure rating of 300 psi.
- b. Welding fittings must match the weight of the pipe.
- c. Low-pressure side piping, vessels, and flanges should be designed for 150 psi.
- d. High-pressure side piping, vessels, and flanges should be designed for 250 psi if the system is water or evaporative cooled, and 300 psi if the system is air cooled.

4. Joints:

- a. 1-1/4" pipe and smaller may be threaded, although welded systems are superior.

b. 1-1/2" pipe and larger must be welded.

5. Recommended low pressure side piping requirements:

a. 1-1/4" and smaller:

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B</i> or carbon steel pipe, <i>ASTM A106, Schedule 80, Type S, Grade B</i> .
Fittings:	Forged steel threaded fittings, 300 lbs.
Joints:	Pipe threads, general purpose (American) <i>ANSI/ASME B1.20.1</i> .

OR

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B</i> or carbon steel pipe, <i>ASTM A106, Schedule 80, Type S, Grade B</i> .
Fittings:	Forged steel socket weld, 150 lbs. <i>ANSI B16.11</i> .
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i> .

b. 1-1/2":

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 80, Type E or S, Grade B</i> or carbon steel pipe, <i>ASTM A106, Schedule 80, Type S, Grade B</i> .
Fittings:	Forged steel socket weld, 150 lbs. <i>ANSI B16.11</i> .
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i> .

c. 2" and larger:

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 40</i> , Type E or S, Grade B or carbon steel pipe, <i>ASTM A106, Schedule 40</i> , Type S, Grade B.
Fittings:	Steel butt-welding fittings, 150 lbs., <i>ANSI/ASME B16.9</i> .
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i> .

6. Recommended high pressure side piping requirements:

a. 1-1/4" and smaller:

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 80</i> , Type E or S, Grade B or carbon steel pipe, <i>ASTM A106, Schedule 80</i> , Type S, Grade B.
Fittings:	Forged steel threaded fittings, 300 lbs.
Joints:	Pipe threads, general purpose (American) <i>ANSI/ASME B1.20.1</i> .

OR

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 80</i> , Type E or S, Grade B or carbon steel pipe, <i>ASTM A106, Schedule 80</i> , Type S, Grade B.
Fittings:	Forged steel socket weld, 300 lbs. <i>ANSI B16.11</i> .
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i> .

b. 1-1/2":

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 80</i> , Type E or S, Grade B or carbon steel pipe, <i>ASTM A106, Schedule 80</i> , Type S, Grade B.
Fittings:	Forged steel socket weld, 300 lbs. <i>ANSI B16.11</i> .
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i> .

c. 2" and larger:

Pipe:	Black steel pipe, <i>ASTM A53, Schedule 40</i> , Type E or S, Grade B or carbon steel pipe, <i>ASTM A106, Schedule 40</i> , Type S, Grade B.
Fittings:	Steel butt-welding fittings, 300 lbs., <i>ANSI/ASME B16.9</i> .
Joints:	Welded pipe, <i>ANSI/AWS D1.1</i> and <i>ANSI/ASME Sec. 9</i> .

E. Refrigerant Piping Installation

1. Slope piping 1 percent in direction of oil return.
2. Install horizontal hot gas discharge piping with 1/2" per 10 feet downward slope away from the compressor.
3. Install horizontal suction lines with 1/2" per 10 feet downward slope to the compressor, with no long traps or dead ends that may cause oil to separate from the suction gas and return to the compressor in damaging slugs.
4. Liquid lines may be installed level.
5. Provide line size liquid indicators in the main liquid line leaving the condenser or receiver. Install moisture-liquid indicators in liquid lines between filter dryers and thermostatic expansion valves and in the liquid line to receiver.
6. Provide a line size strainer upstream of each automatic valve. Provide a shutoff valve on each side of the strainer.

7. Provide permanent filter dryers in low temperature systems and systems using hermetic compressors.
8. Provide replaceable cartridge filter dryers with three-valve bypass assembly for solenoid valves that are adjacent to receivers.
9. Provide refrigerant charging valve connections in the liquid line between the receiver shutoff valve and expansion valve.
10. Normally, only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem, and hot gas lines should be insulated where personal injury from contact may pose a problem.
11. Refrigerant lines should be installed a minimum of 7'6" above the floor.

F. Refrigerant Properties

1. Halocarbon refrigerants absorb 40-80 Btuh/lb., and ammonia absorbs 500-600 Btuh/lb.
2. Ammonia refrigeration systems require smaller piping than halocarbon refrigeration systems for the same pressure drop and capacity.
3. Human or living tissue contact with many refrigerants in their liquid state can cause instant freezing, frostbite, solvent defatting or dehydration, and/or caustic or acid burns.
4. Leak detectors are essential for all halocarbon refrigerants because they are generally heavier than air, are odorless, and can cause suffocation due to oxygen deprivation. Ammonia is lighter than air and has a distinctive and unmistakable odor.
5. Ammonia properties:
 - a. Refrigerant grade ammonia:
 1. 99.98 percent ammonia minimum.
 2. 0.015 percent water maximum.
 3. 3 ppm oil maximum.
 4. 0.2 mL/g noncondensable gases.
 - b. Agricultural grade ammonia:
 1. 99.5 percent ammonia minimum.

2. 0.5 percent water maximum.
3. 0.2 percent water minimum.
4. 5 ppm oil maximum.

c. Ammonia limitations are shown in the following table.

Concentration of Ammonia in the Air	Limitations/Symptoms
4 ppm	Detectable by human sense of smell.
25 ppm	Maximum ACGIH Permissible Exposure Limit (PEL). Maximum European Government Limit.
30–35 ppm	Uncomfortable—breathing support desired or required. Common level around ammonia print machines. Maximum recommended exposure 15 minutes (ACGIH).
50 ppm	Maximum OSHA and NIOSH Permissible Exposure Limit (PEL).
100 ppm	Noticeable irritation to the eyes, throat, and mucous membranes.
400 ppm	Mucous membranes may be destroyed with prolonged contact with ammonia. No serious health threat with infrequent and less-than-one-hour exposures.
500 ppm	Immediate Danger to Life and Health (IDLH) Limit.
700 ppm	Significant eye irritation.
1,700 ppm	Convulsive coughing occurs. Fatal after short exposures of less than one half hour.
2,500 ppm	Exposure in as short a time as 30

<p>2,500 ppm</p> <p>Concentration of Ammonia in the Air</p>	<p>Exposure in as short a time as 30 minutes is dangerous. Affects show up several days later—pulmonary edema (water in the lungs).</p> <p>Limitations/Symptoms</p>
5,000 ppm and above	<p>Immediate hazard to life due to suffocation. Full face respiratory protection is required, including eyes. Causes respiratory spasm, strangulation, and asphyxia—no exposure permissible.</p>
15,000 ppm and above	<p>Full body protection required. Ammonia reacts with body perspiration to form a caustic solution that attacks the skin causing burns and blisters.</p>
160,000–270,000 ppm	<p>Flammable in air at 68°F.</p>
15.5% by volume	<p>Lower Flammability Limit (LFL); also referred to Lower Explosive Limit (LEL)</p>

6. Refrigerant physical properties are shown in the following table.

Refrigerant Physical Properties								
Refrigerant		ASHRAE Std. 15 Group No.	Molecular Mass	Boiling Point at 14.7 Psia °F	Freezing Point °F	Critical		
No.	Name					Temp. °F	Press. psia	Volume ft. ³ /lb.
R-11	—	A1	137.38	74.87	-168.0	388.4	639.5	0.0289
R-12	—	A1	120.93	-21.62	-252.0	233.6	596.9	0.0287
R-13	—	A1	104.47	-114.60	-294.0	83.9	561.0	0.0277
R-13B1	—	A1	148.93	-71.95	-270.0	152.6	575.0	0.0215
R-14	—	A1	88.01	-198.30	-299.0	-50.2	543.0	0.0256
R-22	—	A1	86.48	-41.36	-256.0	204.8	721.9	0.0305
R-40	—	B2	50.49	-11.60	-144.0	289.6	968.7	0.0454
R-113	—	A1	187.39	117.63	-31.0	417.4	498.9	0.0278
R-114	—	A1	170.94	38.80	-137.0	294.3	473.0	0.0275
R-115	—	A1	154.48	-38.40	-159.0	175.9	457.6	0.0261
R-123	—	B1	152.93	82.17	-160.9	362.8	532.9	—
R-134a	—	A1	102.03	-15.08	-141.9	214.0	589.8	0.0290
R-142b	—	A2	100.50	14.40	-204.0	278.8	598.0	0.0368
R-152a	—	A2	66.05	-13.00	-178.6	236.3	652.0	0.0439
R-170	Ethane	A3	30.07	-127.85	-297.0	90.0	709.8	0.0830
R-290	Propane	A3	44.10	-43.73	-305.8	206.3	617.4	0.0728
R-C318	—	A1	200.04	21.50	-42.5	239.6	403.6	0.0258
R-410A	—	A1	72.58	-60.84	—	161.83	714.50	0.0328
R-500	—	A1	99.31	-28.30	-254.0	221.9	641.9	0.0323
R-502	—	A1	111.63	-49.80	—	179.9	591.0	0.0286
R-503	—	A1	87.50	-127.60	—	67.1	607.0	0.0326
R-600	Butane	A3	58.13	31.10	-217.3	305.6	550.7	0.0702
R-600a	Isobutane	A3	58.13	10.89	-255.5	275.0	529.1	0.0725
R-611	—	B2	60.05	89.20	-146.0	417.2	870.0	0.0459
R-717	Ammonia	B2	17.03	-28.00	-107.9	271.4	1657.0	0.0680
R-744	Carbon dioxide	A1	44.01	-109.20	-69.9	87.9	1070.0	0.0342
R-764	Sulfur dioxide	B1	64.07	14.00	-103.9	315.5	1143.0	0.0306
R-1150	Ethylene	A3	28.05	-154.7	-272.0	48.8	742.2	0.0700
R-1270	Propylene	A3	42.09	-53.86	-301.0	197.2	670.3	0.0720

**Refrigerant
Type**

Energy Absorption Rate Btu/lb.

40°F

20°F

0°F

-20°F

-40°F

R-11	80.863	82.507	84.126	85.732	87.335
R-12	64.649	66.953	69.098	71.116	73.038
R-22	86.503	90.344	93.891	97.193	100.296
R-123	76.787	78.078	79.167	80.162	81.340
R-134a	84.011	87.589	90.925	94.063	97.050
R-502	61.687	65.069	68.101	70.795	73.162
R-717 Ammonia	535.936	552.858	568.692	583.540	597.482

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Part 25: Air Handling Units

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25. Part 25: Air Handling Units

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25.01. Air Handling Units, Air Conditioning Units, Heat Pumps

A. Definitions

1. *Air Handling Units (AHUs)*. AHUs contain fans, filters, coils, and other items but do not contain refrigeration compressors.
2. *Air Conditioning Units (ACUs)*. ACUs are AHUs that contain refrigeration compressors.
3. *Heat Pumps*. Heat pumps are ACUs with refrigeration systems capable of providing heat to the space as well as cooling.

B. Air Handling Unit Types

1. Packaged AHUs (central station AHUs):
 - a. 800–50,000 CFM.
 - b. 0–9" SP.
 - c. 1/4–100 hp.
2. Factory-fabricated AHUs (custom AHUs):
 - a. 1,000–125,000 CFM.
 - b. 0–13" SP.
 - c. 1/4–500 hp.
 - d. Shipping limiting factor; two to three times more expensive than packaged

AHUs.

3. Field-fabricated AHUs:
 - a. 10,000–804,000 CFM.
 - b. 0–14" SP.
 - c. 2–2500 hp.
 - d. Fan size limiting factor.

C. Packaged Equipment, All Spaces

1. 300–500 CFM/ton @ 20°F ΔT .
2. 400 CFM/ton @ 20°F ΔT (typical).

D. Water Source Heat Pumps

1. Water heat rejection:
 - a. 2.0–3.0 GPM/ton @ 15–10°F ΔT .
 - b. 3.0 GPM/ton @ 10°F ΔT recommended.
2. 85–95°F Condenser water temperature.
3. 60–90°F Heat pump water loop temperatures:
 - a. Winter design: 60°F.
 - b. Summer design: 90°F.
4. Cooling tower, evap. cooler sizing:
 - a. $1.4 \times$ Block Cooling Load.
5. Supplemental heater sizing:
 - b. $0.75 \times$ Block Heating Load.

E. Geothermal Source Heat Pumps

1. Efficiencies:
 - a. Average: 3.5–4.7 COP; 12–16 EER.
 - b. High: 5.3–5.9 COP; 18–20 EER.
2. Vertical wells used for heat transfer are the most common system type in lieu of horizontal heat transfer sites.

3. Length of heat exchanger pipe required:
 - a. Range: 130 ft./ton–175 ft./ton.
 - b. Average: 150 ft./ton.
4. 50–110°F Heat pump water loop temperatures.
5. If the system is sized to meet cooling requirements, supplemental heat will not be required.
6. If the system is sized to meet heating requirements, a supplemental cooling tower will be required.
7. Pipe spacing:
 - a. Commercial: 15 ft. × 15 ft. center to center grid.
 - b. Residential: 10 ft. × 10 ft. center to center grid.

F. Air Handling Unit Fans

1. 1/2°F temperature rise for each 1" S.P. from fan heat.
2. See Part 26, Fans for more information.
3. A return air system with more than a 1/2" pressure drop should have a return air fan. A return air fan is also required if you intend to use an economizer and still maintain the space under a neutral or negative pressure.

G. Economizers

1. Water side economizers take advantage of low condenser water temperature to either precool entering air, assist in mechanical cooling, or to provide total system cooling.
2. Air side economizers take advantage of cool outdoor air to either assist in mechanical cooling or to provide total system cooling.
 - a. Dry bulb.
 - b. Enthalpy—required by energy conservation codes.

H. System Types

1. VAV systems:
 - a. Fans selected for 100 percent block airflow.
 - b. Normal operation 60–80 percent block airflow.

- c. Minimum airflow 30–50 percent block airflow.
2. Constant volume reheat systems:
 - a. Fans selected and operated at a 100 percent sum of peak airflow.
 - b. Constant volume systems are generally not permitted by energy conservation codes. If employed, a supply temperature reset must be employed.
3. Hybrid VAV/constant volume reheat systems:
 - a. Fans selected for 100 percent block airflow for VAV spaces, plus 100 percent sum of peak airflow for constant volume spaces.
 - b. Normal operation 60–80 percent of the system design airflow.
 - c. Minimum airflow 30–50 percent of the system design airflow.
4. Dual duct systems:
 - a. Cold deck designed for 100 percent of the sum of peak airflow.
 - b. Hot deck designed for 75–90 percent of the sum of peak airflow.
 - c. Fans selected and operated at 100 percent of the sum of peak airflow.
 - d. Dual duct systems are generally not permitted by energy conservation codes. If employed, a cold deck and hot deck supply temperature reset must be employed.
5. Dual duct VAV systems:
 - a. Cold deck designed for 100 percent of block airflow.
 - b. Hot deck designed for 75–90 percent of block airflow.
 - c. Fans selected for 100 percent block airflow.
 - d. Normal operation 60–80 percent block airflow.
 - e. Minimum airflow 30–50 percent block airflow.
6. Single zone and multizone systems:
 - a. Cold deck designed for 100 percent of the sum of peak airflow.
 - b. Hot deck designed for 75–90 percent of the sum of peak airflow.
 - c. Fans selected and operated at 100 percent of the sum of peak airflow.

I. Clearance Requirements

1. Minimum recommended clearance around air handling units and similar equipment is 24 inches on the nonservice side and 36 inches on the service side. Maintain minimum clearance for coil pull as recommended by the equipment manufacturer; this is generally equal to the width of the air handling unit. Maintain minimum clearance as required to open access and control doors on air handling units for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how large air handling units and similar equipment can be moved into and out of the building during the initial installation and after construction for maintenance and repair and/or replacement.

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25.02. Coils

A. General

1. Field-erected and factory-assembled air handling unit coils should be arranged for removal from the upstream side without dismantling supports. Provide galvanized structural steel supports for all coils (except the lowest coil) in banks over two coils high to permit the independent removal of any coil.
2. When air handling units are used to supply makeup air (100 percent OA) for smoke control/smoke management systems, water coil freeze up must be considered. Some possible solutions are listed in the following:
 - a. Provide preheat coil in AHU to heat the air from the outside design temperature to 45–50°F.
 - b. Provide control of the system to open all water coil control valves serving smoke control/smoke management systems to full open and circulate water through the coils.
 - c. Elect not to provide freeze protection with owner concurrence in the event a fire or other emergency occurs on a cold day. Also, many emergency situations are fairly short in duration. A follow-up letter should also be written.
3. Select water coils with tube velocities high enough at design flow so that tube velocities do not end up in the laminar flow region when the flow is reduced in response low-load conditions. Tube velocities become critical with units

designed for 100 percent outside air at low loads near 32°F. Higher tube velocity selection results in a higher water pressure drop for the water coil. Sometimes a trade-off between pressure drop and low load flows must be evaluated.

4. It is best to use water coils with same end connections to reduce flow imbalances caused by differences in velocity head.
5. In horizontal water coil headers, supply water flow should be downward, while return water flow should be upward for proper air venting.
6. Water coil flow patterns:
 - a. Multiple path, parallel flow, grid type coil.
 - b. Series flow, serpentine coil.
 - c. Series and parallel flow.

B. Air Handling Unit Coil Designations

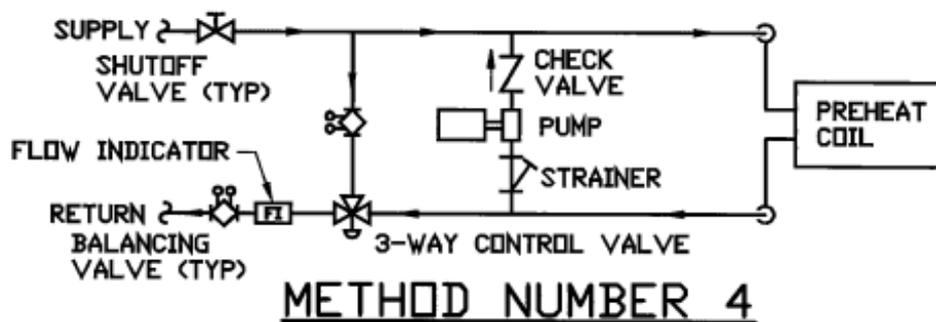
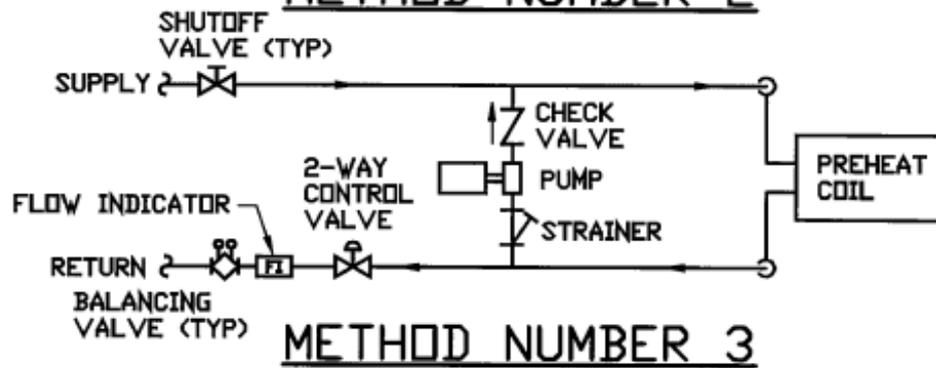
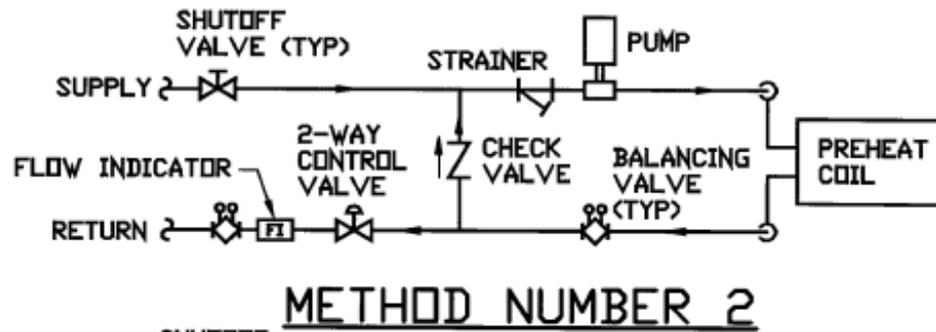
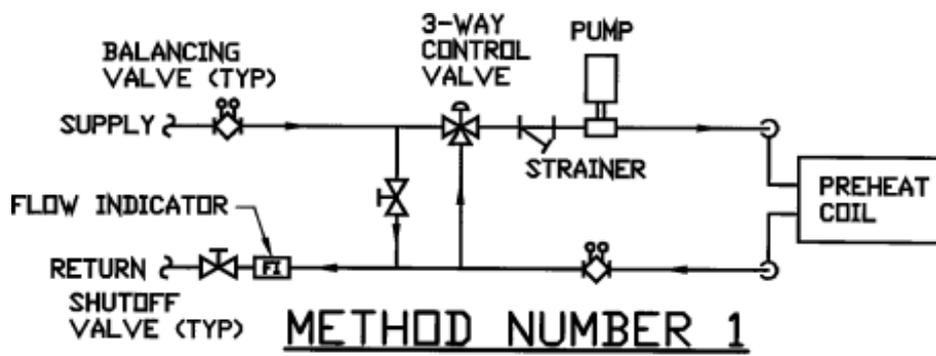
1. Preheat coils normally heat air to a desired setpoint level (quite often the setpoint is the cooling coil discharge temperature plus or minus 5°F). This setpoint temperature may or may not be adequate for maintaining space temperature for human comfort; however, it is generally adequate to prevent freezing and also for equipment room heating. Preheat coils may be hot water, steam, or electric type coils, or they may be direct-fired or indirect-fired gas heaters. Preheat coil (water or steam type) freeze protection methods are listed in the following:
 - a. Preheat pumps (primary/secondary system).
 - b. Internal face and bypass coils.
 - c. Integral face and bypass dampers.
 - d. Preheat coils are required whenever the design mixed air temperature is below 40°F or when 100 percent outside air units have an outside design temperature below 40°F.
2. Cooling coils provide both the sensible and latent cooling required to maintain temperature and humidity levels. Cooling coils are either chilled water or DX (refrigerant) type coils.
3. Heating coils are designed to maintain space temperatures acceptable for human comfort or process requirements. Heating coils should not operate

when cooling coils are operating. Automatic temperature control interlocks should be established to prevent simultaneous operation. Heating coils may be hot water, steam, or electric type coils, or they may be direct-fired or indirect-fired gas heaters.

4. Reheat coils will often operate in conjunction with cooling coils to maintain a temperature and/or relative humidity acceptable for human comfort or process requirements. Reheat coils may be hot water, steam, or electric type coils.

C. Water and Steam Coils

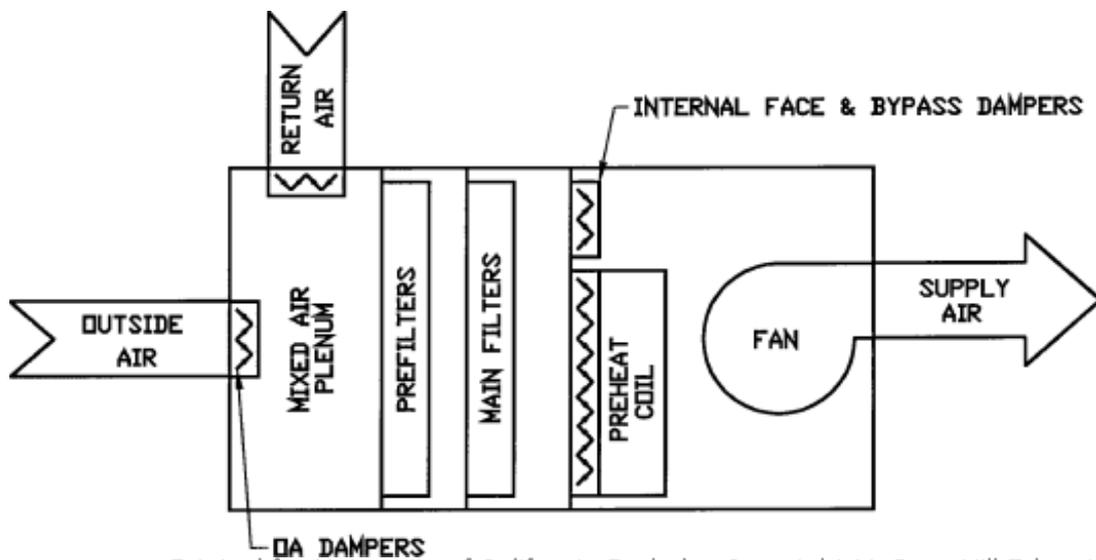
1. Preheat:
 - a. Concurrent air/water or steam flow.
 - b. Freeze protection:
 1. Preheat pumps (primary/secondary system). See [Fig. 25.1](#).



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Figure 25.1. PREHEAT COIL PIPING DIAGRAMS.

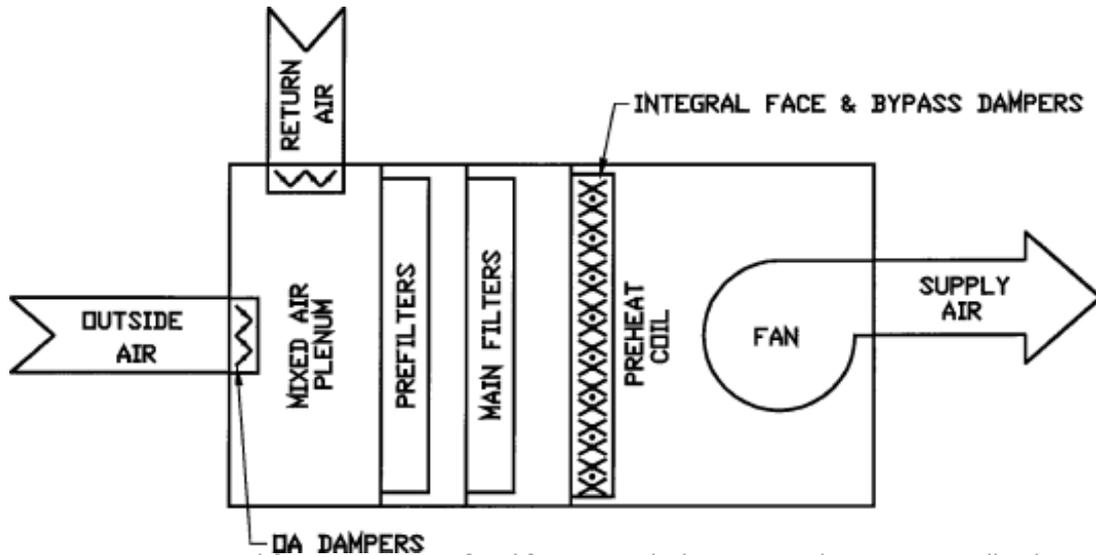
2. Face and bypass dampers—internal. See Fig. 25.2.



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Figure 25.2. AIR HANDLING UNITS W/INTERNAL FACE AND BYPASS DAMPERS (PREHEAT COIL FREEZE PROTECTION).

3. Integral face and bypass (IFB) coils. See Fig. 25.3.



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Figure 25.3. AIR HANDLING UNITS W/INTEGRAL FACE AND BYPASS DAMPERS (PREHEAT COIL FREEZE PROTECTION).

2. Cooling, heating, reheat:
 - a. Counter air/water or steam flow.
3. Cooling coil face velocity:
 - a. 450-550 fpm range.
 - b. 500 fpm recommended.
 - c. 450 fpm preferred.
4. Preheat, heating, and reheat coil face velocity:

- a. 500–900 fpm range.
- b. 600–700 fpm recommended.
- c. 600 fpm preferred.
- d. Use a preheat coil whenever the mixed air temperature (outside air and return air) is below 40°F.

D. Refrigerant Coils

1. Cooling:
 - a. Counter air/refrigerant flow.
 - b. Cooling coil face velocity:
 1. 450–550 fpm range.
 2. 500 fpm recommended.
 3. 450 fpm preferred.

E. Weight and Volume of Water in Standard Water Coils

1. Weight of water in the tubes:

$$W_{WT} = 0.966 \text{ lbs./row sq.ft.} \times \text{No. of Rows} \times \text{Face Area of Coil}$$

2. Total weight of water in coil:

$$W_{WC} = W_{WT} + W_{WH}$$

3. Total weight of water coils:

$$W_T = W_C + W_{WC}$$

4. Volume of water in coil:

$$V = W_{WC} \times 0.12$$

where

W_{WT} = water weight in the tubes (pounds)

W_{WH} = water weight in the headers/U-bends, from table (pounds)

W_{WC} = water weight in the coil (pounds)

W_C = dry coil weight (pounds)

W_T = total weight of the coil (pounds)

V = volume of the coil (gallons)

Weight of Water in Coil Headers and U-Bends

Finned Width	Number of Rows						
	1	2	3	4	5	6	8
6"	0.75	1.75	—	—	—	—	—
9"	1.00	2.75	—	—	—	—	—
12"	1.50	3.26	3.84	4.04	4.75	4.94	7.61
18"	2.75	3.94	4.82	5.07	6.21	8.70	13.10
24"	3.85	5.28	6.50	6.86	8.37	11.61	17.60
30"	4.72	8.66	10.12	10.50	12.48	16.52	24.00
33"	5.21	9.50	11.09	11.58	13.54	17.99	26.10
36"	—	16.34	19.58	22.82	26.06	29.30	32.55
42"	—	18.95	22.73	26.51	30.29	34.07	37.85
48"	—	21.55	25.88	30.20	34.52	38.84	43.16

F. Coil Pressure Drop

1. Air pressure drop (water, steam, refrigerant coils) is given in the following table:
 - a. Cooling coils:
 1. Range: 0.5–1.0" WC.
 2. Recommended schedule value: 0.75" WC.
 - b. Dehumidification/heat recovery coils:
 1. Range: 1.0–1.5" WC.
 2. Recommended schedule value: 1.25" WC.
 - c. Heating coils:
 1. Range: 0.1–0.25" WC.
 2. Recommended schedule value: 0.15" WC.

Number of Rows	Face Velocity (fpm)						
	450	500	550	600	700	800	900
1	0.05–0.15	0.05–0.18	0.08–0.20	0.08–0.25	0.12–0.30	0.15–0.40	0.17–0.50
2	0.10–0.35	0.11–0.50	0.15–0.50	0.16–0.60	0.20–0.80	0.25–0.90	0.32–0.90
4	0.20–0.70	0.22–0.90	0.28–1.00	0.33–1.20	0.40–1.50	0.50–1.80	0.65–1.70
6	0.30–1.10	0.35–1.30	0.45–1.50	0.50–1.70	0.65–2.30	0.75–2.80	1.00–2.70
8	0.40–1.50	0.45–1.75	0.60–2.00	0.60–2.40	0.85–3.00	1.00–3.70	1.30–3.70
10	0.50–1.75	0.60–2.25	0.70–2.50	0.80–3.00	1.10–3.80	1.30–4.50	1.70–4.50

2. Water pressure drop is given in the following table:

a. Cooling coils:

1. Range: 10–20 ft. H₂O.

2. Recommended schedule value: 15 ft. H₂O.

b. Dehumidification/heat recovery coils:

1. Range: 10–20 ft. H₂O.

2. Recommended schedule value: 15 ft. H₂O.

c. Heating coils:

1. Range: 1–5 ft. H₂O.

2. Recommended schedule value: 2.5 ft. H₂O.

Finned Width	Finned Length									
	12	24	36	48	60	72	84	96	108	120
12	0.11 8.77	0.13 10.1	0.14 11.6	0.15 13.1	0.16 14.6	0.17 16.2	0.18 17.7	0.19 19.2	0.20 20.7	0.21 22.2
18	0.07 6.31	0.09 7.65	0.10 9.16	0.11 10.7	0.12 12.2	0.13 13.7	0.14 15.2	0.15 16.7	0.16 18.2	0.17 19.7
24	0.09 8.21	0.11 9.55	0.12 11.1	0.13 12.6	0.14 14.1	0.15 15.6	0.16 17.1	0.17 18.6	0.18 20.1	0.19 21.7
30	0.12 10.3	0.14 11.6	0.15 13.2	0.16 14.7	0.17 16.2	0.18 17.7	0.19 19.2	0.20 20.7	0.21 22.2	0.22 23.7
33	0.15 11.4	0.17 12.7	0.18 14.2	0.19 15.7	0.20 17.2	0.21 18.7	0.22 20.2	0.23 21.8	0.24 23.3	0.25 24.8
36	0.17 13.2	0.19 14.5	0.20 16.1	0.21 17.5	0.22 19.0	0.23 20.5	0.24 22.1	0.25 23.6	0.26 25.1	0.27 26.6
42	0.20 14.7	0.22 16.1	0.23 17.5	0.24 19.1	0.25 20.6	0.26 22.1	0.27 23.6	0.28 25.1	0.29 26.6	0.30 28.1
48	0.22 16.4	0.24 17.8	0.25 19.3	0.26 20.8	0.27 22.3	0.28 23.8	0.29 25.3	0.30 26.8	0.31 28.3	0.32 29.8

Notes:

1. Pressure drops in feet H₂O/row.
2. Top row is based on water velocity of 1.0 FPS.
3. Bottom row is based on water velocity of 8.0 FPS.
4. Water velocity (FPS) = (GPM × 1.66)/finned width.
5. Based on W type coil.



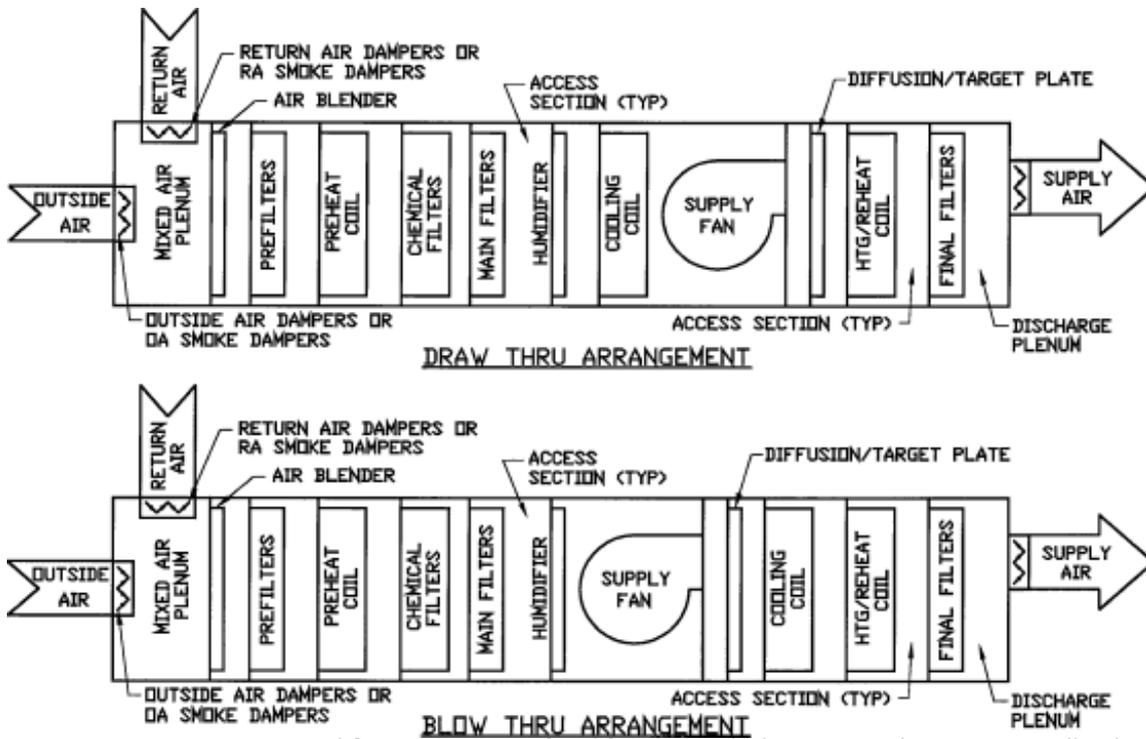
G. Electric Coils

1. Open coils: Use when personnel contact is not a concern. It is the most common type of electric coil used in HVAC applications.
 - a. Air pressure drops:

1. 400–900 fpm 0.01–0.10 WG.
- b. Minimum velocity:
 1. 400 fpm 6 KW/sq.ft. of duct.
 2. 500 fpm 8 KW/sq.ft. of duct.
 3. 600 fpm 10 KW/sq.ft. of duct.
 4. 700 fpm 12 KW/sq.ft. of duct.
 5. 800 fpm 14 KW/sq.ft. of duct.
 6. 900 fpm 16 KW/sq.ft. of duct.
 7. The manufacturer's literature should be consulted.
2. Finned tubular coils: Use when personnel contact is a concern.
 - a. Air pressure drops:
 1. 400–900 fpm 0.02–0.20 WG.
 - b. Minimum velocity:
 1. 400 fpm 6 KW/sq.ft. of duct.
 2. 500 fpm 9 KW/sq.ft. of duct.
 3. 600 fpm 12 KW/sq.ft. of duct.
 4. 700 fpm 15 KW/sq.ft. of duct.
 5. 800 fpm 17 KW/sq.ft. of duct.
 6. 900 fpm 20 KW/sq.ft. of duct.
 7. Manufacturer's literature should be consulted.

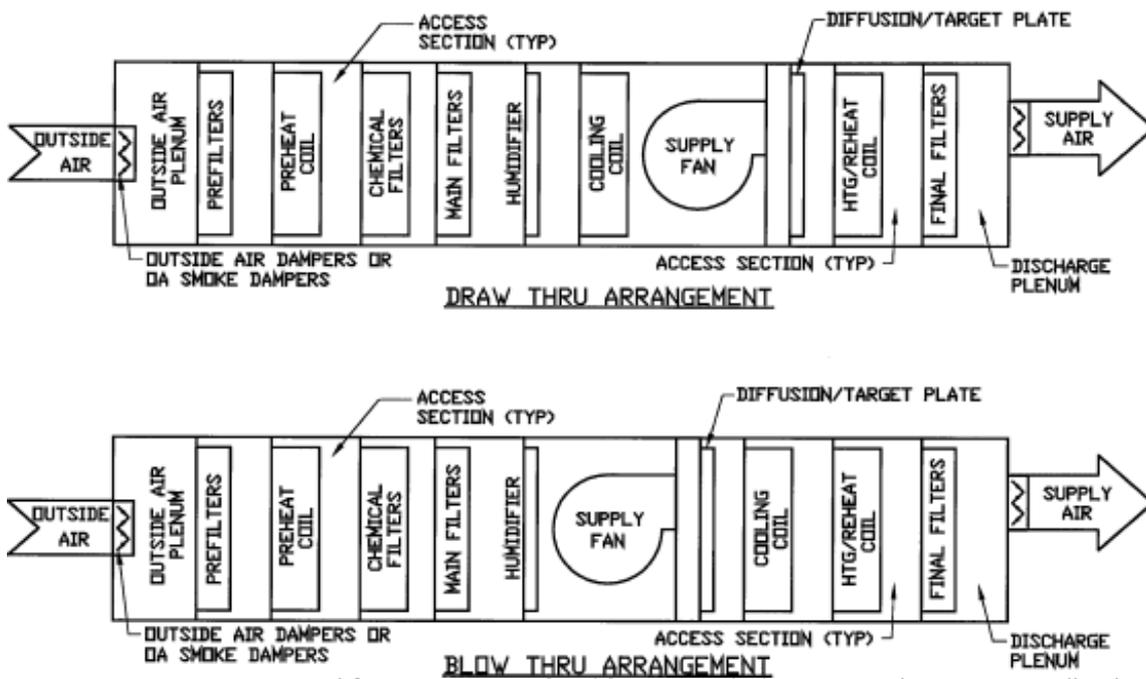
H. Air Handling Units

1. Blow through versus draw through: The terminology of blow through and draw through air handling units is generally in reference to the cooling coil location. If the cooling coil is downstream of the fan, the unit is considered a blow through air handling unit. If the cooling coil is upstream of the fan, the unit is considered a draw through air handling unit. See [Figs. 25.4](#) and [25.5](#).



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Figure 25.4. AIR HANDLING UNIT TERMINOLOGY.



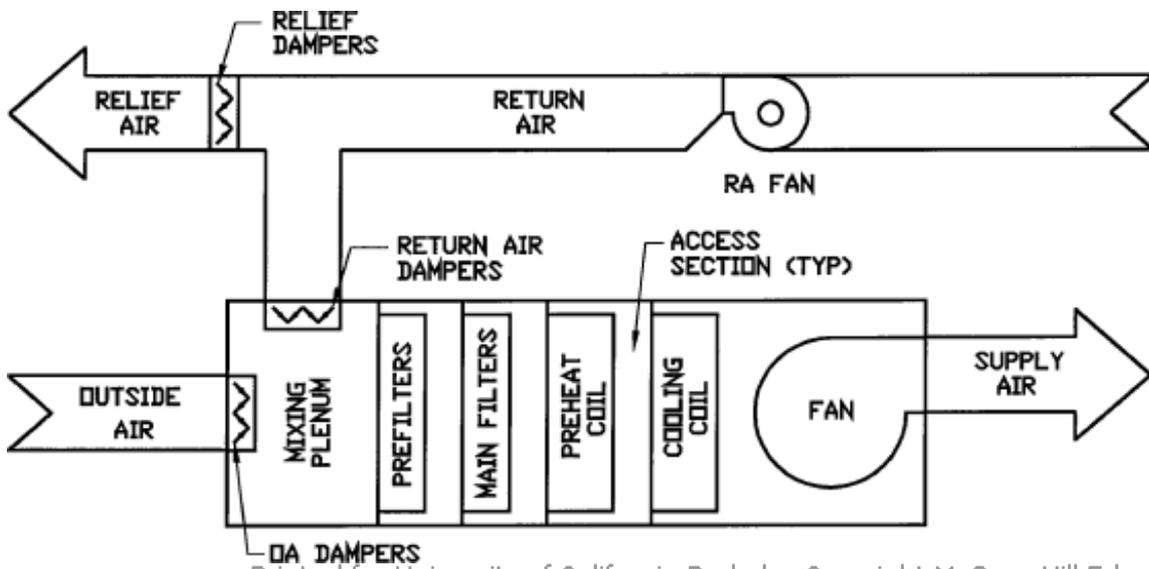
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Figure 25.5. 100 PERCENT O.A. AIR HANDLING UNIT TERMINOLOGY.

2. Air handling unit terminology drawings show a number of different components. The design of air handling units may incorporate any number or combination of the components.
3. Coil arrangements:

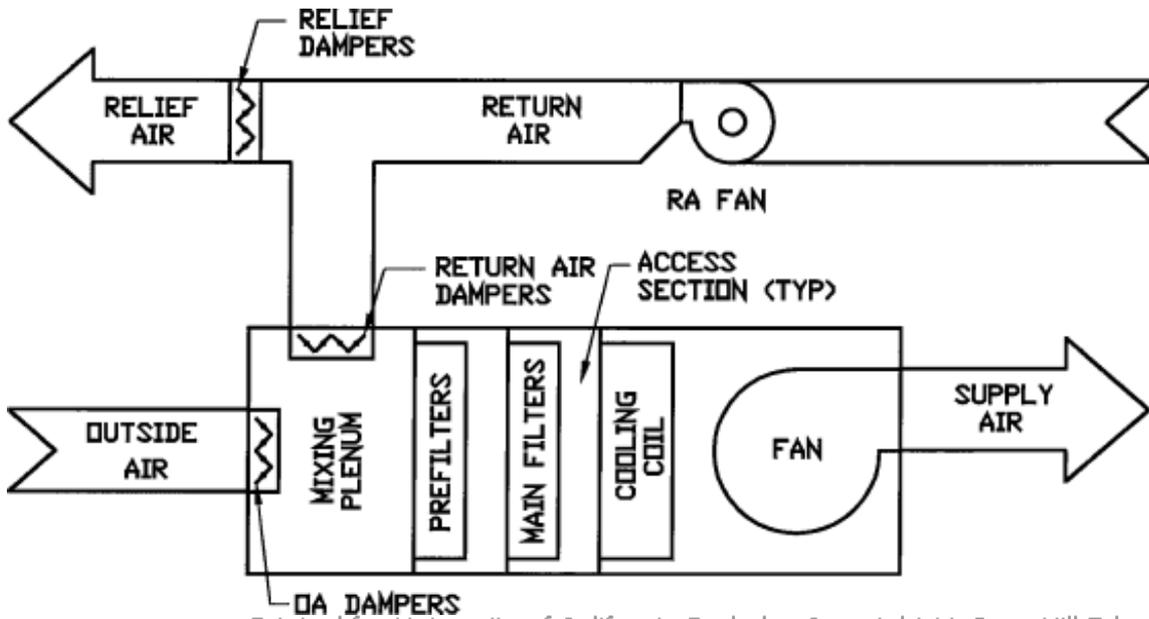
- a. Preheat/cooling: Preheat/cooling coil arrangements are used when mixed air or outside air design temperatures are below 40°F. The preheat coil heats the air to a desired setpoint level; quite often the setpoint is the cooling coil discharge temperature plus or minus 5°F. This setpoint temperature may or may not be adequate for maintaining space temperature for human comfort; however, it is generally adequate to prevent freezing and for equipment room heating.
 - b. Cooling/heating: Cooling/heating coil arrangements are used when the mixed air temperature will not fall below 40°F. Heating coils are designed to maintain space temperatures acceptable for human comfort or process requirements. Heating coils should not operate when cooling coils are operating. Automatic temperature control interlocks should be established to prevent simultaneous operation.
 - c. Heating/cooling: Heating/cooling coil arrangements are used when mixed air or outside air design temperatures are below 40°F. Heating coils are designed to maintain space temperatures acceptable for human comfort or process requirements. Heating coils should not operate when cooling coils are operating. Automatic temperature control interlocks should be established to prevent simultaneous operation.
 - d. Cooling/reheat: Cooling/reheat coil arrangements are used when air must be cooled to a temperature below that required to satisfy the space temperature to remove moisture and then heated to maintain space temperature.
4. Filter terminology:
- a. Prefilters (required):
 - 1. First stage of filtration.
 - 2. Filtration level guideline: 30–60 percent.
 - 3. Prefilters are required for air handling maintenance and operating requirements.
 - b. Main filters (recommended):
 - 1. Second stage of filtration.
 - 2. Filtration level guideline: 60–90 percent.

3. Two stages of filtration are recommended in nearly all air handling systems because of current and future indoor air quality standards and requirements.
- c. Final filters (optional):
1. Last stage of filtration.
 2. Filtration level guideline: 90 percent to HEPA/ULPA filtration levels.
 3. Use final filters whenever clean air is required at space (hospital operating rooms, nurseries, cleanrooms, laboratories).
5. Coils and filters located immediately downstream of fans will require a target/diffusion plate to distribute air evenly over the coil or filter and to prevent damage to that device, especially filters.
 6. Access sections are recommended between each and every component in the air handling unit. However, the prefilters may be adjacent to the main filters without access between them, provided both sets of filters (prefilters and main filters) can be removed without having to remove the other (side access or upstream/downstream access).
 7. Air blenders are used to promote proper mixing of the return air and the outside air flow streams and to prevent air stratification within the air handling unit. The use of air blenders will reduce the risk of localized freezing of water coils.
 8. Smoke dampers and smoke detectors have not been shown on the air handling unit flow diagrams. Smoke dampers and smoke detectors may be required in the supply, return, or outside air ductwork depending on unit capacity, service, and code requirements. Verify smoke damper and smoke detector requirements with NFPA 90A, IBC, and local code requirements.
 9. See [Figs. 25.6](#) through [25.10](#) for examples of air handling units and a few of the many possible arrangements.



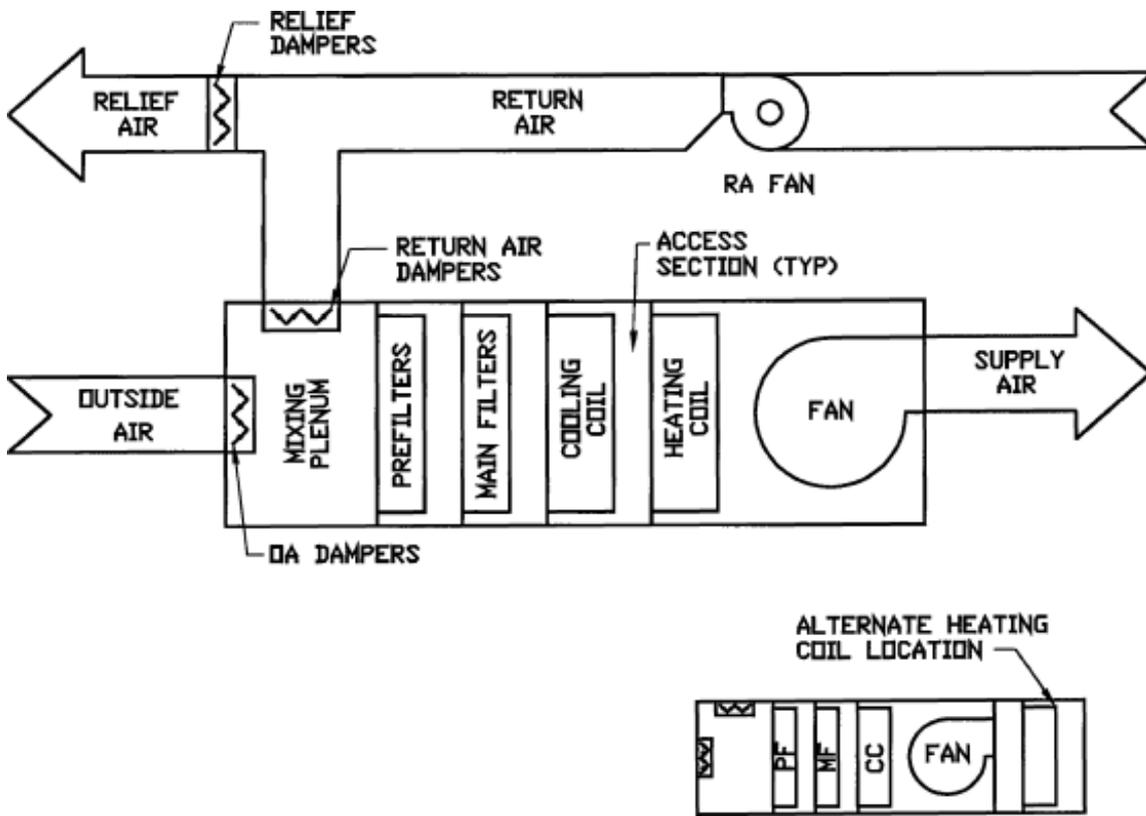
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Figure 25.6. AHU EXAMPLE 1 AIR HANDLING UNITS—W/PREHEAT AND COOLING COILS W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.



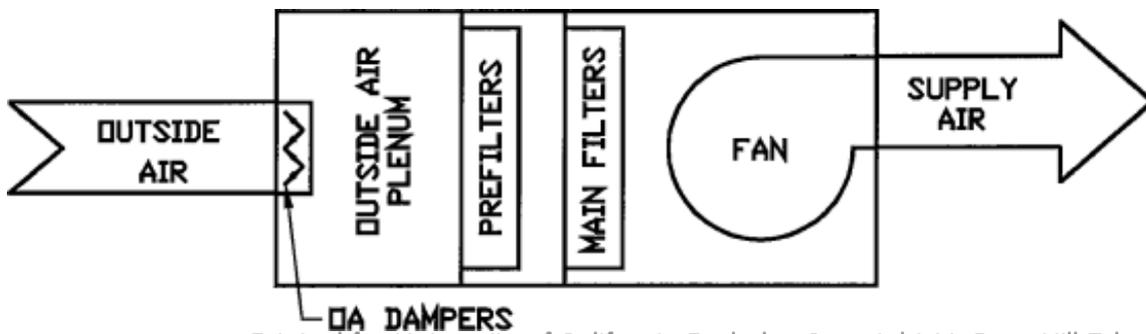
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Figure 25.7. AHU EXAMPLE 2 AIR HANDLING UNITS—W/COOLING COIL ONLY W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.



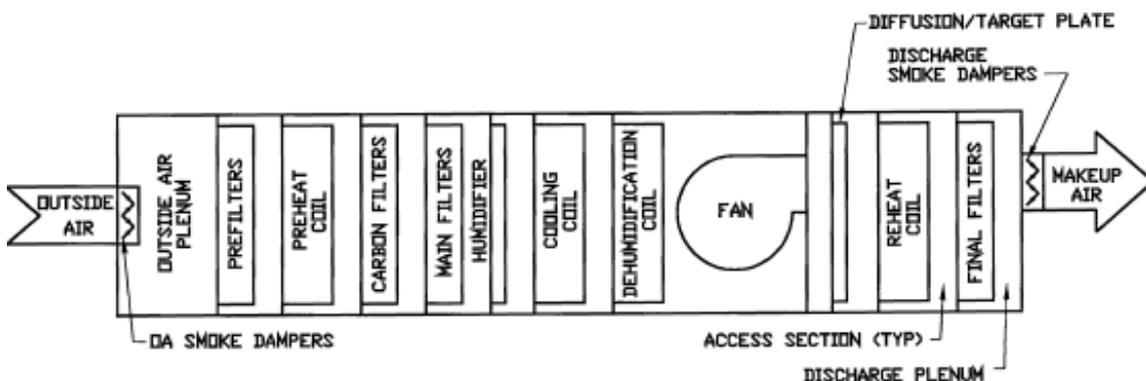
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Figure 25.8. AHU EXAMPLE 3 AIR HANDLING UNITS—W/COOLING AND HEATING COILS W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.



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Figure 25.9. AHU EXAMPLE 4 AIR HANDLING UNITS—VENTILATING 100 PERCENT OUTSIDE AIR.



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Figure 25.10. AHU EXAMPLE 5 CLEANROOM MAKEUP AIR HANDLING UNIT

W/CARBON FILTERS AND 100 PERCENT OUTSIDE AIR.

Citation

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Part 26: Fans

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26. Part 26: Fans

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26.01. Fan Types and Size Ranges

A. Fan types and size ranges are shown in the following table.

FAN COMPARISON TABLE

Fan Type	Wheel\Drive Type	Sp in. W.G.	Wheel Dia. in.	CFM	hp
Utility Sets	FC/B	0-3	8-36	200-	1/6-30
	BI/B	0-4	10-36	27,500	1/6-30
	FC/D	0-2.5	6-12	250- 27,500 100-3,500	1/6-3
Centrifugal	SWSI-BI/B	0-12	10-73	600-	1/3-200
	DWDI-BI/B	0-12	12-73	123,000	1/3-400
	SWSI-AF/B	0-14	18-120	1,300-	1/3-
	DWDI-AF/B	0-14	18-120	225,000 1,400- 447,000 2,400- 804,000	1500 3/4- 2500
Tubular Centrifugal	BI/B	0-9	10-108	450-	1/3-750
	BI/D			332,000	
Notes: Axial	-/B	0-5	18-72	1,400-	1/3-100
FC—Forward-Curved	-/D	0-4	18-60	115,000	1/3-150

FAN COMPARISON TABLE					
Fan Type	Wheel\Drive Type	Sp in.	Wheel Dia in.	CFM	hp
Tubeaxial	-/B -/D	0-15 0-1	18-48	1,200-148,000 900-76,000 2,600-48,000	1/3-25 1/4-15
Mixed Flow	-/B -/D	0-8.5 0-9.0	15-54 15-54	2,000-95,000 1,000-95,000	1/4-100 1/4-100
Propeller	-/B -/D	0-1 0-1	20-72 8-48	400-80,000 50-49,000	1/4-15 1/6-10
Roof Ventilator	BI/B BI/D	0-1.25 0-1	7-54 6-18	100-34,000 75-3,200	1/4-7.5 1/8-3/4
Roof Upblast	BI/B BI/D	0-1.25 0-1.25	9-48 9-14	200-26,000 300-3,100	1/4-5 1/8-1
Sidewall	BI/B BI/D	0-1.25 0-1	14-24 6-18	850-8,200 80-4,000	1/4-2 1/8-3/4
Inline Centrifugal	BI/B BI/D	0-2.25 0-1.75	7-36 6-16	60-22,600 60-5,100	1/4-10 1/8-2

Notes:

FC—Forward Curved

BI—Backward Inclined

AF—Backward Inclined Airfoil

B—Belt Drive

D—Direct Drive

DWDI—Double Width, Double Inlet

SWSI—Single Width, Single Inlet

B. Refer to Figure 26.1 for a photograph of a roof ventilator in its installed condition.



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Figure 26.1. PHOTOGRAPH OF A ROOF VENTILATOR.

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26.02. Fan Construction Classes

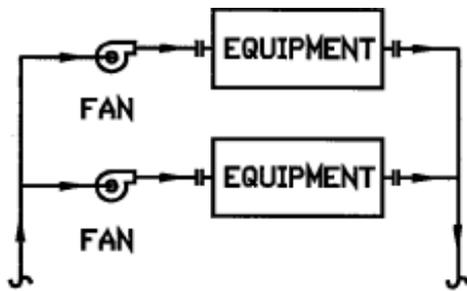
A. Fan construction classes are shown in the following table:

Fan Class	Maximum Total Pressure
I	3-3/4" W.G.
II	6-3/4" W.G.
III	12-3/4" W.G.
IV	Over 12-3/4" W.G.

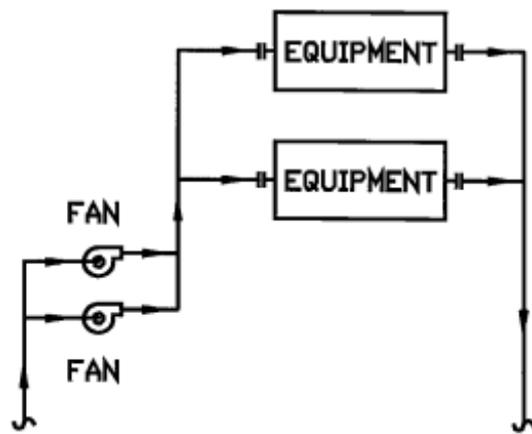
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26.03. Fan Selection Criteria

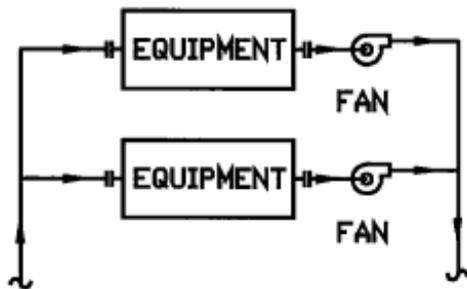
- A. Fan to be catalog rated for 15 percent greater static pressure (SP) than specified SP at specified volume.**
- B. Select the fan so that the specified volume is greater than at the apex of the fan curve.**
- C. Select the fan to provide a stable operation down to 85 percent of the design volume operating at a required speed for the specified conditions.**
- D. Specify SP at specified airflow.**
- E. Consider system effects. Fans are tested with open inlets and a length of straight duct on discharge. When field conditions differ from the test configuration, performance is reduced. Therefore, the fan must be selected at a slightly higher pressure to obtain the desired results.**
- F. Fan Design Arrangements (See Figure 26.2)**



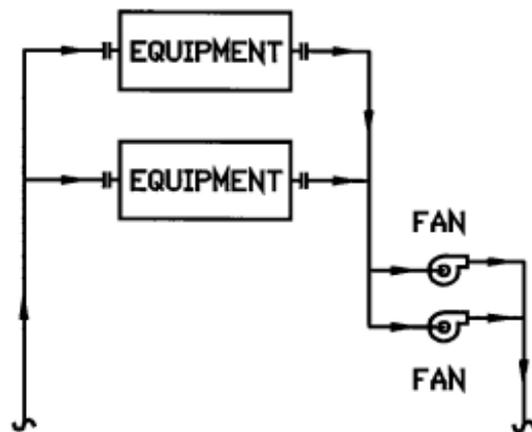
COUPLED FANS



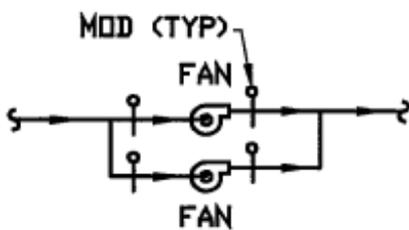
HEADERED FANS



COUPLED FANS

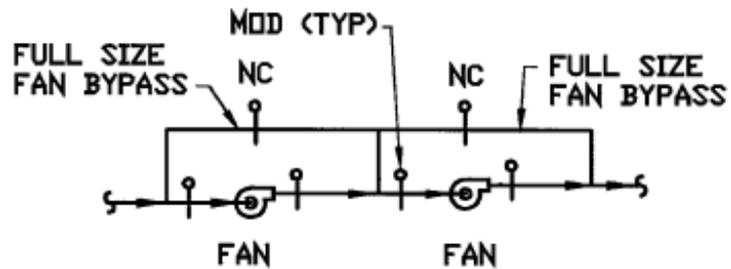


HEADERED FANS



PARALLEL FANS

NOTE: EQUAL SP, CFM ADDITIVE



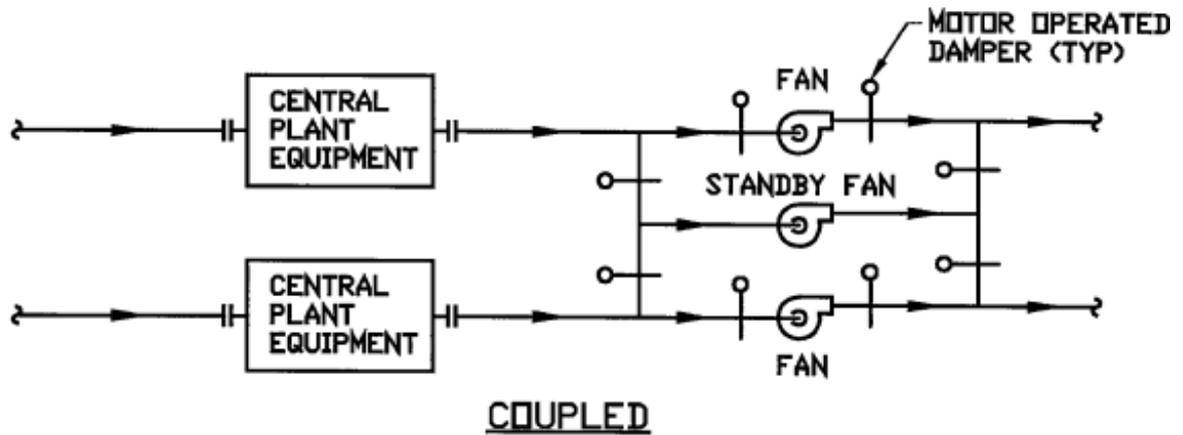
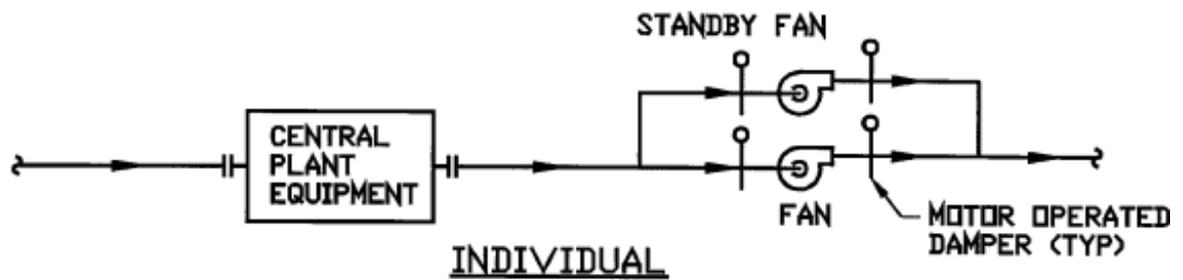
SERIES FANS W/BYPASSES

NOTES: EQUAL CFM, SP ADDITIVE
BYPASSES NOT ALWAYS PROVIDED

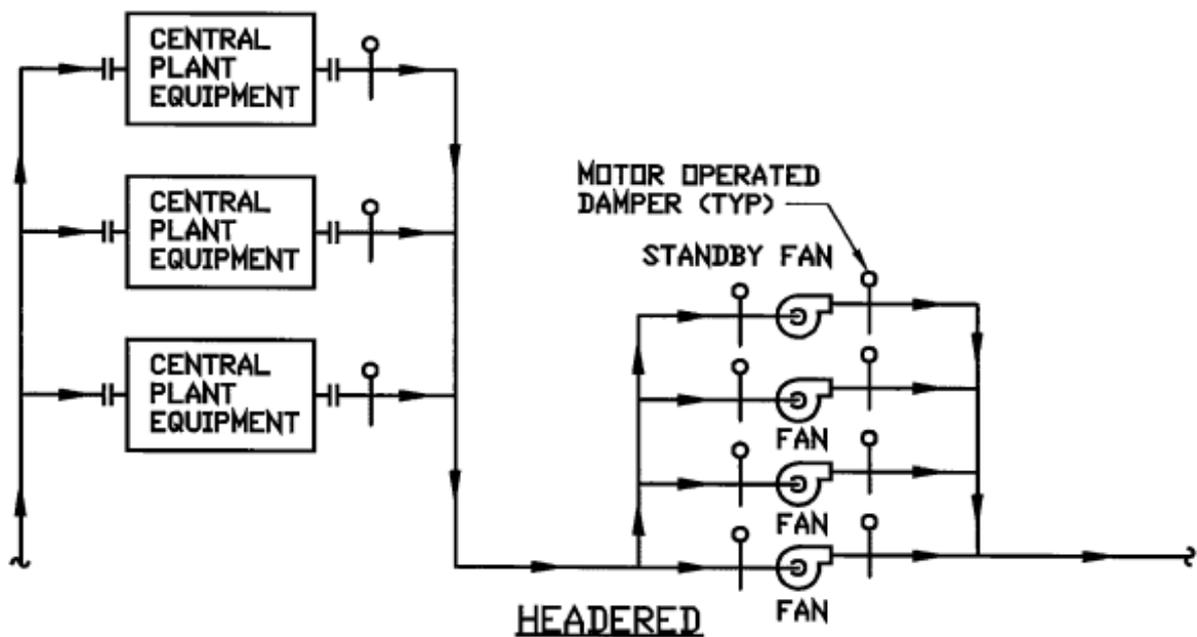
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Figure 26.2. FAN SYSTEM ARRANGEMENTS.

1. Series Fan Operation: At equal CFM, static pressure is additive.
2. Parallel Fan Operation: At equal static pressure, CFM is additive.
3. Standby Fans: Standby fan arrangements are often used for reliability purposes in the event of fan failure. Standby fans may be provided with coupled or headered systems (see [Figs. 26.3](#) and [26.4](#)).



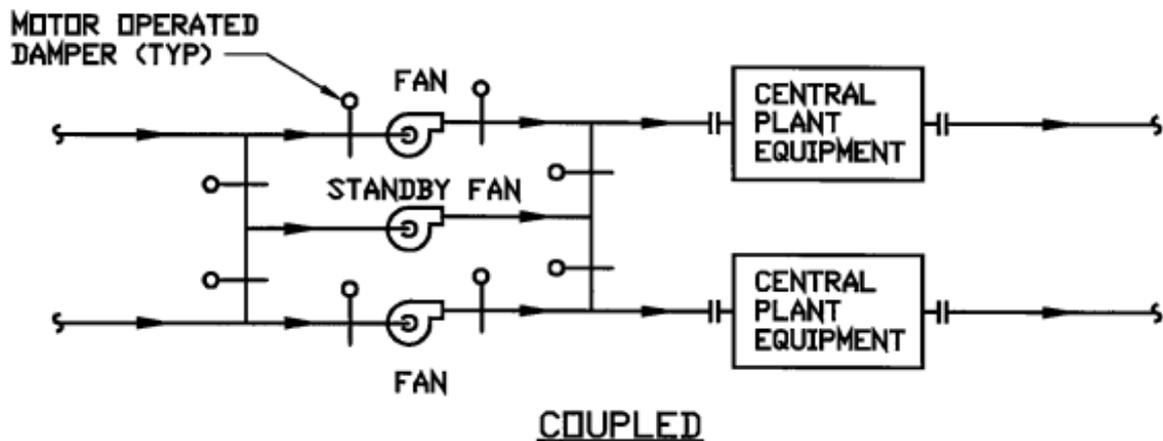
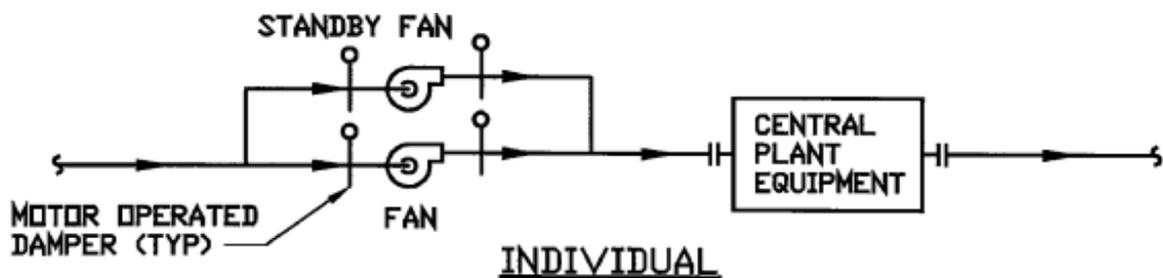
NOTE: STANDBY FAN MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.



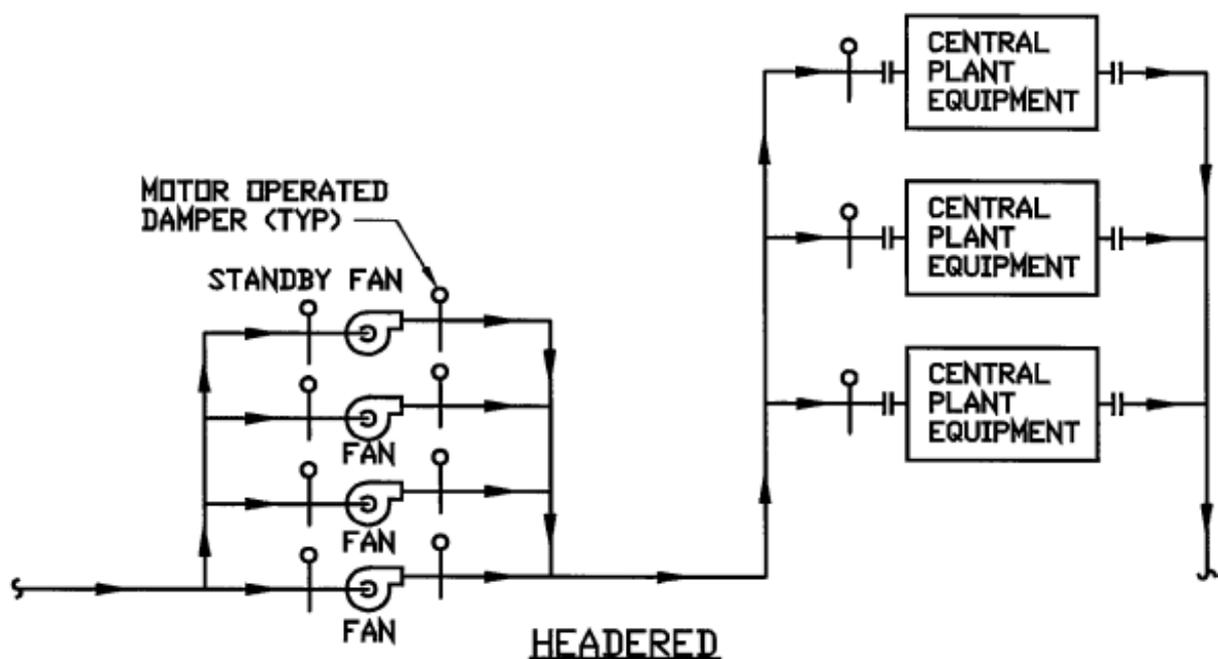
NOTE: STANDBY FAN MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

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Figure 26.3. STANDBY FANS.



NOTE: STANDBY FAN MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.



NOTE: STANDBY FAN MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

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Figure 26.4. STANDBY FANS.

- G. Every attempt should be made to have 1.0-1.5 diameters of straight duct on the discharge of the fan as a minimum.
- H. There should be a minimum of 1.0 diameter of straight duct between fan inlet and an elbow. In plenum installations, there should be a minimum of 0.75 of the wheel diameter between the fan inlet and the plenum wall.

26.04. Fan Terms

- A. ***Centrifugal.*** Flow within the fan is substantially radial to the shaft.
- B. ***Axial.*** Flow within the fan is substantially parallel to the shaft.
- C. ***Static Pressure.*** Static pressure is the compressive pressure that exists in a confined airstream. Static pressure is a measure of potential energy available to produce flow and to maintain flow against resistance. Static pressure is exerted in all directions and can be positive or negative (vacuum).
- D. ***Velocity Pressure.*** Velocity pressure is the measure of the kinetic energy resulting from the fluid flow. Velocity pressure is exerted in the direction of fluid flow. Velocity pressure is always positive.
- E. ***Total Pressure.*** Total pressure is the measure of the total energy of the airstream. Total pressure is equal to static pressure plus velocity pressure. Total pressure can be either positive or negative.
- F. ***Quantity of Airflow.*** Volume measurement expressed in Cubic Feet per Minute (CFM).
- G. ***Fan Outlet Velocity.*** Fan airflow divided by the fan outlet area.
- H. ***Fan Velocity Pressure.*** Fan velocity pressure is derived by converting fan velocity to velocity pressure.
- I. ***Fan Total Pressure.*** Fan total pressure is equal to the fan's outlet total pressure minus the fan's inlet total pressure.
- J. ***Fan Static Pressure.*** Fan static pressure is equal to the fan's total pressure minus the fan's velocity pressure. Numerically, it is equal to the fan's outlet static pressure minus the fan's inlet total pressure.
- K. ***Fan Horsepower.*** Theoretical calculation of horsepower assuming there are no losses.
- L. ***Brake Horsepower (BHP).*** Brake horsepower is the actual power required to drive the fan.
- M. ***System Effect.*** System effect is the reduced fan performance of the manufacturer's fan catalog data due to the difference between field

installed conditions and laboratory test conditions (precisely defined inlet and outlet ductwork geometry assuring uniform entrance and exit velocities).

1. Maintain a minimum of three duct diameters of straight duct upstream and downstream of the fan inlet and outlet at 2,500 feet per minute (fpm) duct velocity or less. One additional duct diameter should be added for each 1,000 fpm above 2,500 fpm.
2. Recommend maintaining a minimum of five duct diameters of straight duct upstream and downstream of the fan inlet and outlet at 2,500 feet per minute (fpm) duct velocity or less. One additional duct diameter should be added for each 1,000 fpm above 2,500 fpm.
3. The system effect may require a range of 3–20 duct diameters of straight duct upstream and downstream of the fan inlet and outlet.

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26.05. AMCA Spark Resistant Construction

- A. Type A. All parts of the fan in contact with the airstream must be made of nonferrous material.**
- B. Type B. The fan shall have a nonferrous impeller and nonferrous ring about the opening through which the shaft passes. Ferrous hubs, shafts, and hardware are allowed if construction is such that a shift of the impeller or shaft will not permit two ferrous parts of the fan to rub or strike.**
- C. Type C. The fan must be so constructed that a shift of the wheel will not permit two ferrous parts of the fan to rub or strike.**

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26.06. Centrifugal Fans

A. Forward Curved (FC) Fan

1. FC fans have a peak static pressure curve corresponding to the region of maximum efficiency, slightly to the right. Best efficiency at low or medium pressure (0–5 in. W.G.).
2. BHP is minimum at no delivery and increases continuously with increasing flow, with maximum BHP occurring at free delivery.

3. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.
4. Fan blades curve toward the direction of rotation.
5. Advantages:
 - a. Low cost. Less expensive than BC, BI, or AF fans.
 - b. Low speed (400–1,200 RPM) minimizes the shaft and bearing sizes.
 - c. Large operating range: 30–80 percent wide open CFM.
 - d. Highest efficiency occurs: 40–50 percent wide open CFM.
6. Disadvantages:
 - a. Possibility of paralleling in multiple fan applications.
 - b. Possibility of overloading.
 - c. Weak structurally: Not capable of high speeds necessary for developing high static pressures.
7. Used primarily in low- to medium-pressure HVAC applications: central station air handling units, rooftop units, packaged units, residential furnaces.
8. High CFM, low static pressure.

B. Backward Inclined (BI) and Backward Curved (BC) Fans

1. BC fans have a peak static pressure curve that occurs to the left of the maximum static efficiency. Best efficiency at medium pressure (3.5–5.0 in. W.G.).
2. BHP increases to a maximum, and then decreases. They are nonoverloading fans.
3. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.
4. Fan operates at high speeds—1,200–2,400 RPM—about double that of FC fans for similar air quantity.
5. Blades curve away from, or incline from, the direction of rotation.
6. BI fans are less expensive than BC fans but do not have as great a range of high efficiency operation.

7. Advantages:
 - a. Higher efficiencies than FC fans.
 - b. Highest efficiency occurs: 50–60 percent wide open CFM.
 - c. Good pressure characteristics.
 - d. Stronger structural design makes it suitable for higher static pressures.
 - e. Nonoverloading power characteristics.
8. Disadvantages:
 - a. Higher speeds require larger shaft and bearings.
 - b. Has a larger surge area than a forward curved fan.
 - c. Operating range 40–80 percent of wide open CFM.
 - d. Can be noisier than FC fans.
 - e. More expensive than FC fans.
9. Used primarily in large HVAC applications where power savings are significant.
Can be used in low-, medium-, and high-pressure systems.

C. Airfoil Fans (AF)

1. AF fans have a peak static pressure curve that occurs to the left of the maximum static efficiency. Best efficiency at medium pressure (4.0–8.0 in. W.G.).
2. BHP increases to a maximum, and then decreases. They are nonoverloading fans.
3. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.
4. Fan operates at high speeds—1,200–2,800 RPM—about double that of FC fans for similar air quantity.
5. Blades have an aerodynamic shape similar to an airplane wing and are backwardly curved (away from direction of rotation).
6. Advantages:
 - a. Higher efficiencies than FC fans.

- b. Highest efficiency occurs: 50–60 percent wide open CFM.
 - c. Good pressure characteristics.
 - d. Stronger structural design makes it suitable for higher static pressures.
 - e. Nonoverloading power characteristics.
7. Disadvantages:
- a. Higher speeds require a larger shaft and bearings.
 - b. Has a larger surge area than a forward curved fan.
 - c. Operating range 40–80 percent of wide open CFM.
 - d. Can be noisier than FC fans.
 - e. Most expensive centrifugal fan.
8. Used primarily in large HVAC applications where power savings are significant. Can be used in low-, medium-, and high-pressure systems.
9. Airfoil blade fans have a slightly higher efficiency and the surge area is slightly larger than backward inclined or backward curved fans.

D. Radial (RA) Fans

- 1. Radial fans have self-cleaning blades.
- 2. Fan horsepower increases with an increase in air quantity (overloads), while static pressure decreases.
- 3. RA fans operate at high speed and pressure—2,000–3,000 RPM.
- 4. Blades radiate from the center along the radius of fan.
- 5. Used in industrial applications to transport dust, particles, or materials handling. Not commonly used in HVAC applications.

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26.07. Axial Fans

A. Propeller Fans

- 1. Low pressure, high CFM fans.

2. Horsepower is lowest at maximum flow.
3. Maximum efficiency is approximately 50 percent and is reached near free delivery.
4. No ductwork.
5. Blade rotation is perpendicular to the direction of airflow.
6. Advantages:
 - a. High volumes, low pressures.
 - b. BHP is lowest at free delivery.
 - c. Inexpensive.
 - d. Operates at relatively low speeds—900–1,800 RPM.
7. Disadvantages:
 - a. Cannot handle static pressure.
 - b. BHP increases with static pressure; could overload and shut off.
 - c. Air delivery decreases with increases in air resistance.

B. Tubeaxial Fans

1. Heavy duty propeller fans arranged for duct connection. Fan blades have aerodynamic configuration.
2. Slightly higher efficiency than propeller fans.
3. Discharge air pattern is circular in shape and swirls, producing higher static losses in the discharge duct.
4. Used primarily in low- and medium-pressure, high-volume, ducted HVAC applications where the discharge side is not critical. Also used in industrial applications: fume hoods, spray booths, drying ovens.
5. Fans operate at high speeds—2,000–3,000 RPM.
6. Fans are noisy.
7. Fans may be constructed to be overloading or nonoverloading. Nonoverloading type fans are more common.

8. Advantages:
 - a. Straight through design.
 - b. Space savings.
 - c. Capable of higher static pressures than propeller fans.

9. Disadvantages:
 - a. The discharge swirl creates higher pressure drops.
 - b. High noise level.

C. Vaneaxial Fans

1. Vaneaxial fans are tubeaxial fans with additional vanes to increase efficiency by straightening out airflow.
2. Vaneaxial fans are more costly than tubeaxial fans.
3. High-pressure characteristics with medium flow rate capabilities.
4. Fans operate at high speeds—2,000–3,000 RPM.
5. Fans are noisy.
6. Fans may be constructed to be overloading or nonoverloading. Nonoverloading type fans are more common.
7. Typical selection: 65–95 percent wide open CFM.
8. Used in general HVAC applications—low-, medium-, and high-pressure—where straight through flow and compact installation are required. Also used in industrial applications: usually more compact than comparable centrifugal type fans for the same duty.
9. Advantages:
 - a. Discharge vanes increase efficiency and reduce discharge losses.
 - b. Reduced size and straight through design.
 - c. Space savings.
 - d. Capable of higher static pressures than propeller fans.
10. Disadvantages:
 - a. Maximum efficiency only 65 percent.

b. Selection range: 65–90 percent wide open CFM.

c. High noise level.

D. Tubular Centrifugal Fans

1. Tubular centrifugal fans are similar to backward inclined centrifugal fans except that the fan capacity and pressure capabilities are lower.
2. Tubular centrifugal fans have a lower efficiency than backward inclined centrifugal fans.
3. Tubular centrifugal fans have a peak static pressure curve that occurs to the left of the maximum static efficiency.
4. BHP increases to a maximum, and then decreases. They are nonoverloading fans.
5. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly affect CFM.
6. The fan operates at high speeds—1,200–2,400.
7. Blades curve away from, or incline from, the direction of rotation.
8. Advantages:
 - a. Good pressure characteristics.
 - b. Nonoverloading power characteristics.
 - c. The fan has straight through flow for inline duct applications.
9. Disadvantages:
 - a. Higher speeds require a larger shaft and bearings.
 - b. An operating range 40–80 percent of wide open CFM.
 - c. Can be noisy.
10. Primarily used for low-pressure, return air HVAC systems.

E. Mixed Flow Fans

1. Mixed flow fans combine the best properties of tubeaxial, vaneaxial, and tubular centrifugal fans.

2. Mixed flow fans operate at a lower RPM than tubeaxial, vaneaxial, or centrifugal fans, resulting in less noise.
3. Used in general HVAC applications, low-, medium-, and high-pressure, where straight through flow and compact installation are required. Also used in industrial applications: usually more compact than comparable centrifugal type fans for the same duty.
4. Advantages:
 - a. Less noisy than either the tubeaxial or vaneaxial fans.
 - b. More efficient and therefore reduced horsepower requirements over tubeaxial, vaneaxial, or tubular centrifugal fans.
 - c. Smaller physical size for equal airflow and static pressure requirements than tubeaxial, vaneaxial, or tubular centrifugal fans.
 - d. Generally less expensive than comparable tubeaxial, vaneaxial, or tubular centrifugal fans.

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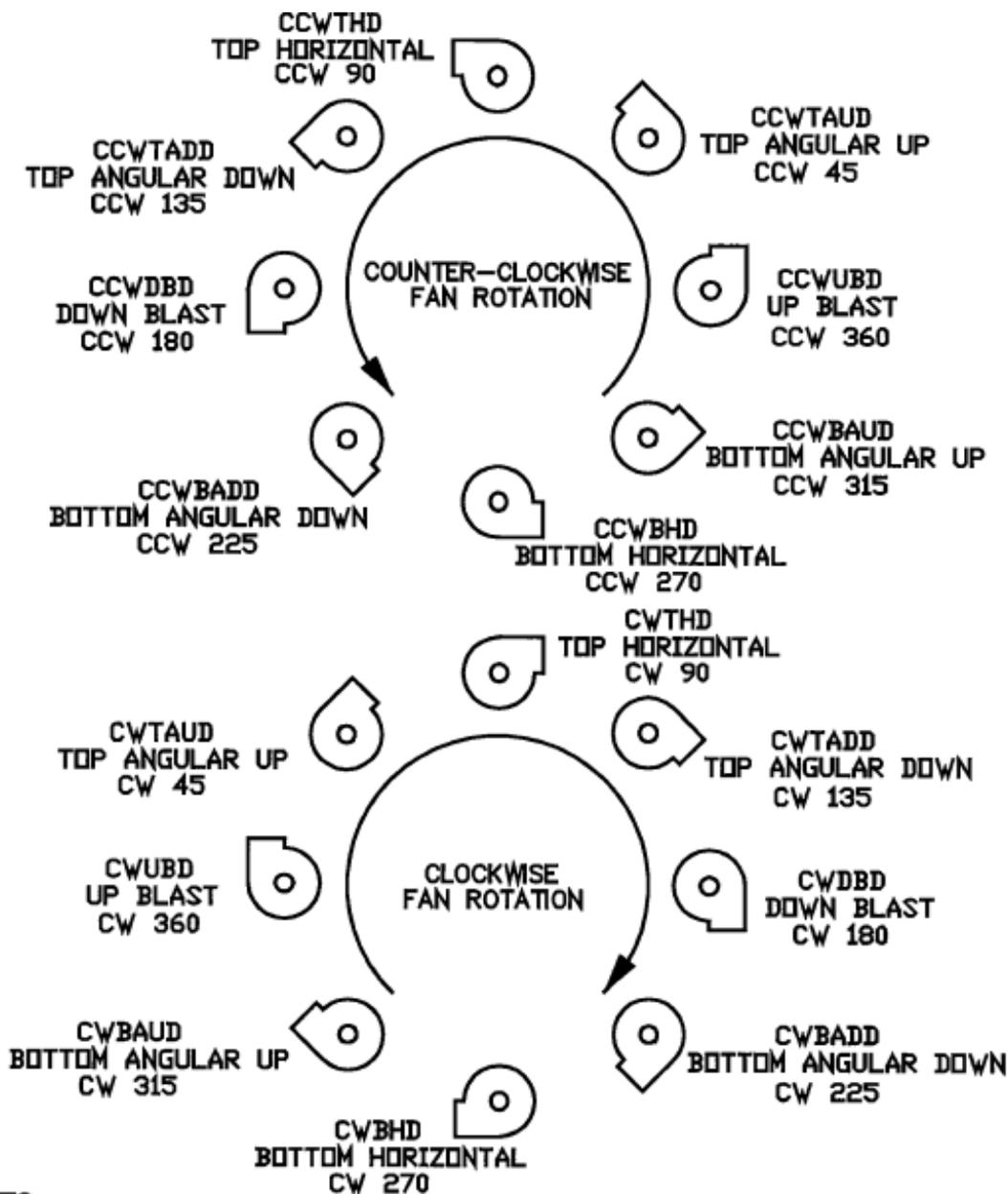
26.08. Installation and Clearance Requirements

- A. **The minimum recommended clearance around fans is 24 inches. Maintain minimum clearance as required to open access and control doors on fans for service, maintenance, and inspection.**
- B. **Mechanical room locations and placement must take into account how fans can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

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26.09. Fan Rotation and Discharge Positions

See [Fig. 26.5](#).



NOTES:

1. DIRECTION OF ROTATION IS DETERMINED FROM DRIVE SIDE OF FAN. ON SINGLE INLET FANS, THE DRIVE SIDE OF THE FAN IS ALWAYS CONSIDERED THE SIDE OPPOSITE THE FAN INLET.
2. ON DOUBLE INLET FANS, WHEN THE DRIVES ARE ON BOTH SIDES OF THE FAN, THE DRIVE SIDE OF THE FAN IS THE SIDE HAVING THE HIGHER HORSEPOWER DRIVING UNIT.
3. DIRECTION OF DISCHARGE IS DETERMINED IN ACCORDANCE WITH THE DIAGRAMS.
4. ANGULAR DISCHARGE IS REFERENCED TO THE HORIZONTAL AXIS OF THE FAN AND DESIGNATED IN DEGREES ABOVE OR BELOW THIS REFERENCE.
5. FANS INVERTED FOR CEILING SUSPENSION, OR SIDE WALL MOUNTING, DIRECTION OF ROTATION AND DISCHARGE IS DETERMINED WHEN FAN IS RESTING ON THE FLOOR.

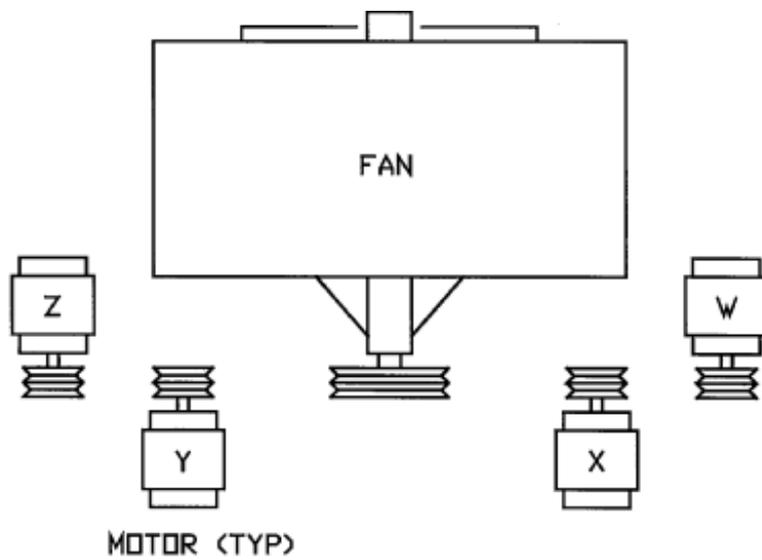
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Figure 26.5. FAN ROTATION AND DISCHARGE POSITIONS.

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26.10. Fan Motor Positions

See [Figs. 26.6](#) and [26.7](#).

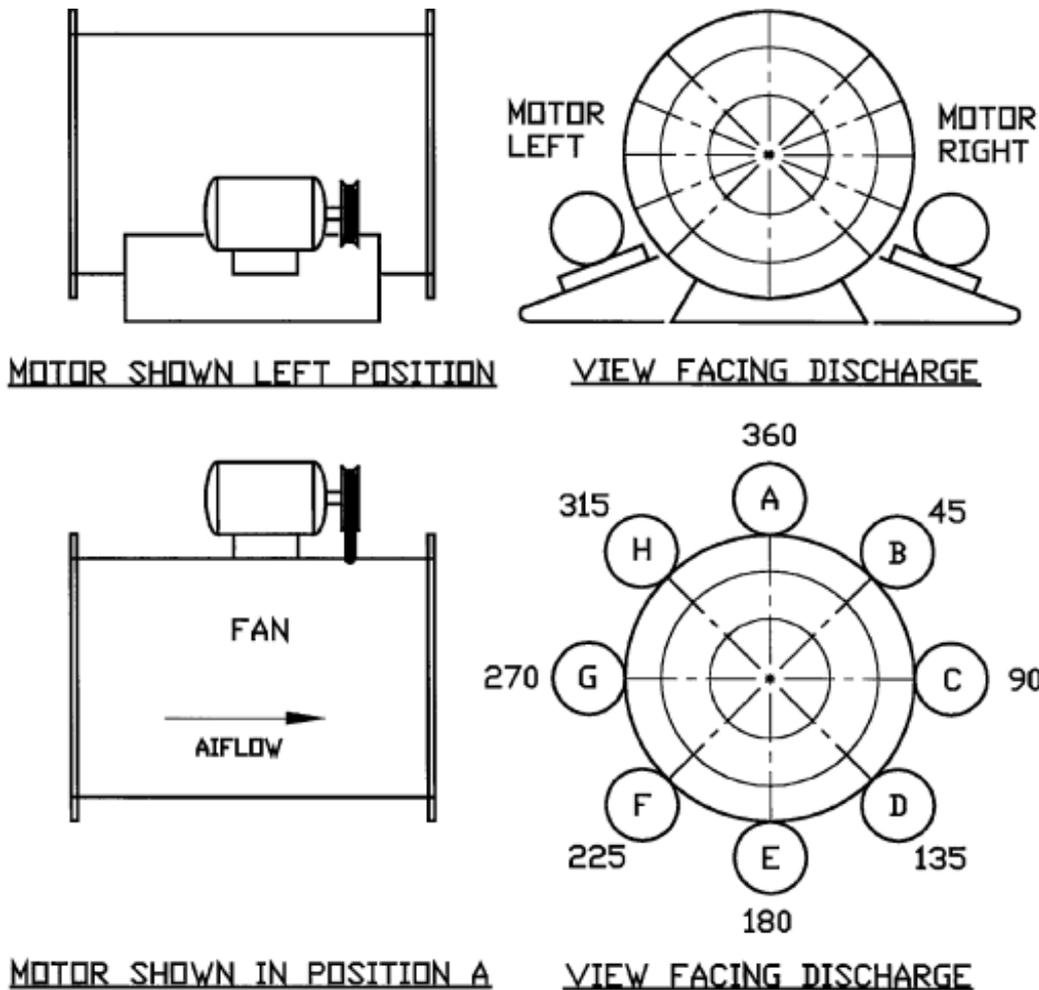


NOTES:

1. LOCATION OF THE MOTOR IS DETERMINED BY FACING THE DRIVE SIDE OF THE FAN OR BLOWER AND DESIGNATING THE MOTOR POSITION BY LETTERS W, X, Y, OR Z AS SHOWN ABOVE. FIGURE IS BASED ON AMCA STANDARD 2407.

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Figure 26.6. CENTRIFUGAL FAN MOTOR ARRANGEMENTS.



NOTES:

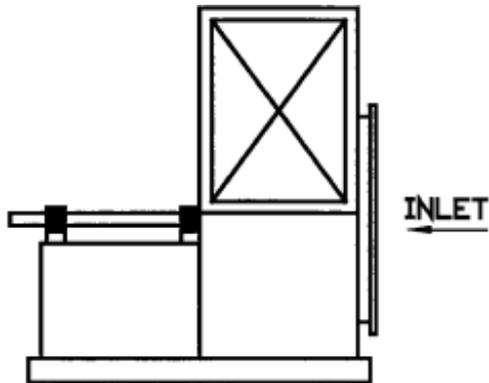
1. LOCATION OF THE MOTOR IS DETERMINED BY FACING THE DRIVE SIDE OF THE FAN OR BLOWER AND DESIGNATING THE MOTOR POSITION BY LETTERS A THROUGH H AS SHOWN ABOVE. FIGURE IS BASED ON AMCA STANDARD 2407.

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Figure 26.7. INLINE FAN MOTOR ARRANGEMENTS. Refer to the online resource for Sections 26.11 Fan Drive Arrangements, 26.12 Centrifugal Fan

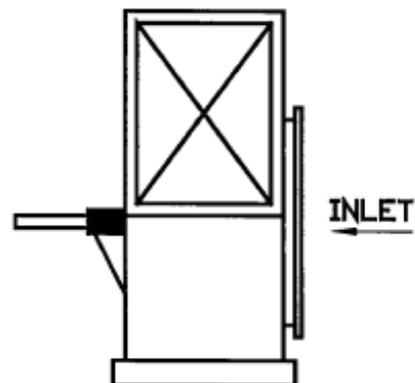
26.11. Fan Drive Arrangements

See Figs. 26.8 to 26.14.



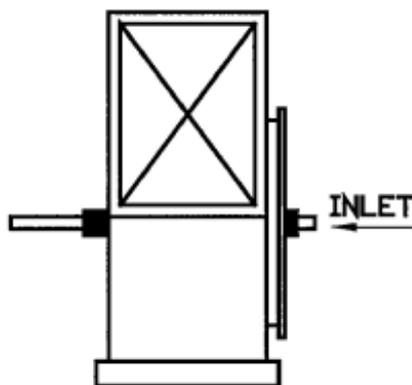
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE

ARR. 1 - SWSI



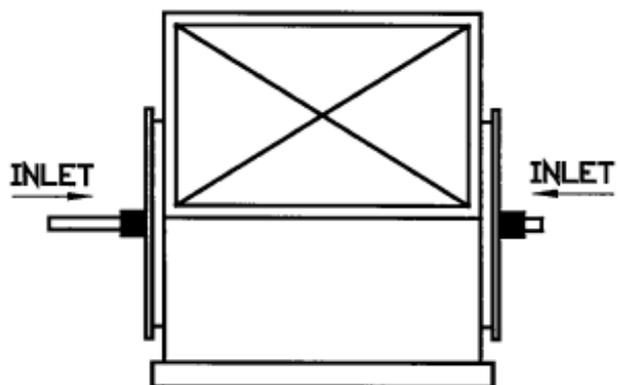
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, BEARINGS IN BRACKET SUPPORTED BY FAN HOUSING

ARR. 2 - SWSI



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING

ARR. 3 - SWSI



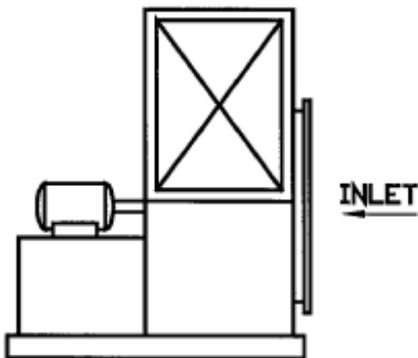
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING

ARR. 3 - DWDI

NOTES:

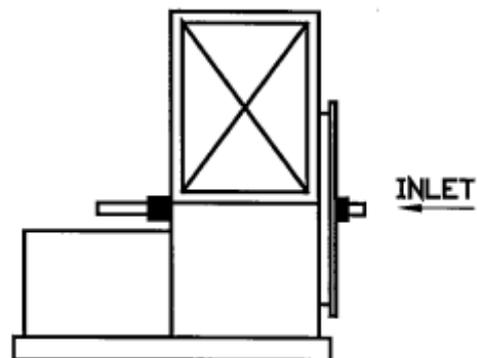
1. DRIVE ARRANGEMENTS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2404-78.
2. SWSI = SINGLE WIDTH, SINGLE INLET
3. DWDI = DOUBLE WIDTH, DOUBLE INLET
4. ARRANGEMENTS 1, 3, 7, AND 8 ARE ALSO AVAILABLE WITH BEARINGS MOUNTED ON PEDESTALS OR BASE SET INDEPENDENT OF THE FAN HOUSING.
5. ALL FIGURES SHOWN FACING DISCHARGE.

Figure 26.8. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



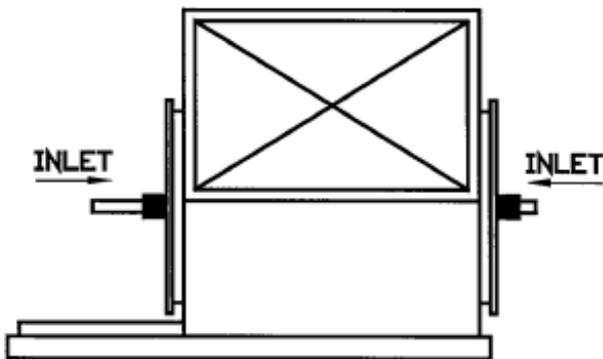
FOR DIRECT DRIVE CONNECTIONS,
IMPELLER OVERHUNG ON PRIME
MOVER SHAFT, NO BEARINGS ON FAN

ARR. 4 - SWSI



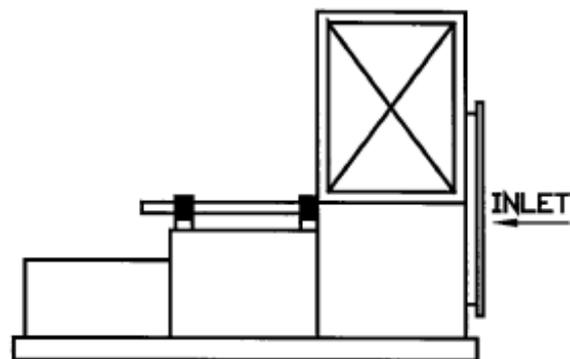
FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, ARRANGEMENT 3 PLUS
BASE FOR PRIME MOVER

ARR. 7 - SWSI



FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, ARRANGEMENT 3 PLUS
BASE FOR PRIME MOVER

ARR. 7 - DWDI



FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, ARRANGEMENT 1 PLUS
EXTENDED BASE FOR PRIME MOVER

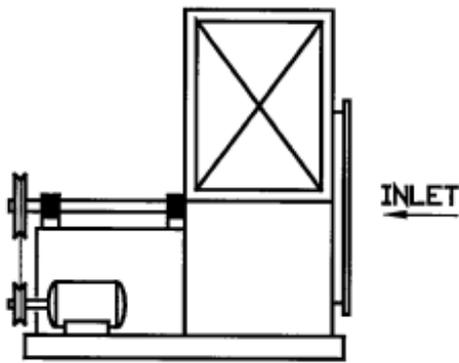
ARR. 8 - SWSI

NOTES:

1. DRIVE ARRANGEMENTS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2404-78.
2. SWSI = SINGLE WIDTH, SINGLE INLET
3. DWDI = DOUBLE WIDTH, DOUBLE INLET
4. ARRANGEMENTS 1, 3, 7, AND 8 ARE ALSO AVAILABLE WITH BEARINGS MOUNTED ON PEDESTALS OR BASE SET INDEPENDENT OF THE FAN HOUSING.
5. ALL FIGURES SHOWN FACING DISCHARGE.

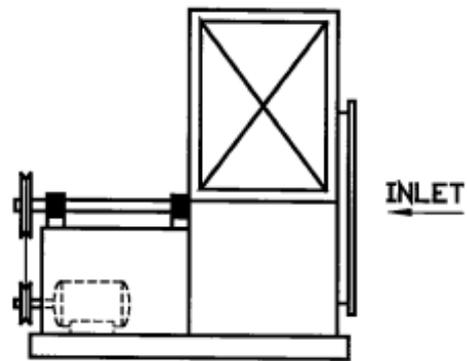
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Figure 26.9. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



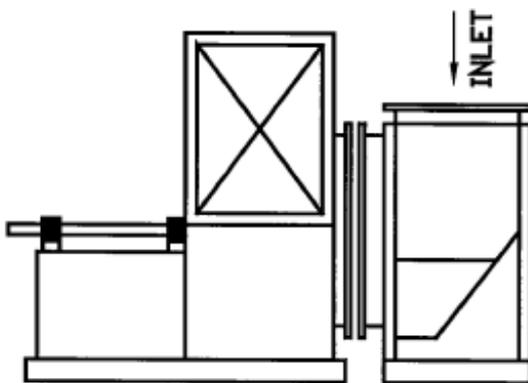
FOR BELT DRIVE CONNECTIONS,
IMPELLER OVERHUNG, TWO BEARINGS
WITH PRIME MOVER OUTSIDE BASE

ARR. 9 - SWSI



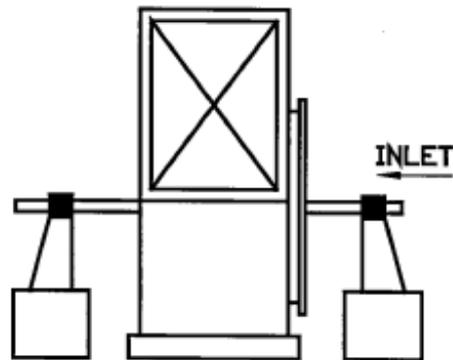
FOR BELT DRIVE CONNECTIONS,
IMPELLER OVERHUNG, TWO BEARINGS
WITH PRIME MOVER INSIDE BASE

ARR. 10 - SWSI



FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, IMPELLER OVERHUNG,
TWO BEARINGS ON BASE

ARR. 1 - SWSI W/INLET BOX



FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, HOUSING IS SELF-
SUPPORTING, ONE BEARING ON EACH
SIDE SUPPORTED BY INDEPENDENT
PEDESTALS

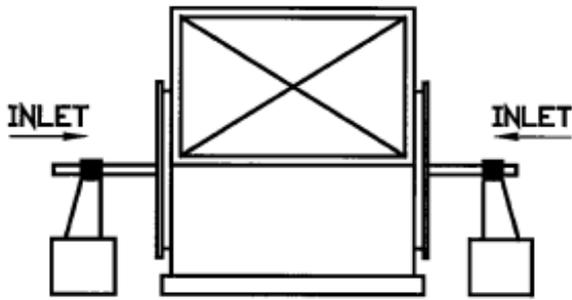
ARR. 3 - SWSI W/INDEPENDENT
PEDESTAL BASE

NOTES:

1. DRIVE ARRANGEMENTS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2404-78.
2. SWSI = SINGLE WIDTH, SINGLE INLET
3. DWDI = DOUBLE WIDTH, DOUBLE INLET
4. ARRANGEMENTS 1, 3, 7, AND 8 ARE ALSO AVAILABLE WITH BEARINGS MOUNTED ON PEDESTALS OR BASE SET INDEPENDENT OF THE FAN HOUSING.
5. ALL FIGURES SHOWN FACING DISCHARGE.

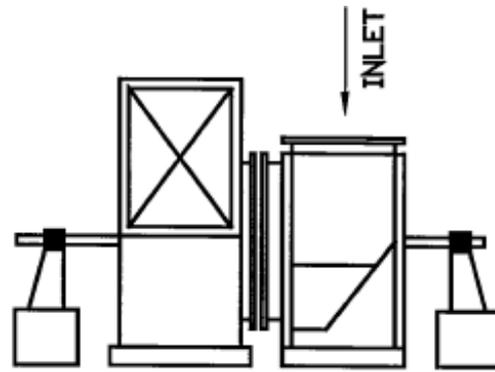
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Figure 26.10. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



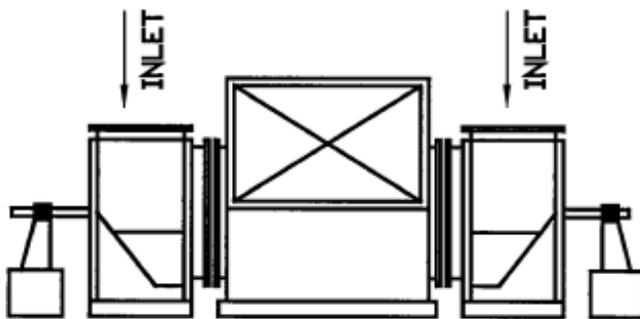
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, HOUSING IS SELF-SUPPORTING, ONE BEARING ON EACH SIDE SUPPORTED WITH INDEPENDENT PEDESTALS

ARR. 3 - DWDI W/INDEPENDENT PEDESTAL BASE



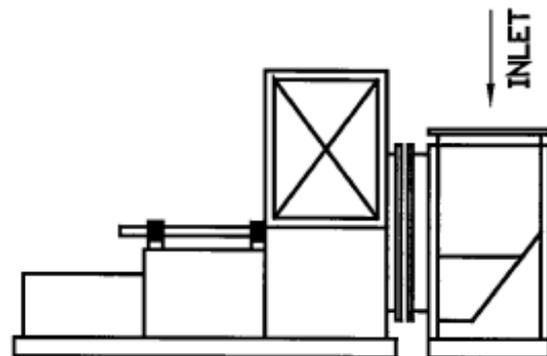
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, HOUSING IS SELF-SUPPORTING, ONE BEARING ON EACH SIDE SUPPORTED BY INDEPENDENT PEDESTALS WITH SHAFT EXTENDING THROUGH INLET BOX

ARR. 3 - SWSI W/INDEPENDENT PEDESTAL BASE



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, HOUSING IS SELF-SUPPORTING, ONE BEARING ON EACH SIDE SUPPORTED BY INDEPENDENT PEDESTALS WITH SHAFT EXTENDING THROUGH INLET BOX

ARR. 3 - SWSI W/INDEPENDENT PEDESTAL BASE



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE PLUS EXTENDED BASE FOR PRIME MOVER

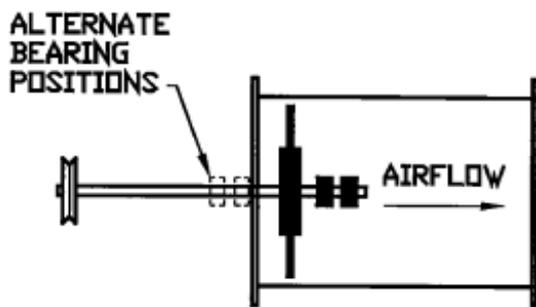
ARR. 8 - SWSI W/INLET BOX

NOTES:

1. DRIVE ARRANGEMENTS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2404-78.
2. SWSI = SINGLE WIDTH, SINGLE INLET
3. DWDI = DOUBLE WIDTH, DOUBLE INLET
4. ARRANGEMENTS 1, 3, 7, AND 8 ARE ALSO AVAILABLE WITH BEARINGS MOUNTED ON PEDESTALS OR BASE SET INDEPENDENT OF THE FAN HOUSING.
5. ALL FIGURES SHOWN FACING DISCHARGE.

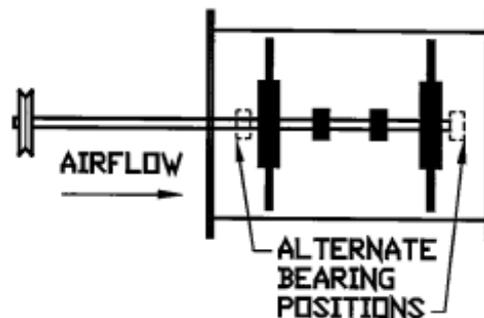
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Figure 26.11. CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



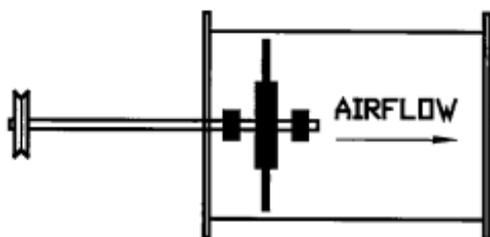
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS LOCATED EITHER UPSTREAM OR DOWNSTREAM OF IMPELLER

ARRANGEMENT 1



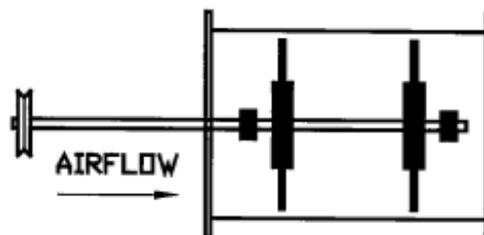
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS LOCATED EITHER UPSTREAM OR DOWNSTREAM OF IMPELLER

ARRNGEMENT 1 - 2 STAGE



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER LOCATED BETWEEN BEARINGS THAT ARE ON INTEGRAL SUPPORTS

ARRANGEMENT 3



FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER LOCATED BETWEEN BEARINGS THAT ARE ON INTEGRAL SUPPORTS

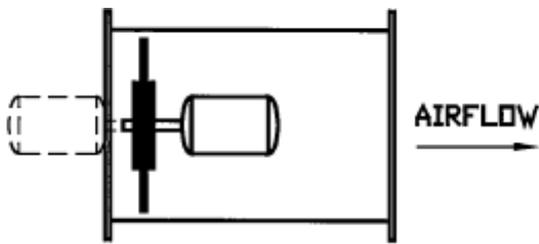
ARRNGEMENT 3 - 2 STAGE

NOTES:

1. DRIVE ARRANGEMENTS FOR AXIAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2407-82.
2. ALL FAN ARRANGEMENTS MAY BE HORIZONTAL OR VERTICAL.
3. FANS MAY BE PROVIDED WITH EITHER AN INTEGRAL BASE OR INTEGRAL SUPPORTS POINTS.

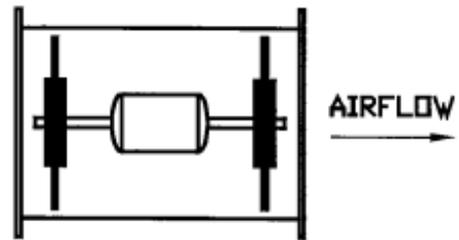
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Figure 26.12. AXIAL FAN DRIVE ARRANGEMENTS.



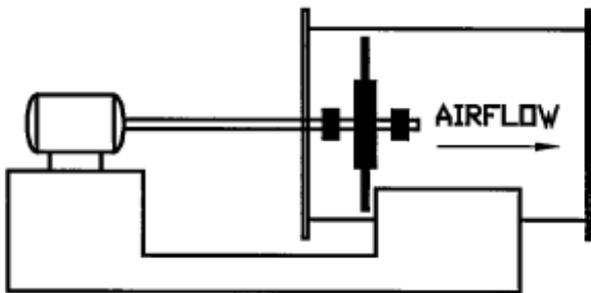
FOR DIRECT DRIVE CONNECTIONS,
IMPELLER OVERHUNG ON MOTOR
SHAFT, NO BEARINGS ON FAN,
MOTOR ON INTERNAL SUPPORTS

ARRANGEMENT 4



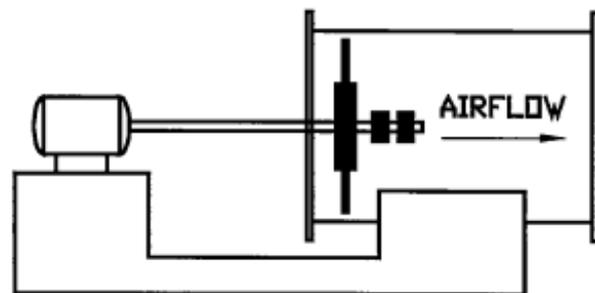
FOR DIRECT DRIVE CONNECTIONS,
IMPELLER OVERHUNG ON MOTOR
SHAFT, NO BEARINGS ON FAN,
MOTOR ON INTERNAL SUPPORTS

ARRANGEMENT 4 - 2 STAGE



FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, ARRANGEMENT 3 PLUS
COMMON BASE FOR PRIME MOVER

ARRANGEMENT 7



FOR BELT DRIVE OR DIRECT DRIVE
CONNECTIONS, ARRANGEMENT 1 PLUS
COMMON BASE FOR PRIME MOVER

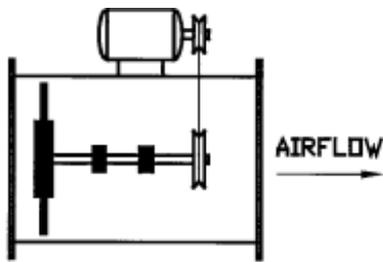
ARRANGEMENT 8

NOTES:

1. DRIVE ARRANGEMENTS FOR AXIAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2407-82.
2. ALL FAN ARRANGEMENTS MAY BE HORIZONTAL OR VERTICAL.
3. FANS MAY BE PROVIDED WITH EITHER AN INTEGRAL BASE OR INTEGRAL SUPPORTS POINTS.

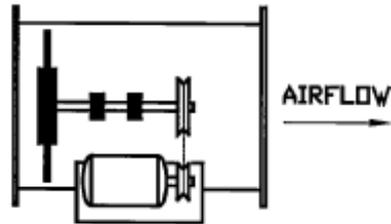
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Figure 26.13. AXIAL FAN DRIVE ARRANGEMENTS.



FOR BELT DRIVE CONNECTIONS,
IMPELLER OVERHUNG, TWO BEARINGS
ON INTERNAL SUPPORTS

ARRANGEMENT 9
MOTOR ON CASING



FOR BELT DRIVE CONNECTIONS,
IMPELLER OVERHUNG, TWO BEARINGS
ON INTERNAL SUPPORTS

ARRANGEMENT 9
MOTOR ON BASE

NOTES:

1. DRIVE ARRANGEMENTS FOR AXIAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2407-82.
2. ALL FAN ARRANGEMENTS MAY BE HORIZONTAL OR VERTICAL.
3. FANS MAY BE PROVIDED WITH EITHER AN INTEGRAL BASE OR INTEGRAL SUPPORTS POINTS.

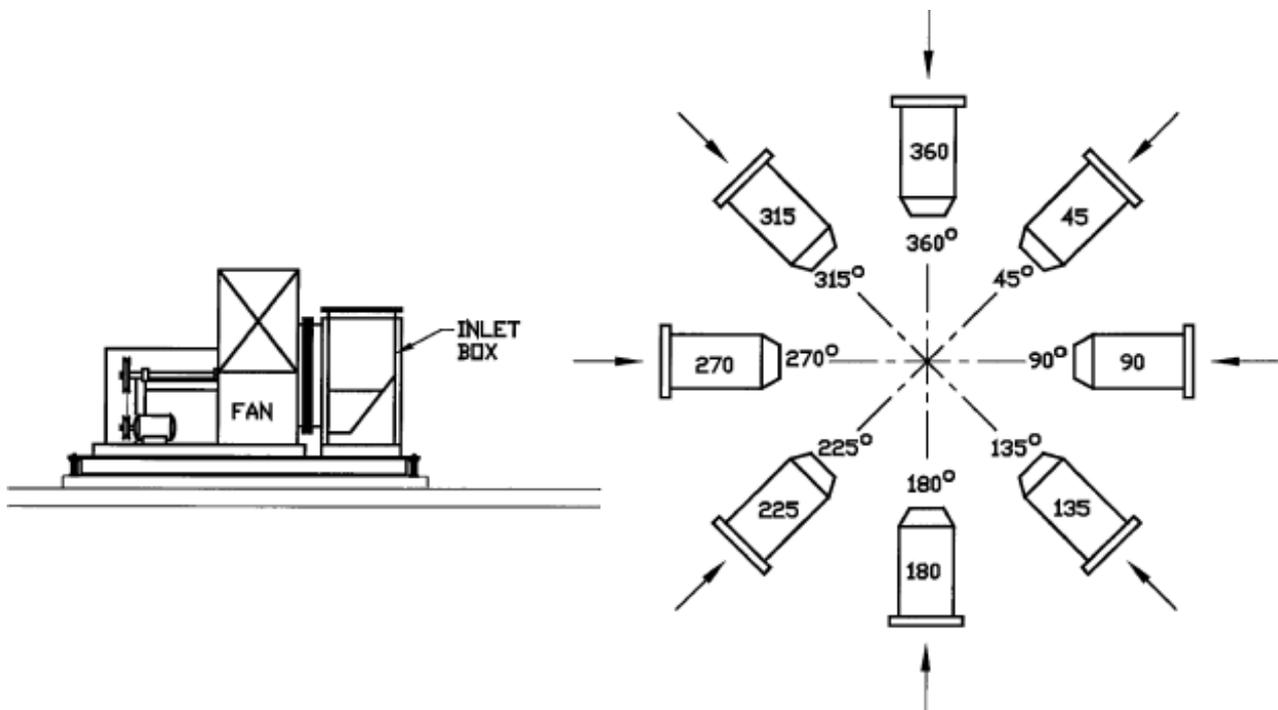
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Figure 26.14. AXIAL FAN DRIVE ARRANGEMENTS.

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26.12. Centrifugal Fan Inlet Box Positions

See Fig. 26.15.



NOTES:

1. INLET BOX POSITIONS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2405-83.
2. REFERENCE LINE IS THE TOP VERTICAL AXIS THROUGH CENTER OF FAN SHAFT.
3. POSITION OF INLET BOX AND AIR ENTRY DETERMINED LOOKING TOWARDS DRIVE SIDE OF FAN.
4. POSITION OF INLET BOX IS DESIGNATED IN DEGREES CLOCKWISE FROM TOP VERTICAL AXIS AS SHOWN, AND MAY BE ANY INTERMEDIATE ANGLE AS REQUIRED BY FIELD CONDITIONS.

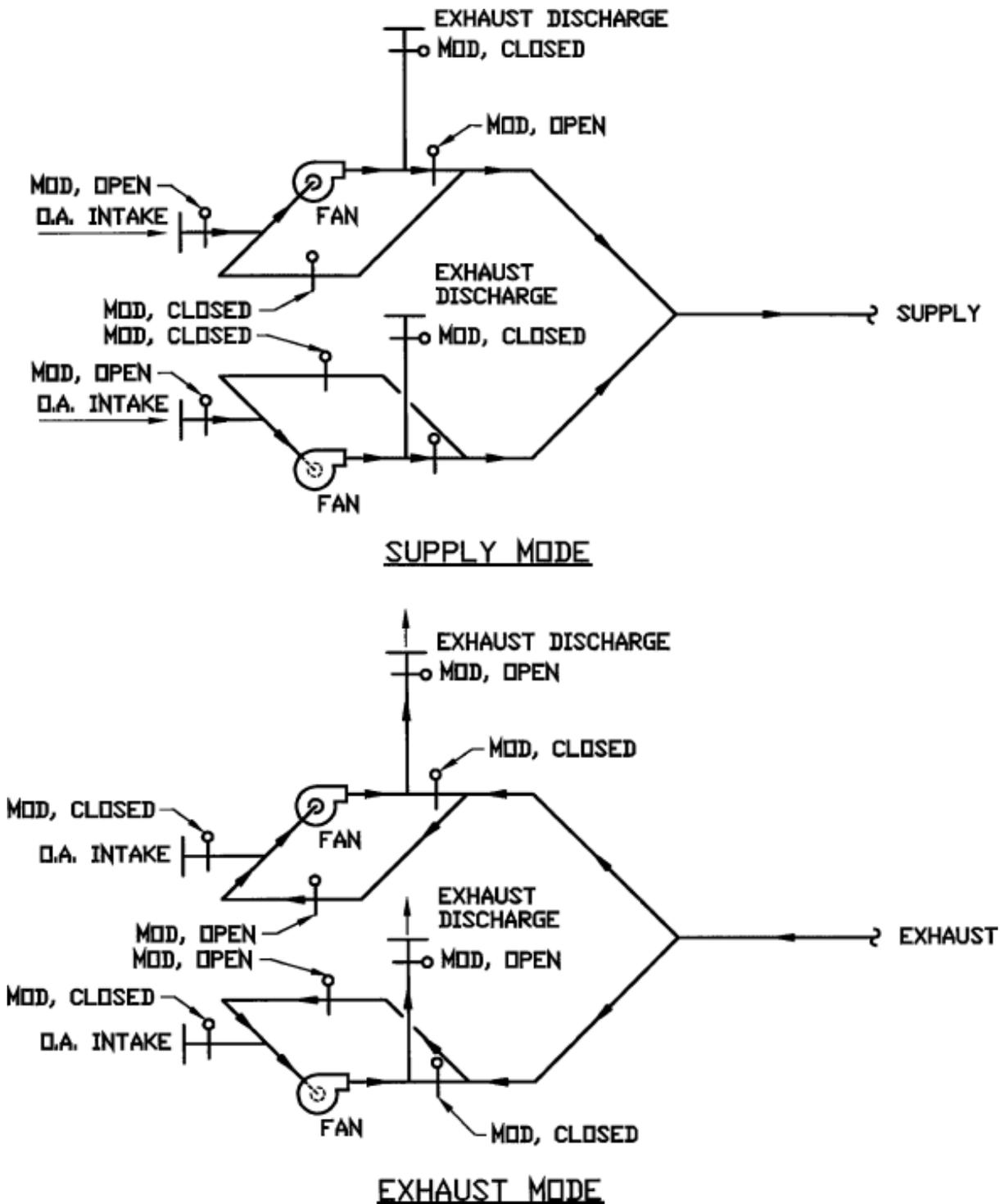
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Figure 26.15. CENTRIFUGAL FAN INLET BOX POSITIONS.

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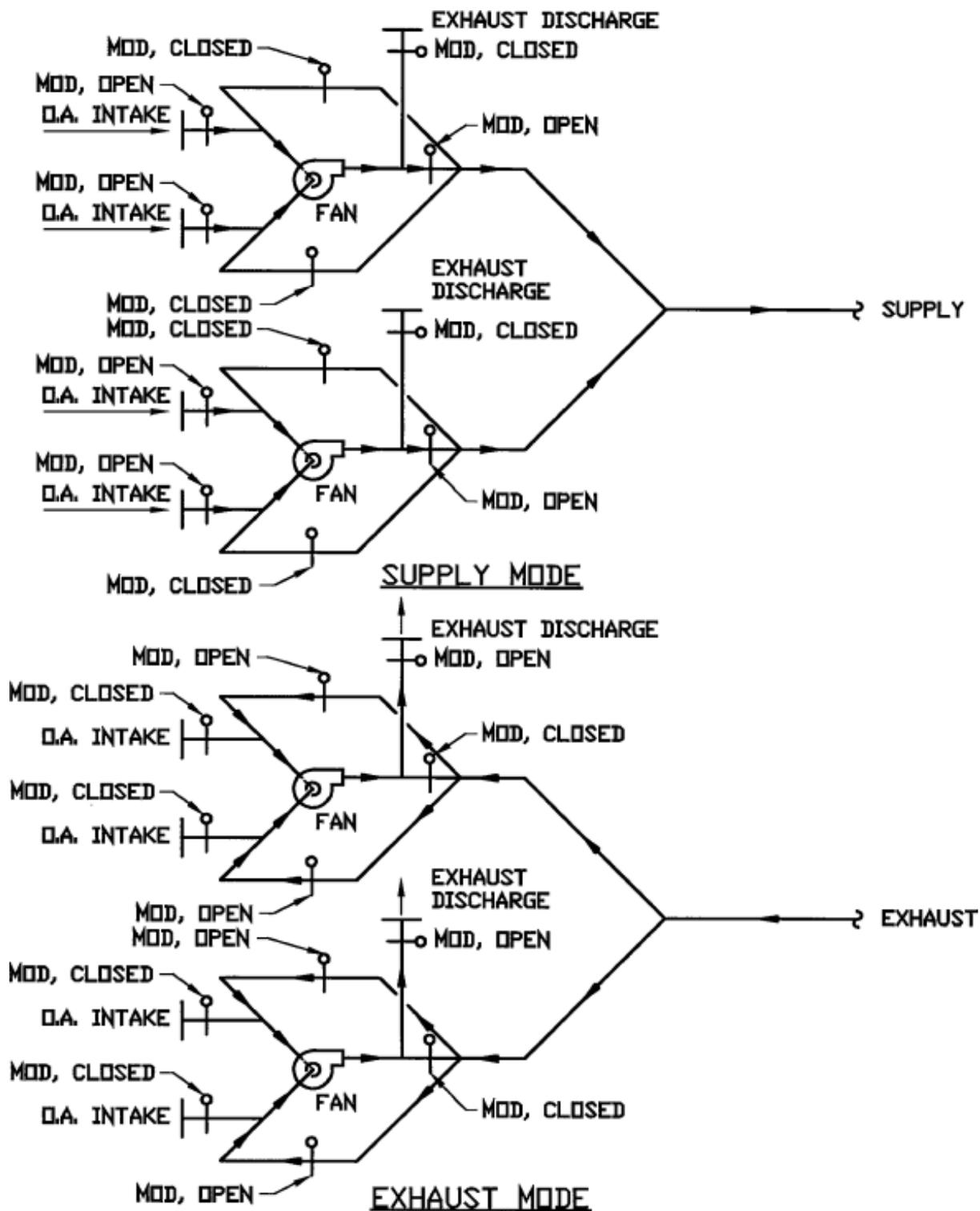
26.13. Centrifugal Fan Damper Arrangements for Reversible Flow

See Figs. 26.16 and 26.17.



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Figure 26.16. SWSI CENTRIFUGAL FANS (REVERSIBLE FLOW).



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Figure 26.17. DWDI CENTRIFUGAL FANS (REVERSIBLE FLOW).

Citation

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Part 27: Pumps

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27. Part 27: Pumps

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27.01. Pump Types and Size Ranges

A. Available RPM

1. 1,150 (1,200).
2. 1,750 (1,800).
3. 3,500 (3,600).

B. Pump types are shown in the following table.

Pump Type	GPM	Head Ft. H ₂ O	Horsepower
Circulators	0-150	0-60	1/4-5
Close coupled, end suction	0-2,000	0-400	1/4-150
Frame mounted, end suction	0-2,000	0-500	1/4-150
Horizontal split case	0-12,000	0-500	1-500
Vertical inline	0-2,000	0-400	1/4-75

C. Refer to Fig. 27.1 for a photograph of frame mounted, end suction pumps in their installed condition.



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Figure 27.1. PHOTOGRAPH OF FRAME MOUNTED, END SUCTION PUMPS.

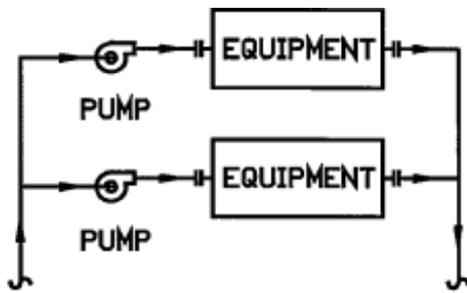
D. Pump Location

1. Heating water systems: Boilers to be on the suction side of pumps; pumps to draw through boilers.
2. Chilled water systems: Chillers to be on the discharge side of pumps; pumps to pump through chillers.

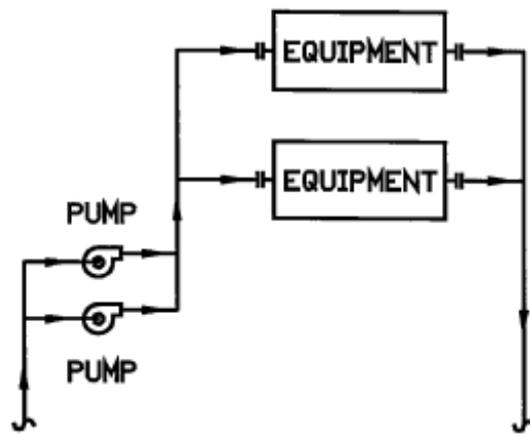
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27.02. Pump Layout and Design Criteria

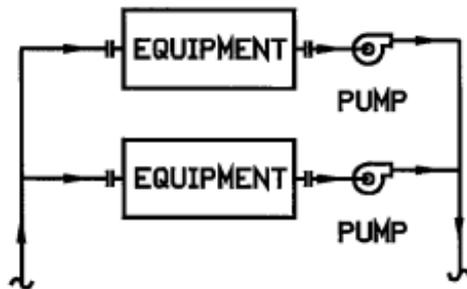
- A. Pump suction piping should be kept as short and direct as possible with a minimum length of straight pipe upstream of the pump suction as recommended by the pump manufacturer. Manufacturers recommend 5-12 pipe diameters.**
- B. Pump suction pipe size should be at least one pipe size larger than the pump inlet connection.**
- C. Use flat on top, eccentric reducer to reduce pump suction piping to the pump inlet connection size.**
- D. Pump suction should be kept free from air pockets.**
- E. Horizontal elbows should not be installed at the pump suction. If a horizontal elbow must be installed at the pump suction, the elbow should be installed at a lower elevation than the pump suction. A vertical elbow at the pump suction with the flow upward toward the pump is desirable.**
- F. Maintain a minimum of 5 pipe diameters of straight pipe immediately upstream of pump suction unless using suction diffuser.**
- G. Variable speed pumping cannot be used for pure lift applications, because reduced speeds will fail to provide the required lift.**
- H. Variable speed pumping is well suited for secondary and tertiary distribution loops of primary/secondary and secondary/tertiary hydronic distribution systems (chilled water and heating water systems).**
- I. Pump Design Arrangements (see Fig. 27.2)**



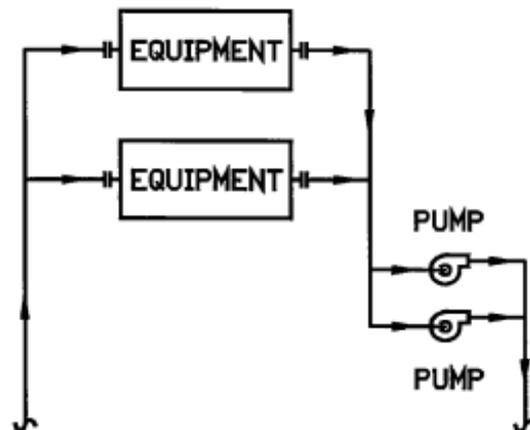
COUPLED PUMPING



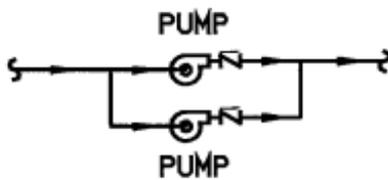
HEADERED PUMPING



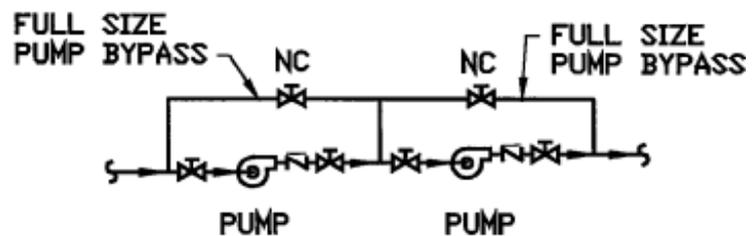
COUPLED PUMPING



HEADERED PUMPING



PARALLEL PUMPING



SERIES PUMPING

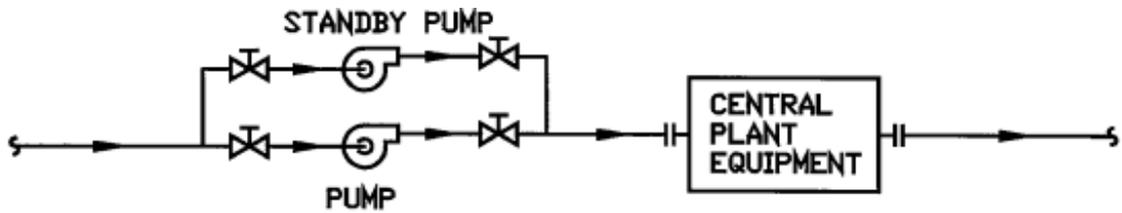
NOTE: EQUAL HEAD, GPM ADDITIVE

NOTE: EQUAL GPM, HEAD ADDITIVE

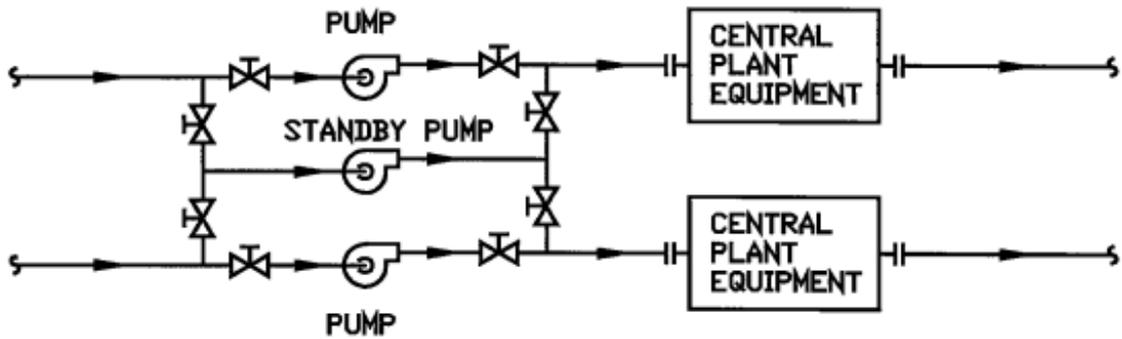
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Figure 27.2. PUMPING ARRANGEMENTS.

1. Series pumps: equal flow, head additive.
2. Parallel pumps: equal head, flow additive.
3. Standby pumps: standby pumping arrangements are often used for reliability purposes in the event of pump failure. Standby pumps may be provided with coupled or headered systems (see Figs. 27.3 and 27.4).

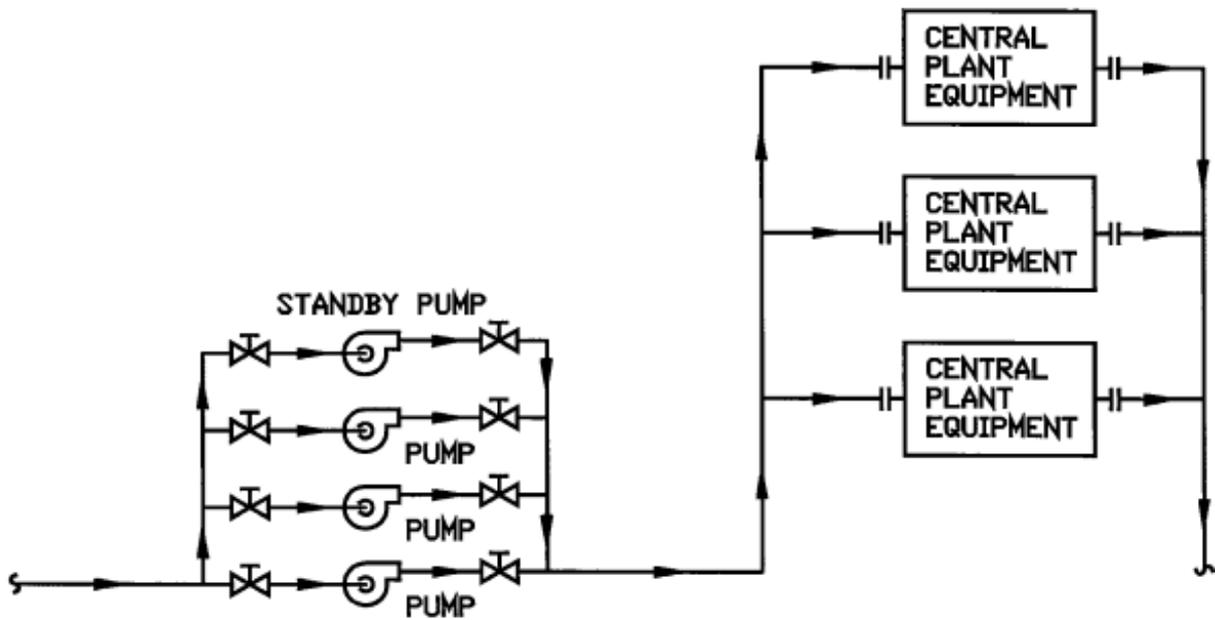


INDIVIDUAL



COUPLED

NOTE: STANDBY PUMP MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.

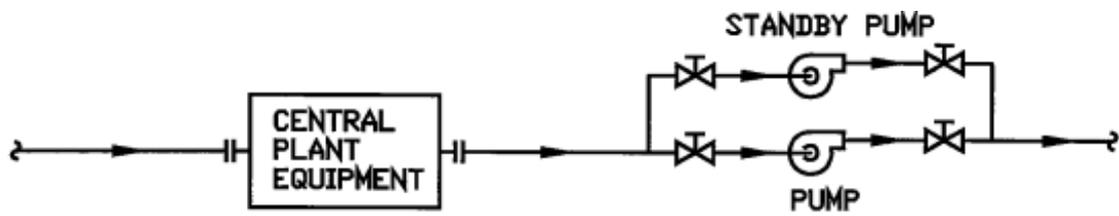


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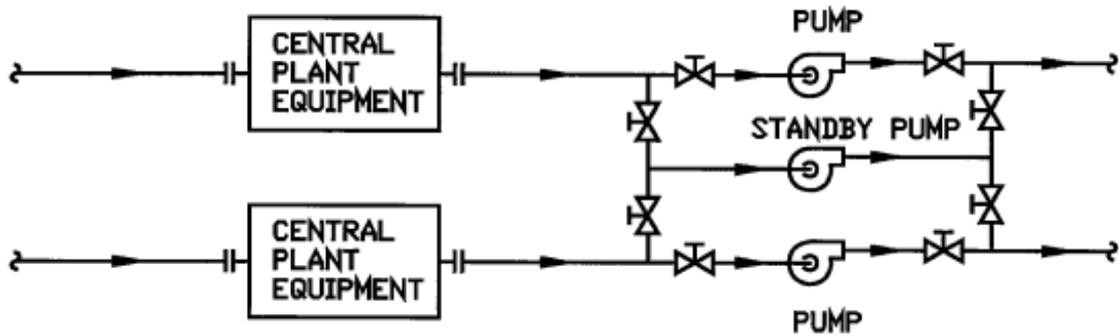
NOTE: STANDBY PUMP MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

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Figure 27.3. STANDBY PUMPS.

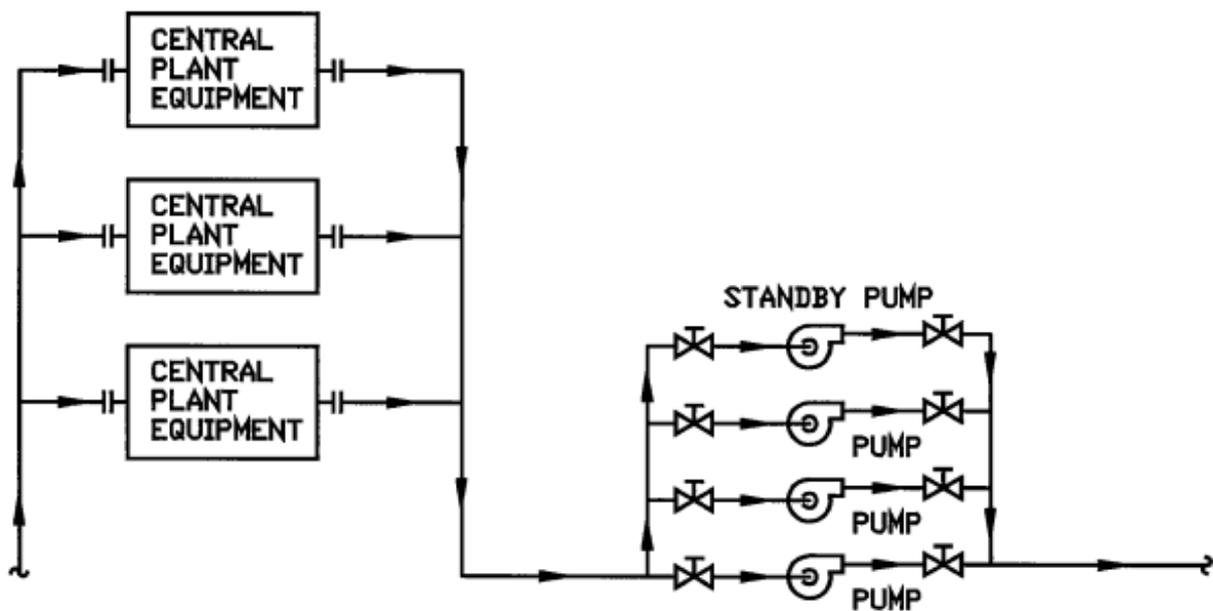


INDIVIDUAL



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NOTE: STANDBY PUMP MAY SERVE EITHER PIECE OF CENTRAL PLANT EQUIPMENT.



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NOTE: STANDBY PUMP MAY SERVE ANY PIECE OF CENTRAL PLANT EQUIPMENT, PROVIDED ALL EQUIPMENT IS THE SAME CAPACITY.

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Figure 27.4. STANDBY PUMPS.

J. Pump Discharge Check Valves

1. Pump discharge check valves should be center-guided, spring-loaded, disc-type check valves.
2. Pump discharge check valves should be sized so the check valve is full open at the design flow rate. Generally, this will require the check valve to be one pipe size smaller than the connecting piping.

3. Condenser water system and other open piping system check valves should have globe-style bodies to prevent flow reversal and slamming.
 4. Installing check valves 4–5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.
- K. Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or at the end each of the subsystems, regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.**

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27.03. Pump Selection Criteria

- A. The impeller size for specified duty should not exceed 85 percent of the volute cutwater diameter.**
- B. The maximum cataloged impeller size should be rated to produce not less than 110 percent of the specified head at the specified flow.**
- C. Parallel Pump Operation: At equal head, the GPM is additive.**
- D. Series Pump Operation: At equal GPM, the head is additive.**
- E. Selection Regions:**
 1. Preferred selection—85–105 percent design flow.
 2. Satisfactory selection—66–115 percent design flow.
- F. Pumps Curves**
 1. Flat. A 12 percent rise from design point to the shutoff head (zero flow). Flat curves should be used for variable flow systems with single pumps. A flat pump curve is a pump curve where the head at shutoff is approximately 25 percent higher than the head at the best efficiency point.
 2. Steep. A 40 percent rise from design point to shutoff head (zero flow). Steep curves should be used for variable speed and constant flow systems where two or more pumps are used.

3. Hump. The developed head rises to a maximum as flow decreases and then drops to a lower value at the point of shutoff. Hump curves should be used for constant flow systems with single pumps due to increased efficiency.
- G. Select pumps so the design point is as close as possible or to the left of the maximum efficiency point.**
- H. Boiler warming pumps should be selected for a flow rate of 0.1 GPM/BHP (range 0.05-0.1 GPM/BHP). See Part 31 for a more detailed description of boiler warming pumps and their operation.**
- I. Pump Seals**
1. Mechanical seal: closed systems.
 2. Stuffing box seals: open systems.
- J. Cavitation. Net Positive Suction Head (NPSH)**
1. Cavitation: "If the pressure at any point inside the pump falls below the operating vapor pressure of the fluid, the fluid flashes into a vapor and forms bubbles. These bubbles are carried along in the fluid stream until they reach a region of higher pressure. Within this region, the bubbles collapse or implode with tremendous shock on the adjacent surfaces. Cavitation is accompanied by a low rumbling and/or a sharp rattling noise and even vibration causing mechanical destruction in the form of pitting and erosion."^[1]
 2. Causes:
 - a. Discharge head is far below the pump's calibrated head at peak efficiency.
 - b. The suction lift or suction head is lower than the pump rating.
 - c. Speeds (RPM) are higher than the pump rating.
 - d. Liquid temperatures are higher than that for which the system was designed.
 3. Remedies:
 - a. Increase the source fluid level height.
 - b. Reduce the distance and/or friction losses (larger pipe) between the source and pump.
 - c. Reduce the temperature of the fluid.

- d. Pressurize the source.
 - e. Use a different pump.
 - f. Place the balancing valve in the pump discharge or trim the pump impeller.
4. Systems most susceptible to NPSH problems include:
- a. Boiler feedwater systems (steam systems).
 - b. Cooling tower and other open systems.
 - c. Medium- and high-temperature water systems.
5. Potential problems increase as:
- a. Elevation above sea level increases.
 - b. Height of source above the pump decreases.
 - c. Friction losses increase.
 - d. Fluid temperature increases.

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27.04. Pump Terms

- A. ***Friction Head.*** Friction head is the pressure expressed in psi or in the feet of liquid needed to overcome the resistance to the flow in the pipe and fittings.
- B. ***Suction Lift.*** Suction lift exists when the source of the supply is below the centerline of the pump.
- C. ***Suction Head.*** Suction head exists when the source of the supply is above the centerline of the pump.
- D. ***Static Suction Lift.*** Static suction lift is the vertical distance from the centerline of the pump down to the free level of the liquid source.
- E. ***Static Suction Head.*** Static suction head is the vertical distance from the centerline of the pump up to the free level of the liquid source.
- F. ***Static Discharge Head.*** Static discharge head is the vertical elevation from the centerline of the pump to the point of free discharge.

- G. **Dynamic Suction Lift.** Dynamic suction lift includes the sum of static suction lift, friction head loss, and velocity head.
- H. **Dynamic Suction Head.** Dynamic suction head includes static suction head minus the sum of friction head loss and velocity head.
- I. **Dynamic Discharge Head.** Dynamic discharge head includes the sum of static discharge head, friction head, and velocity head.
- J. **Total Dynamic Head.** Total dynamic head includes the sum of the dynamic discharge head plus the dynamic suction lift or discharge head minus dynamic suction head.
- K. **Velocity Head.** Velocity head is the head needed to accelerate the liquid. See the following table.

Velocity (ft./sec.)	Velocity Head (feet)	Velocity (ft./sec.)	Velocity Head (feet)	Velocity (ft./sec.)	Velocity Head (feet)
0.5	0.004	7.5	0.875	14.5	3.269
1.0	0.016	8.0	0.995	15.0	3.498
1.5	0.035	8.5	1.123	15.5	3.735
2.0	0.062	9.0	1.259	16.0	3.980
2.5	0.097	9.5	1.403	16.5	4.232
3.0	0.140	10.0	1.555	17.0	4.493
3.5	0.190	10.5	1.714	17.5	4.761
4.0	0.248	11.0	1.881	18.0	5.037
4.5	0.314	11.5	2.056	18.5	5.321
5.0	0.389	12.0	2.239	19.0	5.613
5.5	0.470	12.5	2.429	19.5	5.912
6.0	0.560	13.0	2.627	20.0	6.219
6.5	0.657	13.5	2.833	21.0	6.856
7.0	0.762	14.0	3.047	22.0	7.525

- L. ***Specific Gravity.*** Specific gravity is the direct ratio of any liquid's weight to the weight of water at 62°F (62.4 lbs./cu.ft. or 8.33 lbs./gal.).
- M. ***Viscosity.*** Viscosity is a property of a liquid that resists any force tending to produce flow. It is the evidence of cohesion between the particles of a fluid that causes a liquid to offer resistance analogous to friction. A change in the temperature may change the viscosity depending upon the liquid. Pipe friction loss increases as viscosity increases.
- N. ***Static Pressure.*** Static pressure is the water pressure required to fill the system.
- O. ***Static System Pressure.*** Static system pressure is the water pressure required to fill the system plus 5 psi.
- P. ***Flow Pressure.*** Flow pressure is the pressure the pump must develop to overcome the resistance created by the flow through the system.

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27.05. Installation and Clearance Requirements

- A. **The minimum recommended clearance around pumps is 24 inches. Maintain minimum clearance as required to open access and control doors on pumps for service, maintenance, and inspection.**
- B. **Mechanical room locations and placement must take into account how pumps can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

[1]Carrier Corporation, *Carrier System Design Manuals*, Part 8—Auxiliary Equipment (Syracuse: Carrier Corporation, 1971), pp. 8-11.

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 27: Pumps, Chapter (McGraw-Hill Professional, 2016), AccessEngineering

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Part 28: Chillers

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28. Part 28: Chillers

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28.01. Chiller Types and Manufacturer Offerings

Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	Turndown % Capacity	Refrigerant	Comme
Centrifugal—Water Cooled						
Carrier	200–3000	0.50–0.60	5.86–7.03	10	134a	2
Daikin	200–1250	0.60–0.62	5.86–5.67	10	134a	2, 6
	400–2500	0.61–0.64	5.49–5.76	10	134a	3, 6
Trane	200–2000	0.45–0.55	6.39–7.81	10	123	2
	1500–4000	0.45–0.55	6.39–7.81	10	123	4
York	200–3000	0.50–0.60	5.86–7.03	15	134a	2
	1800–6000	0.50–0.60	5.86–7.03	15 single, 10 dual compressor	134a	3

Centrifugal—Water Cooled with Unit-Mounted VFD

Chiller Carrier Type	Capacity Range (tons)	kW/ton Range (1)	COP Range (2)	Turndown % Capacity	Refrigerant	Comments
Daikin	125-200	0.59-0.64	5.49-5.96	25	134a	2, 7
	145-400	0.62-0.67	5.25-5.67	12.5	134a	3, 7
	400-1500	0.55-0.58	6.06-6.39	10	134a	4, 7
Trane	200-4000	0.45-0.55	6.39-7.81	10	123	2, 4
York	200-1475	0.50-0.60	5.86-7.03	15 single, 10 dual compressor	134a	2

Reciprocating—Air Cooled

Carrier	NA	NA	NA	NA	NA	
Daikin	NA	NA	NA	NA	NA	
Trane	NA	NA	NA	NA	NA	
York	NA	NA	NA	NA	NA	

Reciprocating—Water Cooled

Carrier	NA	NA	NA	NA	NA	
Daikin	NA	NA	NA	NA	NA	
Trane	NA	NA	NA	NA	NA	
York	NA	NA	NA	NA	NA	

Notes: Screw—Air Cooled (see Fig. 28.1)



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Figure 28.1. ROTARY SCREW AIR-COOLED CHILLER WITH UNIT-MOUNTED VARIABLE FREQUENCY DRIVE. (Material Courtesy of Trane.)

Carrier	80-500	1.01- 1.21	2.91- 3.48	6-15	134a	
Daikin	140-200	1.25- 1.30	2.70- 2.81	25	134a	
	170-550	1.20- 1.30	2.70- 2.93	25	134a	
Trane	140-500	1.05- 1.16	3.03- 3.35	15	134a	6
York	150-500	1.15- 1.20	2.93- 3.06	10	134a	

Notes: Screw—Water Cooled (see Fig. 28.2)

1



2

3

ing characteristics and and below the values rers depending on and capacities are n the table based on enser water ines), outside air f refrigerant.

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4. Centrifugal chillers with dual compressors and dual refrigerant circuit
 Figure 28.2. ROTARY SCREW WATER-COOLED CHILLER WITH UNIT-MOUNTED VARIABLE FREQUENCY DRIVE. (Material Courtesy of Trane.)
 (see Fig. 28.4).

Chiller Carrier Type	Capacity	kW/ton	COP	Turndown % Capacity	Refrigerant	Somme
	Range tons	Range (1)	Range (1)			
	75-265	0.69- 0.72	4.88- 5.10	10	134a	
	150-400	0.47- 0.56	6.28- 7.48	10	134a	
Daikin	130-190	0.72- 0.74	4.75- 4.88	10	134a	
Trane	140-450	0.58- 0.70	5.02- 6.06	15	134a	6
York	125-300	0.58- 0.70	5.02- 6.05	15	134a	

Scroll—Air Cooled (see Fig. 28.3)



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Figure 28.3. SCROLL AIR-COOLED CHILLER. (Material Courtesy of Trane.)

Carrier	10-390	1.16- 1.23	2.86- 3.03	4-22	410a	
Notes:	10-150	0.76- 0.91	3.86- 4.63	5-20	410a	

1. KW/ton and COPs are based on full load operating characteristics and

Daikin Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	25 Turndown % Capacity	407c Refrigerant	Comme
	30-70	1.10- 1.20	2.93- 3.20	25	410a	
Trane	20-130	1.05- 1.20	2.93- 3.34	25, 50	410a	
York	15-150	1.15- 1.25	2.81- 3.05	20	410a	
Scroll—Water Cooled						
Carrier	15-71	0.56- 0.58	6.06- 6.28	10	410a	
Daikin	30-200	0.76- 0.80	4.39- 4.63	10	410a	
York	60-200	0.77- 0.85	4.13- 4.56	12, 25 depending upon no. of compressors	410a	

Notes:

- 1. KW/ton and COPs are based on full load operating characteristics and are "ball park" figures. KW/ton and COPs above and below the values listed in the table are possible for all manufacturers depending on desired operating characteristics. KW/ton, COP, and capacities are driven by, and will vary from, the values listed in the table based on chilled water supply/return temperatures, condenser water supply/return temperatures (water-cooled machines), outside air temperatures (air-cooled machines), and type of refrigerant.**
- 2. Centrifugal chillers with single compressor.**
- 3. Centrifugal chillers with dual compressors.**
- 4. Centrifugal chillers with dual compressors and dual refrigerant circuit (see Fig. 28.4).**



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Figure 28.4. CENTRIFUGAL WATER-COOLED CHILLER WITH DUAL COMPRESSORS. (Material Courtesy of Trane.)

5. Variable frequency drive screw chiller.

6. Variable frequency drive available.

7. Magnetic bearings.

8. COP, EER, and kW/ton relationships:

$$\text{EER} = \text{COP} \times 3.413$$

$$\text{COP} = 12,000 / (\text{kW/ton} \times 3,413)$$

$$\text{kW/ton} = 12,000 / (\text{COP} \times 3,413)$$

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28.02. Chiller Motor Types

A. Hermetic Chillers/Motors

1. Motors are refrigerant cooled.
2. Motor heat absorbed by the refrigerant must be removed by the condenser cooling medium (air or water).
3. $\text{TONS}_{\text{COND}} = \text{TONS}_{\text{EVAP}} \times 1.25$
 $= 12,000 \text{ Btu/h ton} \times 1.25 = 15,000 \text{ Btu/h ton.}$
Therefore, motor heat gain is approximately 3,000 Btu/h ton.

B. Open Chillers/Motors

1. Motors are air cooled.
2. Motor heat is rejected directly to the space. Therefore, the space HVAC system must remove approximately 3,000 Btu/h ton of motor heat gain.

C. **In either case, the chillers must remove the 3,000 Btu/h ton of heat generated by the motors; the only difference is the method by which it is accomplished.**

28.03. Code Required Chiller Efficiencies

Equipment Type	Equipment Capacity Size Range	2015 IECC and ASHRAE Std. 90.1-2013	
		FL kW/ton	IPLV kW/ton
Air-Cooled Chillers with Condenser—Electric	< 150 tons	10.100 EER	13.700 EER
	≥ 150 tons	10.100 EER	14.000 EER
Air-Cooled Chillers without Condenser—Electric	All Capacities	Same as air-cooled chillers	
Water-Cooled Positive Displacement—Electric	< 75 tons	0.750	0.600
	≥ 75 tons and < 150 tons	0.720	0.560
	≥ 150 tons and < 300 tons	0.660	0.540
	≥ 300 tons and < 600 tons	0.610	0.520
	≥ 600 tons	0.560	0.500
Water-Cooled Centrifugal Chillers—Electric	< 150 tons	0.610	0.550
	≥ 150 tons and < 300 tons	0.610	0.550
	≥ 300 tons and < 400	0.560	0.520
Notes:	≥ 400 tons and <	0.560	0.500

Equipment Type	Equipment Capacity Size Range ≥ 600 tons	2015 IECC and ASHRAE Std. 90.1-2013	
		FL kW/ton	IPLV kW/ton
Air-Cooled Absorption Chillers—Single Effect	All Capacities	0.600 COP	–
Water Cooled Absorption Chillers—Single Effect	All Capacities	0.700 COP	–
Absorption Chillers—Double Effect, Indirect Fired	All Capacities	1.000 COP	1.050 COP
Absorption Chillers—Double Effect, Direct Fired	All Capacities	1.000 COP	1.000 COP

Notes:

- 1. Efficiency values apply to chillers with water temperatures above 40°F.**
- 2. 1 ton = 3.516 kW.**
- 3. For centrifugal chillers operating at temperatures other than 44°F chilled water, 85°F condenser water, and 3.0 GPM/ton condenser water flow rate, maximum full-load kW/ton and part-load ratings shall be adjusted according to the equations given in ASHRAE Standard 90.1-2013, Section 6.4.1.2.1.**

28.04. Chiller Terms

- A. **Refrigeration Effect.** The refrigeration effect is the amount of heat absorbed by the refrigerant in the evaporator.

- B. ***Heat of Rejection.*** The heat of rejection is the amount of heat rejected by the refrigerant in the condenser, which includes compressor heat.
- C. ***Subcooling.*** Subcooling is the cooling of the refrigerant below the temperature at which it condenses. Subcooling the liquid refrigerant will increase the refrigeration effect of the system.
- D. ***Superheating.*** Superheating is the heating of the refrigerant above the temperature at which it evaporates. Superheating the refrigerant by the evaporator is part of the system design to prevent a slug of liquid refrigerant from entering the compressor and causing damage.
- E. ***Coefficient of Performance (COP).*** The coefficient of performance is defined as the refrigeration effect (Btu/h) divided by the work of the compressor (Btu/h). Another way to define COP is Btu output divided by Btu input. COP is equal to EER divided by 3.413.
- F. ***Energy Efficiency Ratio (EER).*** The energy efficiency ratio is defined as the refrigeration effect (Btu/h) divided by the work of the compressor (watts). Another way to define EER is the Btu output divided by the watts input. The EER is equal to 3.413 times the COP.
- G. ***Pressure/Enthalpy Chart.*** Pressure/Enthalpy chart is a graphic representation of the properties of a specific refrigerant with the pressure on the vertical axis and the enthalpy on the horizontal axis. The graph is used and is helpful in visualizing the changes that occur in a refrigeration cycle.
- H. ***Integrated Part Load Value (IPLV). ARI Specified Conditions .*** Acceptable tolerances for specified conditions are 6.5 percent.
- I. ***Application Part Load Value (APLV). Engineer Specified Conditions (Real World Conditions).*** Acceptable tolerances for specified conditions are 6.5 percent.
- J. ***Rupture Disc.*** A relief device on low-pressure machines.
- K. ***Relief Valve.*** A relief device on high-pressure machines.
- L. ***Pumpdown.*** Refrigerant pumped to the condenser for storage.

- M. **Pumpout.** Refrigerant pumped to a separate storage vessel. Use pumpout type storage when a reasonable size and number of portable storage containers cannot be moved into the building.
- N. **Purge Unit.** Removes air from the refrigeration machine; required on low-pressure machines only.
- O. **Prevac.** Device that prevents air from entering the refrigeration machine. It is used to leak test the refrigeration machine. Required on low-pressure machines only.
- P. **Factory Run Tests.** 1,500 tons and smaller; most manufacturers can provide them.
 - 1. *Certified Test.* Certifies performance—full load and/or part load—IPLV, and/or APLV.
 - 2. Witnessed Tests:
 - a. *Generic.* Any chiller the manufacturer produces of the same size and characteristics.
 - b. *Specific.* The specific chiller required by the customer.
- Q. **Hot Gas Bypass.** Low limit to suction pressure of the compressor. Hot gas bypass is beneficial on DX systems and generally not beneficial on chilled-water systems, except when tight temperature tolerances are required for a manufacturing process. Chillers specified with both hot gas bypass and low ambient temperature control will result in the hot gas bypass increasing the low ambient temperature operating point of the chiller (decreases the ability for the chiller to operate at low ambient conditions).

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28.05. Basic Refrigeration Cycle Terminology

- A. **Compressor.** Mechanical device where the refrigerant is compressed from a lower pressure and lower temperature to a higher pressure and higher temperature.
- B. **Hot Gas Piping.** Refrigerant piping from the compressor discharge to the compressor suction, to the evaporator outlet, or to the evaporator inlet, or from the compressor discharge and the condenser inlet to the compressor suction.

- C. **Condenser.** Heat exchanger where the system heat is rejected and the refrigerant condenses into a liquid.
- D. **Liquid Piping.** Refrigerant piping from the condenser outlet to the evaporator inlet.
- E. **Evaporator.** Heat exchanger where the system heat is absorbed and the refrigerant evaporates into a gas.
- F. **Suction Piping.** Refrigerant piping from the evaporator outlet to the compressor suction.
- G. **Thermal Expansion Valve.** Pressure and temperature regulation valve, located in the liquid line, which is responsive to the superheat of the vapor leaving the evaporator coil.

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28.06. Chiller Energy Saving Techniques

- A. **Constant Speed Chillers.** For each 1°F increase in chilled-water temperature, the chiller efficiency increases 1.0-2.0 percent.
- B. **Variable Speed Chillers.** For each 1°F increase in chilled-water temperature, the chiller efficiency increases 2.0-4.0 percent.
- C. **For each 1°F decrease in condenser water temperature, the chiller efficiency increases 1.0-2.0 percent.**

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28.07. Cooler (Evaporator)/Chilled-Water System

- A. **Leaving Water Temperature (LWT): 42-46°F**
- B. **ΔT Range: 10-20°F**
- C. **2.4 GPM/ton@10°F ΔT**
- D. **2.0 GPM/ton@12°F ΔT**
- E. **1.5 GPM/ton@16°F ΔT**
- F. **1.2 GPM/ton@20°F ΔT**
- G. **5,000 Btuh/GPM@10°F ΔT**

- H. **6,000 Btuh/GPM@12°F ΔT**
- I. **8,000 Btuh/GPM@16°F ΔT**
- J. **10,000 Btuh/GPM@20°F ΔT**
- K. **AHRI Evaporator Fouling Factor: 0.00010 h ft.² °F/Btu**
- L. **Chilled Water Flow Range: Chiller Design Flow ±10 percent**
- M. **Chiller Tube Velocity for Variable Flow Chilled Water**
 - a. Minimum flow: 3.0 FPS.
 - b. Maximum flow: 12.0 FPS.

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28.08. Condenser/Condenser Water Systems

- A. **Entering Water Temperature (EWT): 85°F**
- B. **ΔT Range: 10-20°F**
- C. **Normal ΔT: 10°F**
- D. **3.0 GPM/ton@10°F ΔT**
- E. **2.5 GPM/ton@12°F ΔT**
- F. **2.0 GPM/ton@15°F ΔT**
- G. **1.5 GPM/ton@20°F ΔT**
- H. **5,000 Btuh/GPM@10°F ΔT**
- I. **6,000 Btuh/GPM@12°F ΔT**
- J. **7,500 Btuh/GPM@15°F ΔT**
- K. **10,000 Btuh/GPM@20°F ΔT**
- L. **AHRI Condenser Fouling Factor: 0.00025 h ft.² °F/Btu**

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28.09. Chilled Water Storage Systems

- A. **10°F ΔT**
 - 1. 19.3 cu.ft./ton h

2. 623.1 Btu/cu.ft.; 83.3 Btu/gal.

B. 12°F ΔT

1. 16.1 cu.ft./ton h

2. 747.7 Btu/cu.ft.; 100.0 Btu/gal.

C. 16°F ΔT

1. 12.4 cu.ft./ton h

2. 996.9 Btu/cu.ft.; 133.3 Btu/gal.

D. 20°F ΔT

1. 9.6 cu.ft./ton h

2. 1246.2 Btu/cu.ft.; 166.7 Btu/gal.

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28.10. Ice Storage Systems

A. 144 Btu/lb.@32°F + 0.48 Btu/lb. for each 1°F below 32°F.

B. 3.2 cu.ft./ton h

C. Only the latent heat capacity of ice should be used when designing ice storage systems.

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28.11. Water-Cooled Condensers

A. Entering Water Temperature (EWT): 85°F

B. Leaving Water Temperature (LWT): 95°F

C. 3.0 GPM/ton@10°F ΔT

D. For each 1°F decrease in condenser water temperature, chiller efficiency increases 1.0-2.0 percent.

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28.12. Refrigerant Estimate—Split Systems

A. Total 3.0 lbs./ton

B. Equipment 2.0 lbs./ton

C. Piping 1.0 lbs./ton

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28.13. Chilled Water System Makeup Connection

Minimum connection size shall be 10 percent of the largest system pipe size or 1", whichever is greater. (A 20" system pipe size results in a 2" makeup water connection.)

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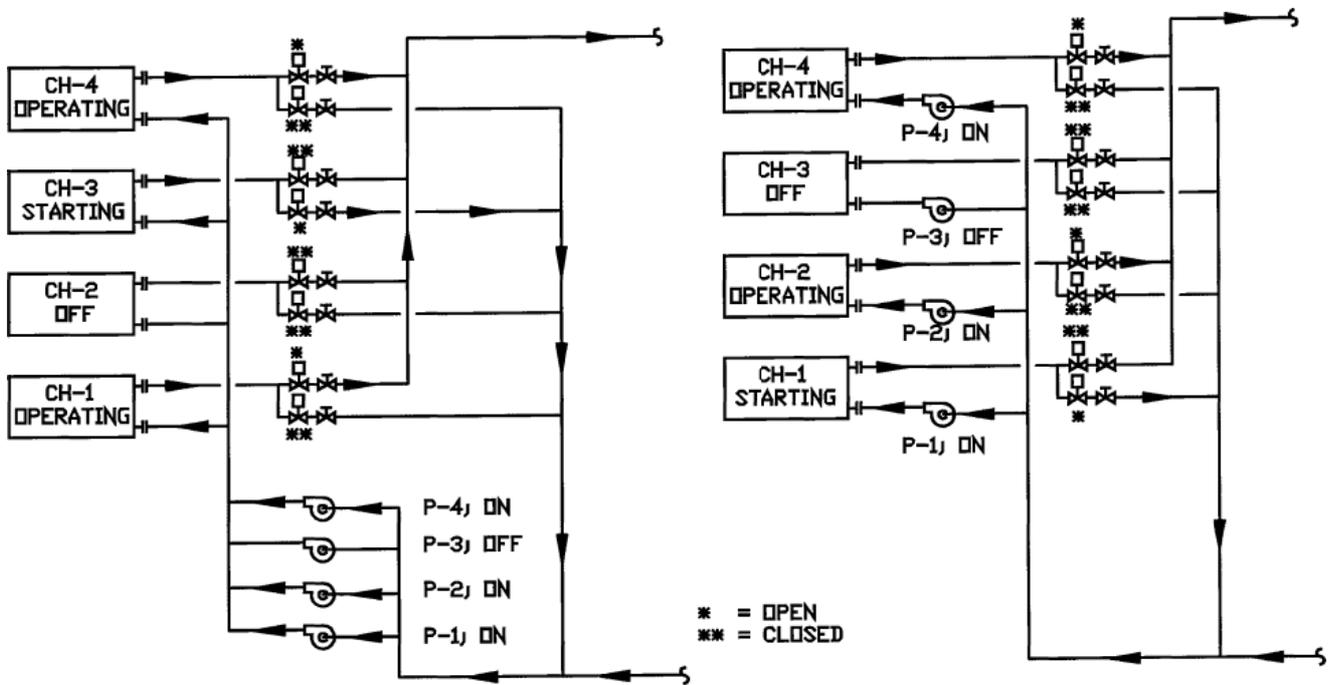
28.14. Chemical Feed Systems for Chillers. Chemical Feed Systems are Designed to Control the Following

- A. System pH, normally between 8 and 9.**
- B. Corrosion.**
- C. Scale.**

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28.15. Chiller Operating Sequence

- A. Start chilled water and condenser water pumps. Verify chilled water and condenser water flow.**
- B. Start chiller and cooling tower.**
- C. Runtime.**
- D. Stop chiller and cooling tower.**
- E. Stop chilled water and condenser water pumps after 0- to 30-second delay because some chiller manufacturers use chilled water or condenser water to cool the solid state starter circuitry.**
- F. Chiller Startup Piping (see Fig. 28.5)**



HEADERED SYSTEM

COUPLED SYSTEM

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Figure 28.5. CHILLER STARTUP PIPING DIAGRAM.

1. Because it takes 5–15 minutes from the time the chiller start sequence is initiated until the time the chiller starts to provide chilled water at the design temperature, the chilled water supply temperature often rises above the desired control setpoint. If the chilled water supply temperature is critical, the method to correct this problem is to provide the chillers with startup piping which runs from the chiller discharge to the pump return main.
2. The designer should size startup piping for the flow of the largest chiller in the system. The common pipe size only needs to be sized for the flow of one chiller because it is unlikely that more than one chiller will be started at the same time.
3. Chilled-water system operation with startup piping should be as follows:
 - a. On initiation of the chiller start sequence, the primary chilled water pump is started, the bypass valve is opened, and the supply header valve is closed. When the chilled water supply setpoint temperature is reached, as sensed in the bypass, the supply header valve is slowly opened, maintaining the setpoint temperature at all times. When the supply header valve is fully opened, the bypass valve is slowly closed.
 - b. On initiation of the chiller stop sequence, the bypass valve is slowly opened. When the bypass valve is fully opened, the supply header valve is slowly closed. The chiller is stopped, and after a delay, the primary chilled

water pump is stopped. When the primary chilled water pump stops, the bypass valve is left open to permit water to expand into, or contract from, the system. On headered systems, the chilled water return valve must be closed as well.

4. The chilled water diagram shows the chiller startup piping with motorized shutoff valves. Motorized valves are required for automatic or remote manual control. If the chilled-water system will be manually operated, these valves may be deleted. A separate manual shutoff valve has also been provided to allow for manual isolation of the system and to permit repair of the motorized valve without having to shut down the system. This manual shutoff valve may be deleted, provided the motorized shutoff valve has a manual means by which it can be opened and closed. Most motorized control valves do not have a manual means to open and close them.

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28.16. Chiller Design, Layout, and Clearance Requirements/Considerations

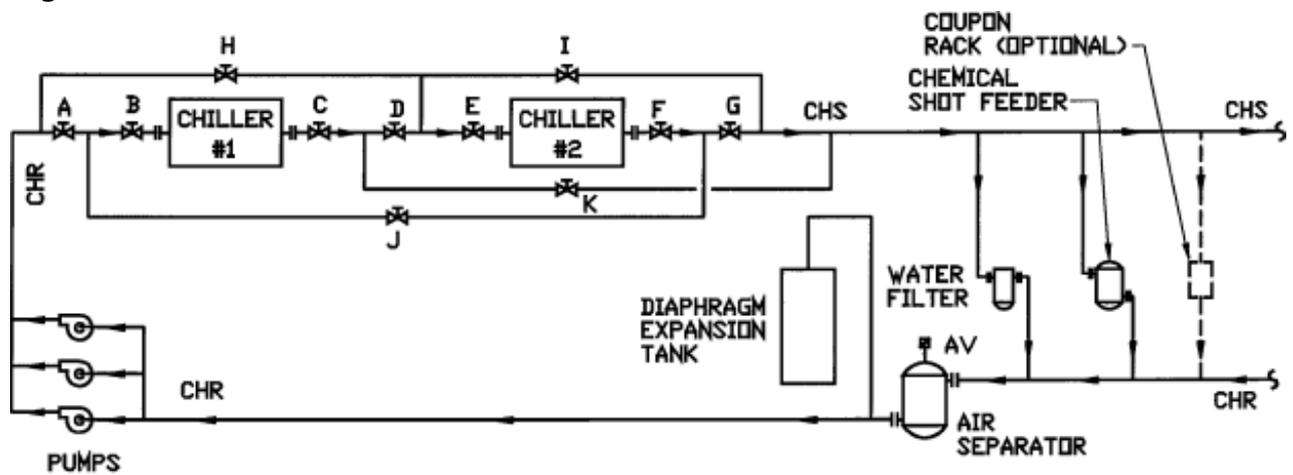
A. Design Conditions

1. Chiller load. Tons, Btu/h, or MBH.
2. Chilled water temperatures. Entering and leaving or entering and ΔT .
3. Condenser water temperatures. Entering and leaving or entering and ΔT .
4. Chilled water flows and fluid type (correct all data for fluid type).
5. Condenser water flows and fluid type (correct all data for fluid type).
6. Evaporator and condenser pressure drops.
7. Fouling factor.
8. IPLV, desirable.
9. APLV, optional.
10. Chilled water or condenser water reset if applicable.
11. Ambient operating temperature, dry bulb and wet bulb.
12. Electrical data:
 - a. Compressor or unit KW.

- b. Full load, running load, and locked rotor amps.
- c. Power factor.
- d. Energy Efficiency Ratio (EER).
- e. Voltage-phase-hertz.

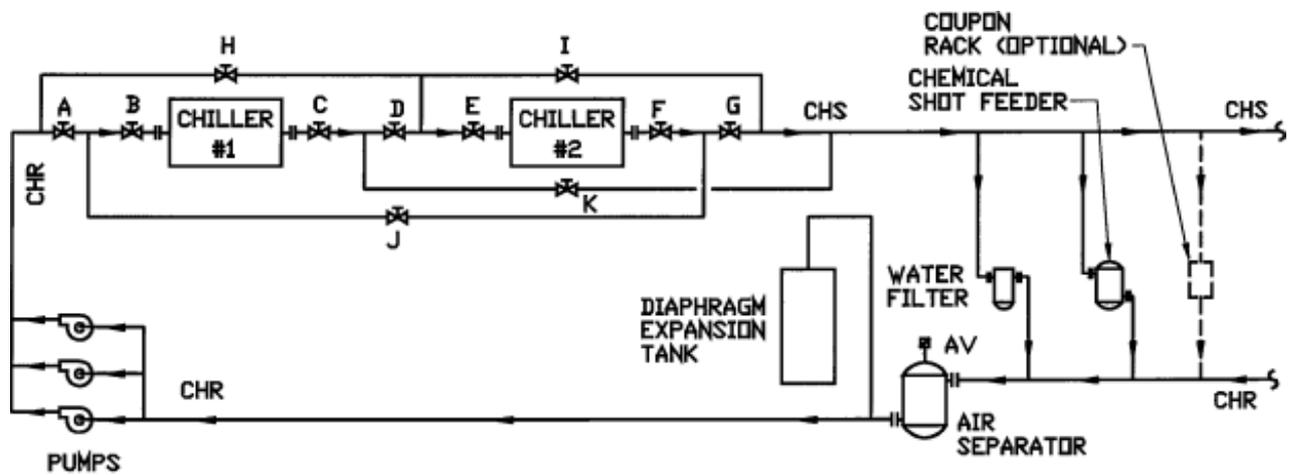
B. Multiple chillers should be used to prevent complete system or building shutdown upon failure of one chiller in all chilled-water systems over 200 tons (i.e., 2@50 percent, 2@67 percent, 2@70 percent, 3@34 percent, 3@40 percent).

1. Series chiller design: Piping chillers in series can accomplish large temperature differentials without penalizing the chiller performance (see Figs. 28.6 and 28.7).



- NOTES:**
- 1 CHILLER #1 LEAD/CHILLER #2 LAG
OPEN VALVES: A, B, C, D, E, F, AND G.
CLOSE VALVES: H, I, J, AND K.
 - 2 CHILLER #2 LEAD/CHILLER #1 LAG
OPEN VALVES: B, C, E, F, H, J, AND K.
CLOSE VALVES: A, D, G, AND I.
 - 3 VALVES H AND I ARE BYPASS VALVES FOR CHILLER #1 AND #2, RESPECTIVELY.
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Figure 28.6. SERIES CHILLED-WATER SYSTEM.



- NOTES:**
- 1 CHILLER #1 LEAD/CHILLER #2 LAG
OPEN VALVES: A, B, C, D, E, F, AND G.
CLOSE VALVES: H, I, J, AND K.
 - 2 CHILLER #2 LEAD/CHILLER #1 LAG
OPEN VALVES: B, C, E, F, H, J, AND K.
CLOSE VALVES: A, D, G, AND I.
 - 3 VALVES H AND I ARE BYPASS VALVES FOR CHILLER #1 AND #2, RESPECTIVELY.
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Figure 28.7. SERIES CHILLED-WATER SYSTEM WITH LEAD-LAG CHILLER CONTROL.

2. Parallel chiller design: Piping chillers in parallel provides a simpler installation and provides for multiple chiller arrangements with standby opportunities. Standby opportunities are also available with series chiller arrangements, but they become more complex and cumbersome (see Figs. 28.8 and 28.9).

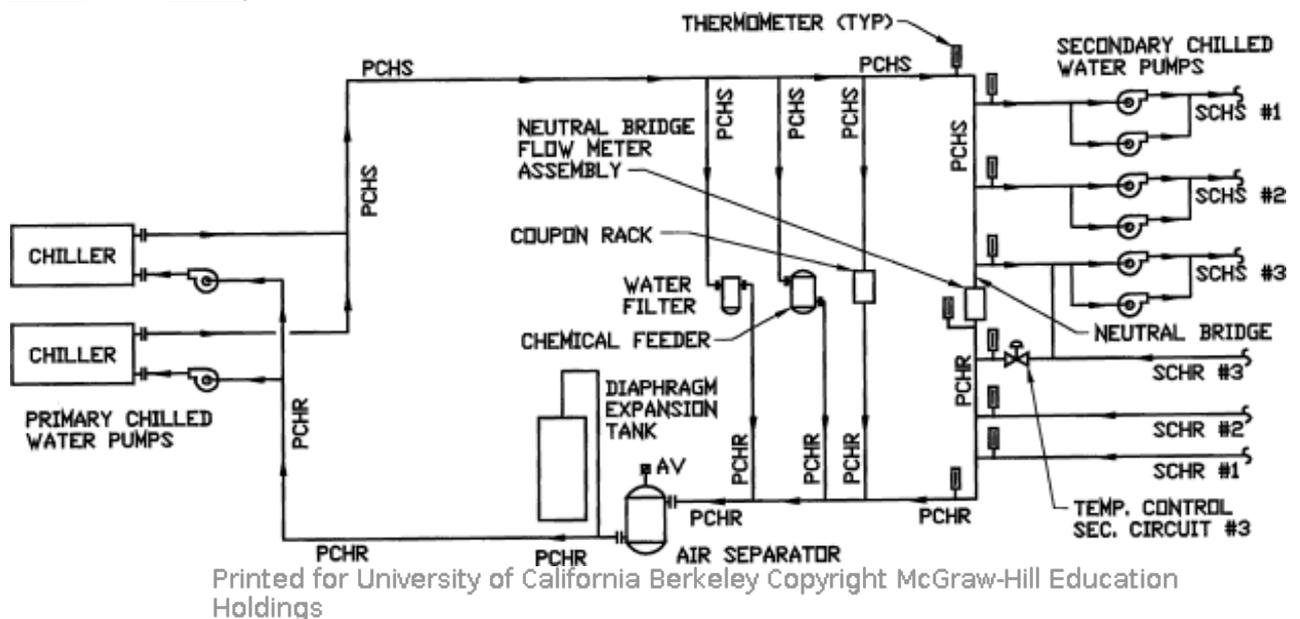
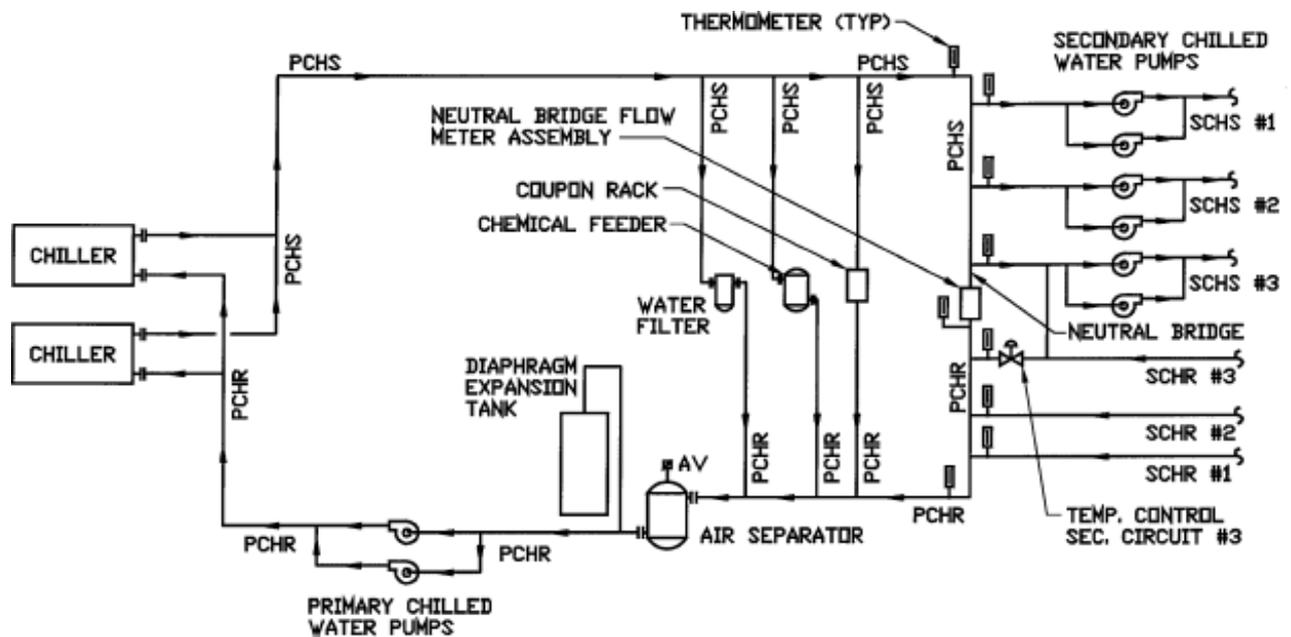


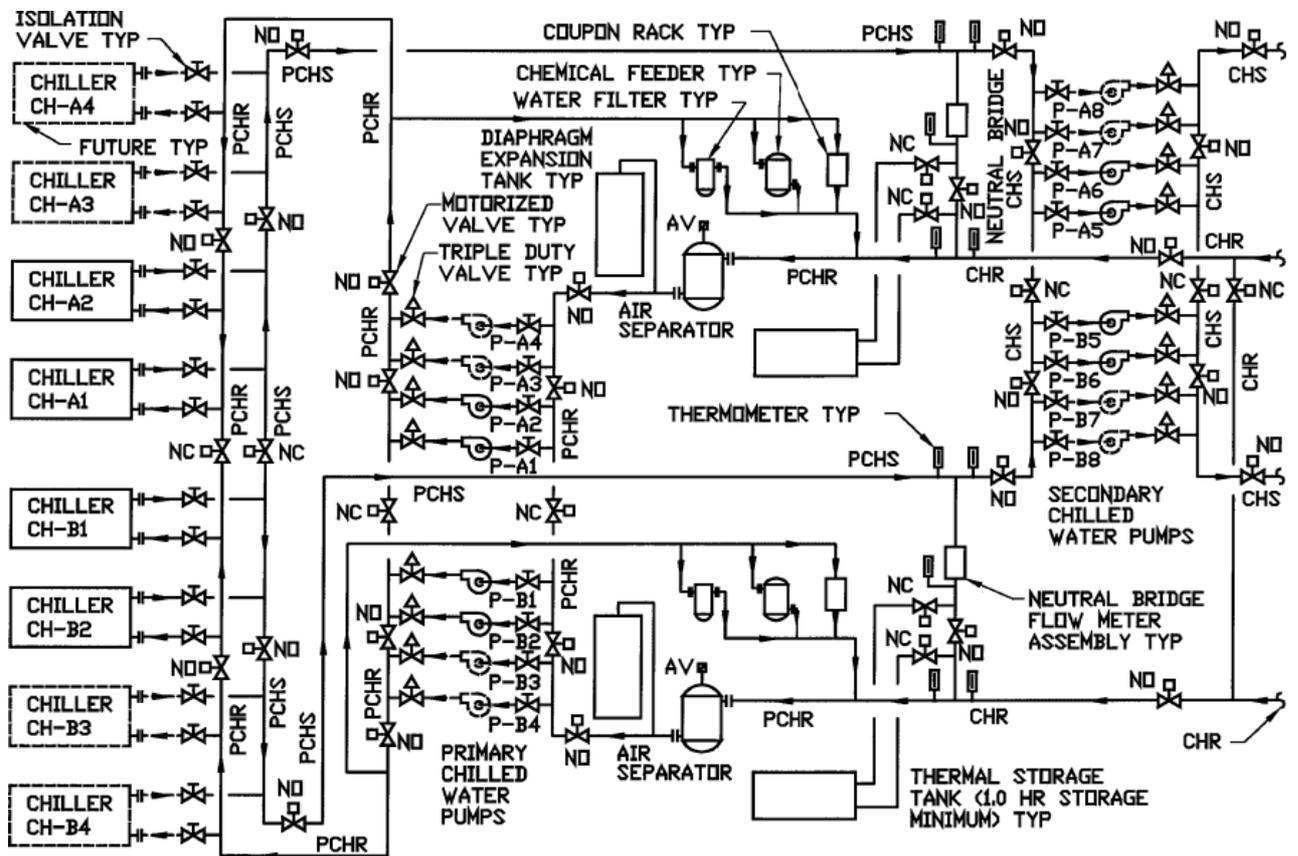
Figure 28.8. PARALLEL CHILLED-WATER SYSTEM—COUPLED PUMPS.



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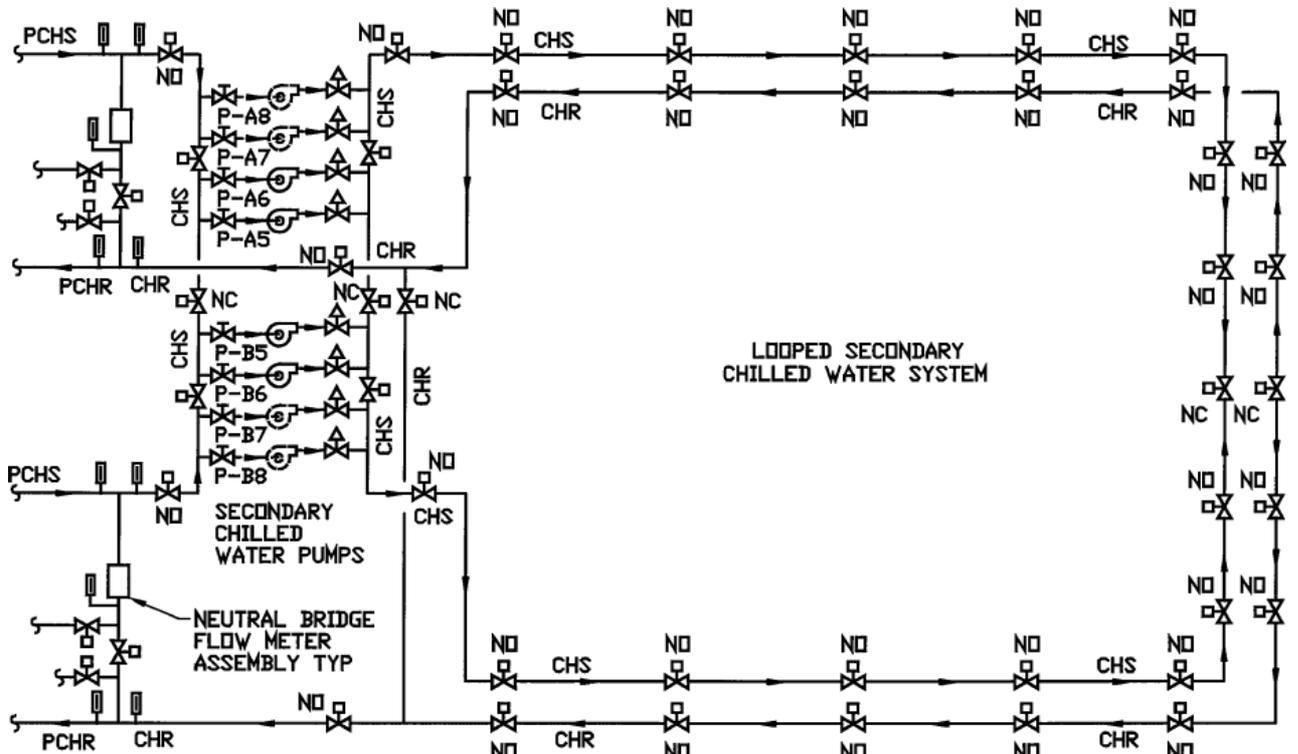
Figure 28.9. PARALLEL CHILLED-WATER SYSTEM—HEADERED PUMPS.

- When designing chilled-water systems for computer centers, data centers, Internet host sites, and other mission-critical facilities where down time is not acceptable, consider utilizing a dual primary/secondary chilled-water system with primary/secondary chilled-water cross-connections and looped secondary system (see [Figs. 28.10](#) and [28.11](#)). This chilled-water system design permits isolating the piping segments as well as the equipment to permit service and repairs to both piping and equipment without shutdown of the system. The dual primary/secondary chilled-water system can be designed and sized to meet the Uptime Institute's Tier III classification (N+1 redundancy requirements; the arrangement actually provides N+2) and Tier IV classification (2[N+1] redundancy requirements). Chilled-water systems serving mission-critical facilities should always be designed for future expansion and growth. All future equipment and systems must provide for this growth. Space must be provided for future equipment, valved and capped connections must be provided for connections to piping mains so shutdowns are not required, piping mains must be sized for the ultimate growth of the facility, and electrical power systems must be designed and sized for the ultimate power utilized by the facility.



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Figure 28.10. DUAL PRIMARY/SECONDARY CHILLED-WATER SYSTEM FLOW DIAGRAM.



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Figure 28.11. LOOPED SECONDARY CHILLED-WATER SYSTEM FLOW DIAGRAM.

C. Water Boxes/Piping Connections

1. Marine type. Marine water boxes enable piping to be connected to the side of the chiller so piping does not need to be disconnected in order to service machine. Recommend on large chillers, 500 tons and larger.
 2. Nonmarine or standard type. Recommend on small chillers, less than 500 tons.
 3. Provide victaulic or flanged connections for first three fittings at chiller with nonmarine or standard type connections.
 4. Locate piping connections against the wall.
 5. Locate all piping connections opposite the tube clean/pull side of the chiller.
 6. Locate oil cooler connections.
- D. Show tube clean/pull clearances and location.**
- E. The minimum recommended clearance around chillers is 36 inches. Maintain minimum clearances for tube pull and cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the chiller. Maintain minimum clearance as required to open access and control doors on chillers for service, maintenance, and inspection.**
- F. Maintain minimum electrical clearances as required by NEC.**
- G. Mechanical room locations and placement must take into account how chillers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**
- H. If the chiller must be disassembled for installation (the chiller cannot be shipped disassembled), specify the manufacturer's representative for reassembly; do not specify insulation with chiller (field insulate), and specify the chiller to come with remote mounted starter.**
- I. Show the location of the chiller starter, disconnect switch, and control panel.**
- J. Show the chiller relief piping.**
- K. Show sanitary drain locations and chiller drain connections.**

- L. Locate refrigerant monitoring system refrigerant sensors and the refrigerant purge exhaust fan. The refrigerant exhaust system should be designed to remove refrigerant based on its specific gravity (lighter than air—high exhaust, heavier than air—low exhaust). Refrigerant detection devices are required by code, *ASHRAE Standard 15*. Detection devices sound an alarm at certain levels (low limit) and sound an alarm and activate ventilation system at a higher level (high limit), with levels dependent on refrigerant type.**
- M. Providing self-contained breathing apparatus within buildings for refrigerant emergencies is not recommended as in previous versions of ASHRAE Standard 15. Pre-positioning emergency response equipment should only be used by trained emergency responders and must be labeled for use by trained personnel only.**
- N. Coordinate the height of the chiller with overhead clearances and obstructions. Is a beam required above the chiller for lifting the compressor or other components?**
- O. Low ambient operation. Is the operation of the chiller required below 40°F, 0°F, etc., or will airside economizers provide cooling?**
- P. Wind direction and speed (air-cooled machines). Orient the short end of the chiller to the wind.**
- Q. If isolators are required for the chiller, has the isolator height been considered in clearance requirements? If isolators are required for the chiller, has piping isolation been addressed?**
- R. Locate flow switches in both the evaporator and condenser water piping systems serving each chiller and flow meters as required by system design.**
- S. Locate pumpdown, pumpout, and refrigerant storage devices if they are required.**
- T. When combining independent chilled-water systems into a central plant**
 - 1. Create a central system concept, control scheme, and flow schematics.
 - 2. The system shall only have a single expansion tank connection point sized to handle entire system expansion and contraction.

3. All systems must be altered, if necessary, to be compatible with central system concept (temperatures, pressures, flow concepts—variable or constant control concepts).
 4. For constant flow and variable flow systems, the secondary chillers are tied into the main chiller plant return main. Chilled water is pumped from the return main through the chiller and back to the return main.
 5. District chilled-water systems, due to their size, extensiveness, or both, may require that independent plants feed into the supply main at different points. If this is required, design and layout must enable isolating the plant; provide start-up and shutdown bypasses; and provide adequate flow, temperature, pressure, and other control parameter readings and indicators for proper plant operation and other design issues that affect plant operation and optimization.
- U. In large systems, it may be beneficial to install a steam-to-water or water-to-water heat exchanger to place an artificial load on the chilled-water system to test individual chillers or groups of chillers during plant startup, after repairs, or for troubleshooting chiller or system problems.**
- V. Large and campus chilled-water systems should be designed for large delta Ts and for variable flow secondary and tertiary systems.**
- W. Chilled-water pump energy must be accounted for in the chiller capacity because it adds heat load to the system.**
- X. It is best to design chilled-water and condenser-water systems to pump through the chiller.**

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Part 29: Cooling Towers and Condensers

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29. Part 29: Cooling Towers and Condensers

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29.01. Cooling Tower Types (CTs)

A. Induced Draft—Cross Flow

1. 200–900 tons single cell.
2. 400–1,800 tons double cell.

B. Forced Draft, Counter Flow

1. 200–1,300 tons centrifugal fans.
2. 250–1,150 tons axial fans.
3. Figure 29.1 is a photograph of a forced draft, counter flow cooling tower in its installed condition.



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Figure 29.1. PHOTOGRAPH OF A FORCED DRAFT, COUNTER FLOW COOLING TOWER.

C. Ejector Parallel Flow

1. 5-750 tons.

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29.02. Definitions

- A. **Range.** Difference between entering and leaving water, system ΔT .
- B. **Approach.** Difference between leaving water temperature and entering air wet bulb.

- C. **Evaporation.** Method by which cooling towers cool the water.
- D. **Drift.** Entrained water droplets carried off by the cooling tower. An undesirable side effect.
- E. **Blowdown or Bleed.** Water intentionally discharged from the cooling tower to maintain water quality.
- F. **Plume.** Hot moist air discharged from the cooling tower forming a dense fog.

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29.03. Condenser Water

- A. **Most Common Entering Water Temperature (EWT): 95°F**
- B. **Most Common Leaving Water Temperature (LWT): 85°F**
- C. **Range: 10-40°F ΔT**
- D. **3.0 GPM/ton@10°F ΔT**
- E. **2.5 GPM/ton@12°F ΔT**
- F. **2.0 GPM/ton@15°F ΔT**
- G. **1.5 GPM/ton@20°F ΔT**
- H. **0.75 GPM/ton@40°F ΔT**

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29.04. Power

0.035-0.040 kW/ton

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29.05. TONS_{COND}

$$= \text{TONS}_{\text{EVAP}} \times 1.25$$

$$= 12,000 \text{ Btu/h ton} \times 1.25$$

$$= 15,000 \text{ Btu/h ton}$$

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29.06. Condenser Water Makeup to Cooling Tower

A. Range:	0.0306-0.0432 GPM/ton
B. Range:	0.0102-0.0144 GPM/Cond. GPM (1.0-1.4 percent Condenser GPM)
C. Centrifugal:	40 GPM/1,000 tons
D. Reciprocating:	40 GPM/1,000 tons
E. Screw:	40 GPM/1,000 tons
F. Scroll:	40 GPM/1,000 tons
G. Absorption:	80 GPM/1,000 tons

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29.07. Cooling Tower Drains

Use two times the makeup water rate for sizing cooling tower drains.

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29.08. Cycles of Concentration

A. Range:	2-10
B. Recommend:	3-5

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29.09. Evaporation

A. Range:	0.024-0.03 GPM/ton
B. Range:	0.008-0.01 GPM/Cond. GPM (0.8-1.0 percent Condenser GPM)
C. Recommend:	0.01 GPM/Cond. GPM

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29.10. Drift

A. Range:	0.0006-0.0012 GPM/ton
B. Range:	0.0002-0.0004 GPM/Cond. GPM (0.02-0.04 percent Condenser GPM)
C. Recommend:	0.0002 GPM/Cond. GPM

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29.11. Blowdown or Bleed (Based on 108F Range)

A. Range:	0.006-0.012 GPM/ton
B. Range:	0.002-0.004 GPM/Cond. GPM (0.2- 0.4 percent Condenser GPM)
C. Recommend:	0.002 GPM/Cond. GPM
D. Centrifugal:	10 GPM/1,000 tons
E. Reciprocating:	10 GPM/1,000 tons
F. Screw:	10 GPM/1,000 tons
G. Scroll:	10 GPM/1,000 tons
H. Absorption:	20 GPM/1,000 tons

Blowdown GPM—% of Cond. GPM

**Cooling
Tower
Range**

Cycles of Concentration

	2	3	4	5	6	7	8	9	10
10	0.80	0.40	0.30	0.20	0.10	0.10	0.10	0.10	0.10
15	1.20	0.60	0.40	0.30	0.20	0.20	0.15	0.15	0.15
20	1.60	0.80	0.50	0.40	0.30	0.30	0.20	0.20	0.20
25	2.00	1.00	0.65	0.50	0.40	0.35	0.25	0.25	0.23
30	2.40	1.20	0.80	0.60	0.50	0.40	0.30	0.30	0.25
35	2.75	1.40	0.95	0.70	0.55	0.45	0.35	0.35	0.30
40	3.10	1.60	1.10	0.80	0.60	0.50	0.40	0.40	0.35

29.12. Installation Location

Cooling towers should be located at least 100 feet from the building, when located on the ground, to reduce noise and prevent moisture from condensing on the building during the intermediate seasons (spring and fall). Cooling towers should also be located 100 feet from parking structures or parking lots to prevent staining of automobile finishes due to water treatment.

29.13. Air-Cooled Condensers and Condensing Units (ACCs and ACCUs)

A. Size Range:	0.5-500 tons
B. Air Flow:	600-1,200 CFM/ton
C. Power:	
1. Condenser Fans: 0.1-0.2 HP/ton.	
2. Compressors: 1.0-1.3 KW/ton.	

29.14. Evaporative Condensers and Condensing Units (ECs and ECUs)

A. Types and Sizes:	
1. 10-1,600 tons centrifugal fans.	
2. 10-1,500 tons axial fans.	
B. Drift:	0.002 GPM/cond. GPM
C. Evaporation:	1.6-2.0 GPM/ton
D. Bleed:	0.8-1.0 GPM/ton
E. Total:	2.4-3.0 GPM/ton

29.15. Installation of CTs, ACCs, ACCUs, ECs, and ECUs

- A. Allow ample space to provide the proper airflow to fans and units in accordance with the manufacturer's recommendations.**
- B. The top discharge of the unit should be at the same height or higher level than the adjoining building or wall to minimize recirculation caused by down drafts between the unit and wall. Raise the unit or provide a discharge hood to obtain the proper discharge height.**
- C. Elevating units may decrease the space required between units and between units and walls. Only decrease space in accordance with the manufacturer's recommendations.**
- D. Decking or metal plates over units between walls and other units may decrease the space required between units and between units and walls. Only decrease space in accordance with the manufacturer's recommendations.**
- E. Providing discharge hoods with units may decrease the space required between units and between units and walls. Only decrease space in accordance with the manufacturer's recommendations.**
- F. Chemical Feed Systems for CTs, ECs, and ECUs. Chemical feed systems are designed to control the following.**
 - 1. System pH; normally between 8 and 9.
 - 2. Corrosion.
 - 3. Scale.
 - 4. Biological and microbial growth.
- G. Clearance Requirements**
 - 1. The minimum recommended clearance around CTs, ACCs, ACCUs, ECs, and ECUs is 36 inches. Maintain minimum clearances as recommended by the equipment manufacturer. Maintain the minimum clearance as required to open access and control doors on equipment for service, maintenance, and inspection.
 - 2. Mechanical room locations and placement must take into account how CTs, ACCs, ACCUs, ECs, and ECUs can be moved into and out of the building during initial installation and after construction for maintenance and repair

and/or replacement.

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 29: Cooling Towers and Condensers, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 30: Heat Exchangers

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30. Part 30: Heat Exchangers

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30.01. Shell and Tube Heat Exchangers

- A. **Used Where the Approach of the System Is Greater than $15\pm^{\circ}\text{F}$**
- B. **Straight Tube or U-Tube Design**
- C. **Generally Used in Heating Systems**
- D. **Water to Water**
 - 1. Maximum tube velocity: 6 ft./sec.
 - 2. Maximum shell velocity: 5 ft./sec.
- E. **Steam to Water**
 - 1. Maximum water velocity: 6 ft./sec.
 - 2. If system steam capacity exceeds 2" control valve size, provide 2 control valves with 1/3 and 2/3 capacity split.

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30.02. Plate and Frame Heat Exchangers

- A. **Used Where the Approach of the System Is Less than $15\pm^{\circ}\text{F}$**
- B. **Generally Used in Cooling Systems**
- C. **Refer to Fig. 30.1 for a photograph of a plate and frame heat exchanger in its installed condition.**



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Figure 30.1. PHOTOGRAPH OF A PLATE AND FRAME HEAT EXCHANGER.

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30.03. Definitions

- A. **Range:** Difference between entering and leaving water, system ΔT .
- B. **Approach:** Difference between hot side entering water temperature and cold side leaving water temperature.

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30.04. Clearance and Design Requirements

- A. **The minimum recommended clearance around heat exchangers is 36 inches. Maintain minimum clearances for tube pull and the cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the heat exchanger.**
- B. **Mechanical room locations and placement must take into account how heat exchangers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

C. **Multiple heat exchangers should be used to prevent complete system or building shutdown upon failure of one heat exchanger in all water systems over 200 tons or 2,400,000 Btu/h (e.g., 2@50 percent, 2@67 percent, 2@70 percent, 3@34 percent, 3@40 percent).**

D. **Heat Transfer Factors**

1. Change in enthalpy on the primary side (hydronic side).
2. Change in enthalpy on the secondary side.
3. Heat transfer through the heat exchanger is dependent on film coefficients and the heat transfer surface area.

E. **Methods of Heat Transfer**

1. Parallel flow. Both mediums flow in the same direction. The least effective method of heat transfer.
2. Counter-flow. Mediums flow in opposite directions. The most effective method of heat transfer.
3. Cross-flow. Mediums flow at right angles to each other. Heat transfer effectiveness between parallel and counter flow methods.
4. Combination. Cross-Flow/Counter-Flow or Cross-Flow/Parallel Flow. Typical in shell and tube heat exchangers.

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 30: Heat Exchangers, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 31: Boilers

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31. Part 31: Boilers

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31.01. Boilers, General

A. **Class I Boilers. ASME Boiler and Pressure Vessel Code, Section I**

1. Steam boilers, greater than 15 psig
2. Hot water boilers:
 - a. Greater than 160 psig.
 - b. Greater than 250°F.
3. Common terminology:
 - a. Process boilers.
 - b. Power boilers.
 - c. High-pressure boilers.

B. **Class IV Boilers. ASME Boiler and Pressure Vessel Code, Section IV**

1. Steam boilers, 15 psig and less
2. Hot water boilers:
 - a. 160 psi and less.
 - b. 250°F and less.
3. Common terminology:
 - a. Commercial boilers.
 - b. Industrial boilers.

c. Heating boilers.

d. Low-pressure boilers.

C. Common Boiler Design Pressures

1. 15 psig.

2. 30 psig.

3. 60 psig.

4. 125 psig.

5. 150 psig.

6. 200 psig.

7. 250 psig.

8. 300 psig.

9. 350 psig.

D. Boiler Sequence of Operation

1. Prepurge.

2. Pilot ignition and verification.

3. Main flame ignition and verification.

4. Run time.

5. Post purge.

6. Boiler operational considerations:

a. Hot water and steam boilers:

1. Prevent hot or cold shock.

2. Prevent frequent cycling.

3. Provide proper water treatment.

b. Hot water boilers only:

1. Provide continuous circulation.

2. Balance flow through boilers.

3. Provide proper overpressure.

c. Causes of increased stack temperature:

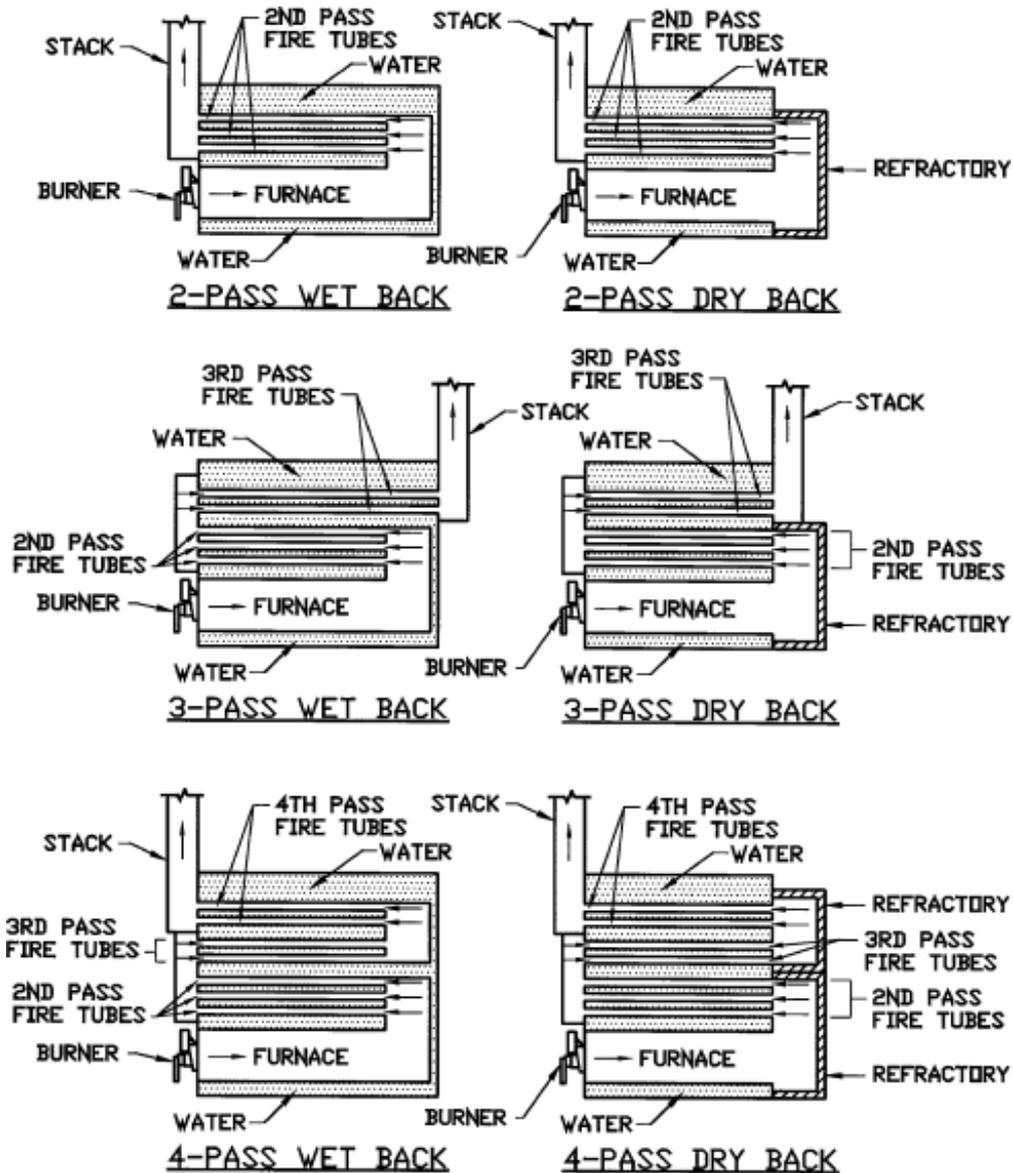
1. Soot buildup.

2. Scale buildup.

3. Combustion chamber and pass sealing problems.

E. Boiler Types

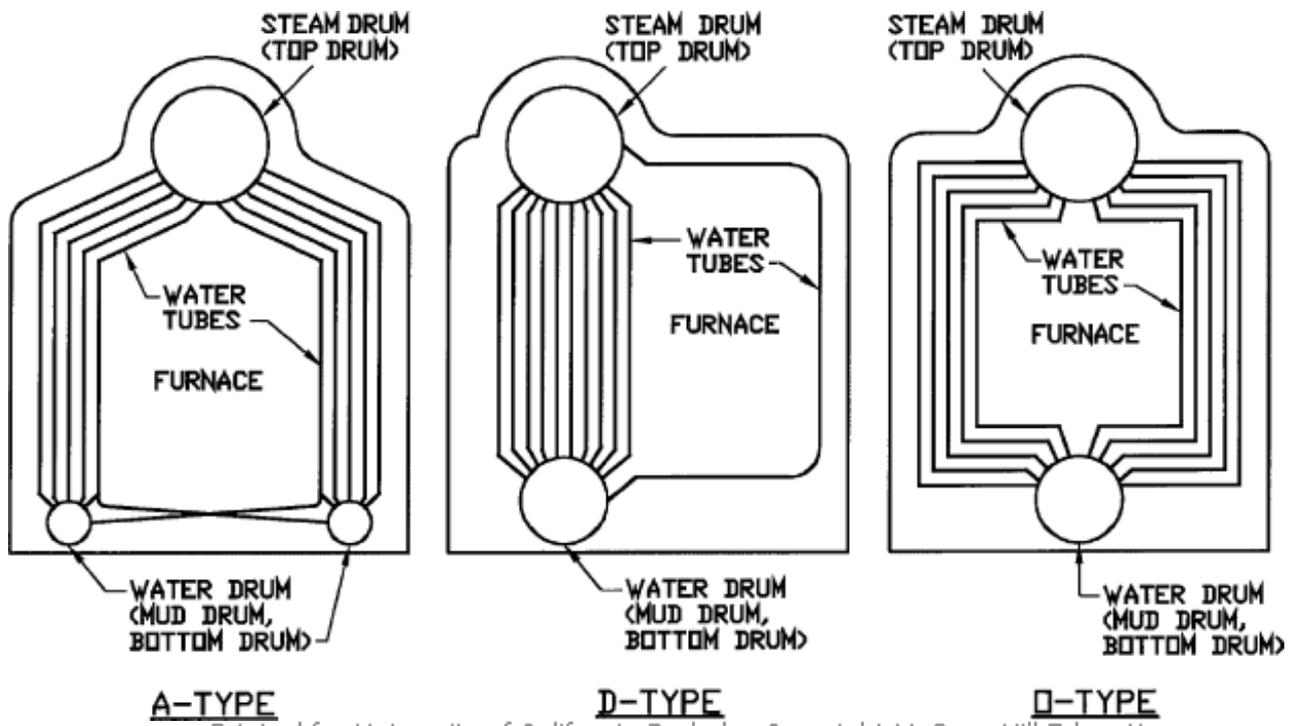
1. Fire tube boilers (Scotch Marine—see Fig. 31.1).



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Figure 31.1. FIRE TUBE BOILER TYPES.

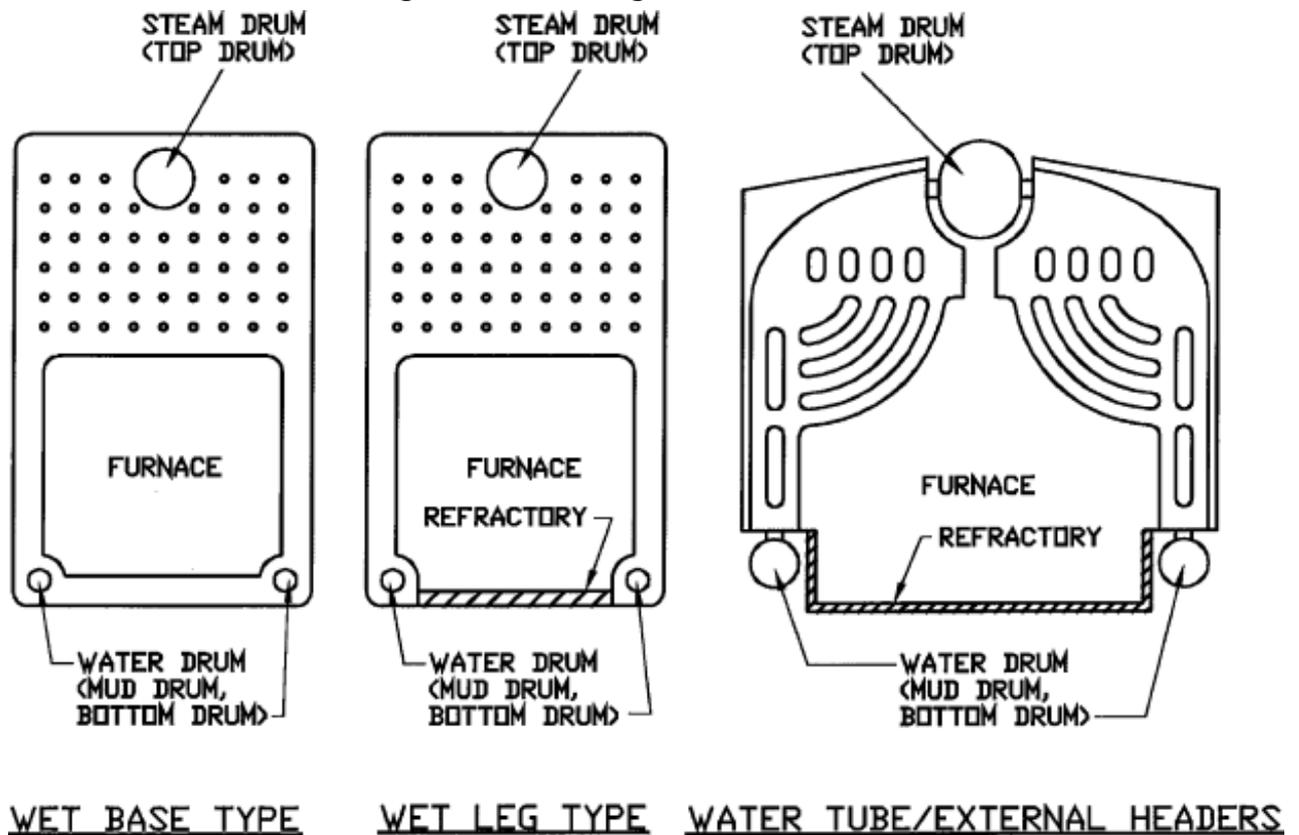
2. Water tube boilers (see Fig. 31.2).



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Figure 31.2. WATER TUBE BOILER TYPES.

3. Flexible tube boilers.
4. Cast iron boilers (see Figs. 31.3 through 31.5).



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Figure 31.3. CAST IRON BOILER TYPES.



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Figure 31.4. PHOTOGRAPH OF WET BASE CAST IRON BOILER.



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Figure 31.5. PHOTOGRAPH OF WATER TUBE BOILER CAST IRON BOILER WITH EXTERNAL HEADERS.

5. Modular boilers.
6. Electric boilers.
7. Fire tube versus water tube boiler characteristics are shown in the following table:

FIRE TUBE VS. WATER TUBE BOILERS

Compared Item	Fire Tube Boilers	Water Tube Boilers
Steam Quality	98.5%	99.5%
Steam Purity	52.5 ppm	17.5 ppm can be modified to obtain 1 ppm
Efficiency	85% average	80% average
Design Pressure	300 psig	900 psig
Design Temperature	350°F	455°F
Super Heaters	None	Available to 750°F
Load Swings	Long recovery time	Short recovery time
Water Weight	Factor of 2.5	Factor of 1.0
Length	Longer	Shorter
Height	Shorter	Higher
Overfire	No	10–15% for short periods
Space	Door swing and tube pull	3'0" minimum all around
Electrical Load	Greater hp required	Lower hp required
Water Quality	Same	Same
Turn Down	10:1 gas; 8:1 fuel oil #2	10:1 gas; 8:1 fuel oil #2
U.L. Label	Standard entire package	Not available for entire package—components only
Soot Blowers	None	Standard option
Ultimate Decision	Customer preference	Customer preference

F. Boiler Efficiency

1. Combustion efficiency: Indication of the burner's ability to burn fuel measured by the unburned fuel and excess air in the exhaust.

2. Thermal efficiency: Indication of the heat exchanger's effectiveness to transfer heat from the combustion process to the water or steam in a boiler. Does not account for radiation and convection losses, however.
3. Fuel-to-steam efficiency: Indication of the overall efficiency of the boiler including effectiveness of the heat exchanger, radiation losses, and convection losses (output divided by input). The test to determine fuel-to-steam efficiency is defined by *ASME Power Test Code, PTC 4.1*:
 - a. Input-output method.
 - b. Heat loss method.
4. Boiler efficiency: Indication of either thermal efficiency or fuel-to-steam efficiency depending on context.

G. Boiler Plant Efficiency Factors

1. Boiler, 80–85% efficient:
 - a. Radiation losses.
 - b. Convection losses.
 - c. Stack losses.
2. Boiler room, steam:
 - a. Heating of combustion air.
 - b. Heating of makeup water.
 - c. Steam condensate not returned.
 - d. Boiler blowdown.
 - e. Radiation losses:
 1. Condensate tank.
 2. Condensate pump.
 3. Feedwater pump.
 4. Deaerator or feedwater tank.
3. Boiler room, hot water:
 - a. Heating of combustion air.
 - b. Radiation losses:

1. Expansion tank.
2. Air separator.
3. Pumps.
4. Plant, system:
 - a. Steam leaks and bad steam traps.
 - b. Piping, valves, and equipment radiation losses.
 - c. Control valve operational problems.
 - d. Flash steam losses.
 - e. Water or condensate leaks/losses.

H. Steam System Energy Saving Tips

1. Insulate all hot surfaces to prevent heat loss.
2. Isolate all steam supply piping not being used.
3. Repair all steam piping leaks.
4. Repair all steam traps not operating properly which are bypassing steam.
5. Stop all internal steam leaks including venting of flash steam and open bypass valves around steam traps and control valves.
6. Produce clean, dry steam with the use of a steam separator and proper water treatment.
7. Properly control steam flow at equipment.
8. Use and properly select steam traps.
9. Use flash steam for preheating and other uses whenever possible.

I. Packaged Boiler Fuel Types

1. Natural gas.
2. Propane.
3. Light fuel oil #1 and #2.
4. Heavy fuel oil #4, #5, and #6.

5. Digester or landfill gas.

J. **Gas Trains**

1. Underwriter Laboratories, Standard (UL).
2. Industrial Risk Insurers (IRI).
3. Factory Mutual (FM).
4. Kemper.
5. ASME CSD-1 *Controls and Safety Devices for Automatically Fired Boilers*
6. NFPA 8501 *Standard for Single Burner Boiler Operation*.

K. **Boiler Capacity Terminology**

1. Startup load. Capacity required to bring the boiler system up to temperature, pressure, or both.
2. Running load. Design capacity.
3. Maximum Instantaneous Demand (MID). A sudden peak load requirement of unusually short duration:
 - a. MID loads are often hidden in process equipment loads.
 - b. Cold startup or pickup loads that far exceed their normal operating demands.
 - c. A full understanding of MID loads is required to properly select boiler system capacity.
 - d. MID shortfall corrective actions:
 1. Change load reaction time to reduce impact; slow down valve operation, reduce number of items with simultaneous startup (staged startup).
 2. Add boiler capacity.
 3. Add back pressure regulator downstream of deaerator or feedwater tank steam supply connection.
 4. Add an accumulator.

L. **Combustion**

1. Improper combustion:

- a. Oxygen rich-fuel lean: Wastes energy.
- b. Oxygen lean-fuel rich: Produces CO, soot, and potentially hazardous conditions.

2. What affects combustion?

- a. Changes in barometric pressure.
- b. Changes in ambient air temperature:
 1. Oxygen trim systems compensate for ambient air temperature changes.
- c. Ventilation air:
 1. Total: 10 CFM/BHP
 2. Combustion air: 8 CFM/BHP
 3. Ventilation: 2 CFM/BHP
- d. Keep boiler room positive with respect to the stack and breeching (+0.10 in. W.G. maximum) to prevent the entrance of flue gases into the boiler room.
- e. Never exhaust boiler rooms; use supply air with relief air.

M. Stacks and Breeching. Provide a manual damper (lock damper in the open position) or a motorized damper (two-position damper) at the boiler outlet. A motorized damper interlocked with boiler operation is preferred.

1. Multiple boilers with common stack and breeching. Damper will prevent products of combustion from entering the boiler room when repairing or inspecting boilers while system is still in operation.
2. Multiple boilers with individual or common stack and breeching. Damper will prevent the natural draft through the boiler when not firing, thus reducing the energy lost up the stack.

N. 1990 Clean Air Act—Focused on the reduction of the following pollutants

1. Ozone (O₃).
2. Carbon monoxide (CO).
3. Nitrogen oxides (NO_x-NO/NO₂).

4. Sulfur oxides (SO_x - SO_2/SO_3).
5. Particulate matter, 10 ppm.
6. Lead.

O. **Standard Controls**

1. Steam boiler control and safeties:
 - a. High limit pressure control. Provides a margin of safety.
 - b. Operating limit pressure control. Starts/stops burner.
 - c. Modulation pressure control. Varies burner firing rate.
 - d. Low limit pressure control.
 - e. Low water cutoff.
 - f. Auxiliary low water cutoff.
 - g. High water cutoff.
2. Hot water boiler controls and safeties:
 - a. High limit pressure control. Provides a margin of safety.
 - b. High limit temperature control. Provides a margin of safety.
 - c. Operating limit temperature control. Starts/stops burner.
 - d. Modulation temperature control. Varies burner firing rate.
 - e. Low limit pressure control.
 - f. Low limit temperature control.
 - g. Low water cutoff.
 - h. High water cutoff.
3. Fuel system controls and safeties:
 - a. Low gas pressure switch.
 - b. High gas pressure switch.
 - c. Low oil pressure switch.
 - d. High oil pressure switch.

- e. Low oil temperature.
- 4. Combustion controls and safeties:
 - a. Pilot failure switch.
 - b. Flame failure switch.
 - c. Combustion air proving switch.
 - d. Oil atomization proving switch.
 - e. Low fire hold control.
 - f. Low fire switch.
 - g. High fire switch.

P. Safety, relief, and safety relief valve testing is dictated by the Insurance Underwriter.

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31.02. Hot Water Boilers

A. Boiler Types

- 1. Fire tube boilers:
 - a. 15–800 BHP.
 - b. 500–26,780 MBH.
 - c. 30–300 psig.
- 2. Water tube boilers:
 - a. 350–2,400 BHP.
 - b. 13,000–82,800 MBH.
 - c. 30–525 psig.
- 3. Flexible water tube boilers:
 - a. 30–250 BHP.
 - b. 1,000–8,370 MBH.
 - c. 0–150 psig.
- 4. Cast-iron boilers:

- a. 10–400 BHP.
 - b. 345–13,800 MBH.
 - c. 0–40 psig.
5. Modular boilers:
- a. 4–115 BHP.
 - b. 136–4,000 MBH.
 - c. 0–150 psig.
6. Electric boilers:
- a. 15–5,000 KW.
 - b. 51–17,065 MBH.
 - c. 0–300 psig.

B. Hot Water Boiler Plant Equipment

1. Boilers (see Fig. 31.6).

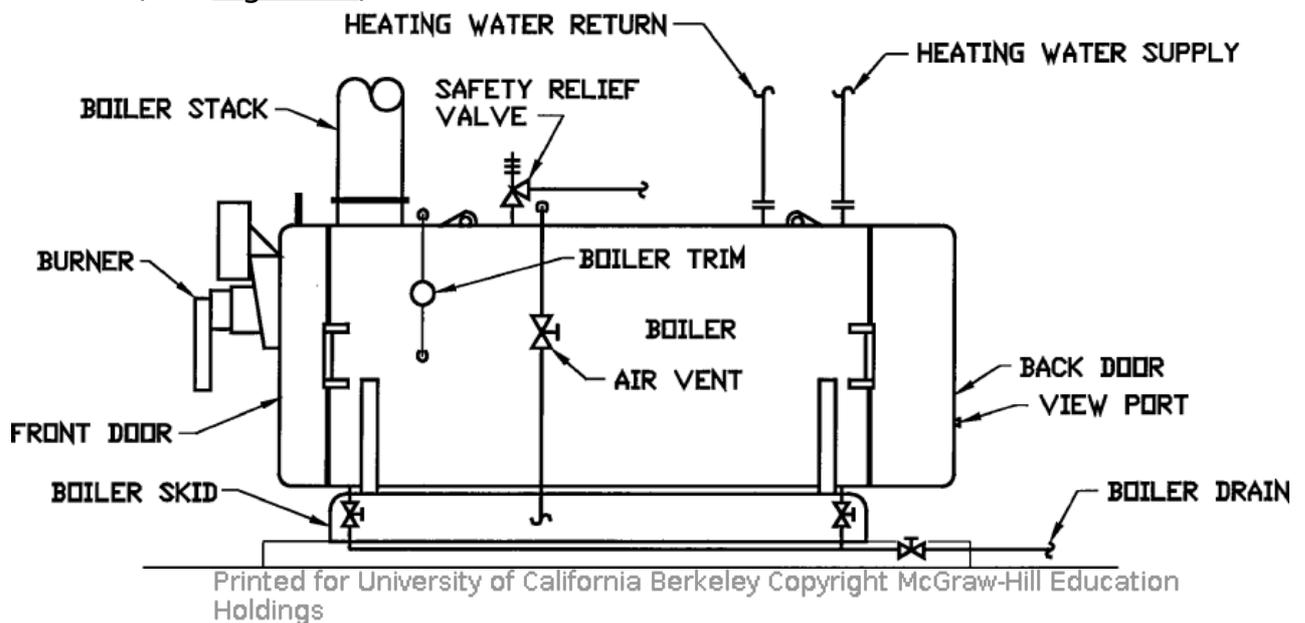


Figure 31.6. HEATING WATER SYSTEM AND BOILER TERMINOLOGY.

- 2. Pumps.
- 3. Air separators.
- 4. Expansion tanks.

C. Heating Water

1. Leaving water temperature (LWT): 180–200°F.

2. 20–40°F ΔT most common.
3. Boiler system design limits:
 - a. Minimum flow through a boiler: 0.5–1.0 GPM/BHP.
 - b. Maximum flow through a boiler: Boiler capacity divided by the temperature difference divided by 500.
 - c. Pressure drop through a boiler: 3–5 feet H₂O.
 - d. Minimum supply water temperature: 170°F. This temperature may vary with boiler design and with manufacturer; verify the exact temperature with the manufacturer.
 - e. Minimum return water temperature: 150°F. This temperature may vary with boiler design and with manufacturer; verify the exact temperature with the manufacturer.
 - f. Maximum supply water temperature: Based on the ASME Design Rating of the boiler.
4. Heating capacities:
 - a. 3.45 GPM/BHP @20°F ΔT .
 - b. 2.30 GPM/BHP @30°F ΔT .
 - c. 1.73 GPM/BHP @40°F ΔT .
 - d. 10.0 GPM/therm @20°F ΔT .
 - e. 6.7 GPM/therm @30°F ΔT .
 - f. 5.0 GPM/therm @40°F ΔT .
 - g. 10,000 Btuh/GPM @20°F ΔT .
 - h. 15,000 Btuh/GPM @30°F ΔT .
 - i. 20,000 Btuh/GPM @40°F ΔT .

D. **System Types**

1. Low-temperature heating water systems:
 - a. 250°F and less.
 - b. 160 psig maximum.

2. Medium-temperature heating water systems:

- a. 251–350°F.
- b. 160 psig maximum.

3. High-temperature heating water systems:

- a. 351–450°F.
- b. 300 psig maximum.

E. Heating Water Storage Systems

1. 20°F ΔT :

- a. 0.80 cu.ft./MBtu
- b. 1246.2 Btu/cu.ft.
- c. 166.6 Btu/gal.

2. 30°F ΔT :

- a. 0.54 cu.ft./MBtu
- b. 1869.3 Btu/cu.ft.
- c. 249.9 Btu/gal.

3. 40°F ΔT :

- a. 0.40 cu.ft./MBtu
- b. 2492.3 Btu/cu.ft.
- c. 333.2 Btu/gal.

F. Hot Water System Makeup Connection: Minimum connection size shall be 10 percent of largest system pipe size or 1", whichever is greater (20" system pipe size results in a 2" makeup water connection).

G. Chemical Feed Systems for Water Boilers. Chemical feed systems are designed to control the following:

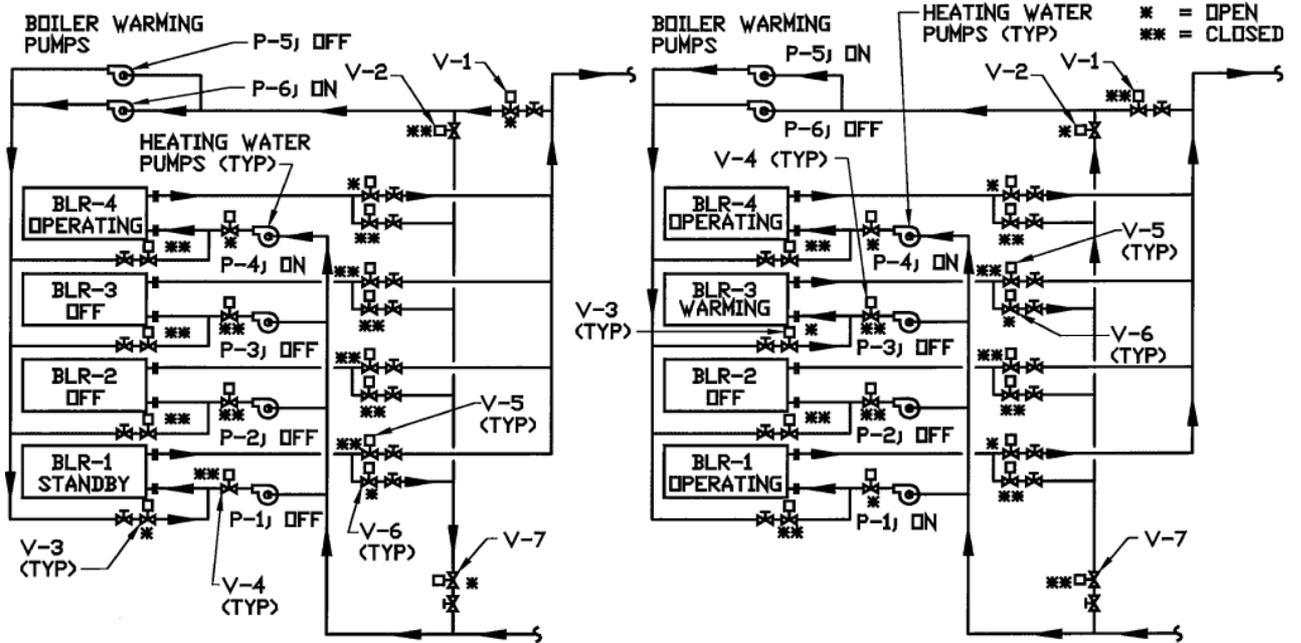
- 1. System pH, normally between 8 and 9.
- 2. Corrosion.
- 3. Scale.

H. Design, Layout, and Clearance Requirements/Considerations

- 1. Design conditions:

- a. Boiler load, Btu/h, or MBH.
 - b. Heating water temperatures, entering and leaving, or entering and ΔT .
 - c. Heating water flows and fluid type (correct all data for fluid type).
 - d. Fuel input, gas, fuel oil, electric, etc.
 - e. Overall boiler efficiency.
 - f. Water pressure drops.
 - g. Fouling factor.
 - h. Heating water reset, if applicable. Verify with boiler manufacturer that temperature limits are not exceeded.
 - i. Electrical data:
 1. Unit kW, blower hp, compressor hp, and fuel oil pump hp.
 2. Full load, running load, and locked rotor amps.
 3. Voltage-phase-hertz.
2. Multiple hot water boilers should be used to prevent complete system or building shutdown upon failure of one hot water boiler in all heating water systems over 70 boiler horsepower or 2,400,000 Btu/h (i.e., 2 @ 50 percent, 2 @ 67 percent, 2 @ 70 percent, 3 @ 34 percent, 3 @ 40 percent).
 3. Show tube clean/pull clearances and location.
 4. The minimum recommended clearance around boilers is 36 in. Maintain minimum clearances for tube pull and the cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the boiler. Maintain minimum clearance as required to open access and control doors on boilers for service, maintenance, and inspection.
 5. Mechanical room locations and placement must take into account how boilers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.
 6. Maintain the minimum electrical clearances as required by NEC.
 7. Show the location of the boiler starter, disconnect switch, and control panel.

8. Show gas train and/or fuel oil train location.
9. Show boiler relief piping.
10. Show sanitary drain locations and boiler drain connections.
11. Design and locate combustion air louvers and motorized dampers, or engineered combustion air system. What happens if the engineered combustion air system malfunctions? Is a standby available? Verify that items that might freeze are not located in front of a combustion air intake.
12. Coordinate the height of the boiler with overhead clearances and obstructions. Is a beam required above the boiler for lifting components? Is a catwalk required to service the boiler?
13. Boiler stack and breeching. Coordinate routing in boiler room, through building, and discharge height above the building with the architect and structural engineer.
14. If isolators are required for the boiler, has the isolator height been considered in clearance requirements? If isolators are required for the boiler, has piping isolation been addressed?
15. Provide stop check valves (located closest to the boiler) and isolation valves with a drain between these valves on both the supply and return connections to all heating water boilers.
16. Boiler systems pumps should be located so the pump draws water out of the boiler, because it decreases the potential for entry of air into the system, and it does not impose the pump pressure on the boiler.
17. Interlock the boiler and the pump so the burner cannot operate without the pump operating.
18. Boiler warming pumps should be piped to both the system header and the boiler supply piping, allowing the boiler to be kept warm (in standby mode) from the system water flow or to warm the boiler when it has been out of service for repairs without the risk of shocking the boiler with the system water temperature (see [Figs. 31.7](#) and [31.8](#)).



BOILER STANDBY OPERATION

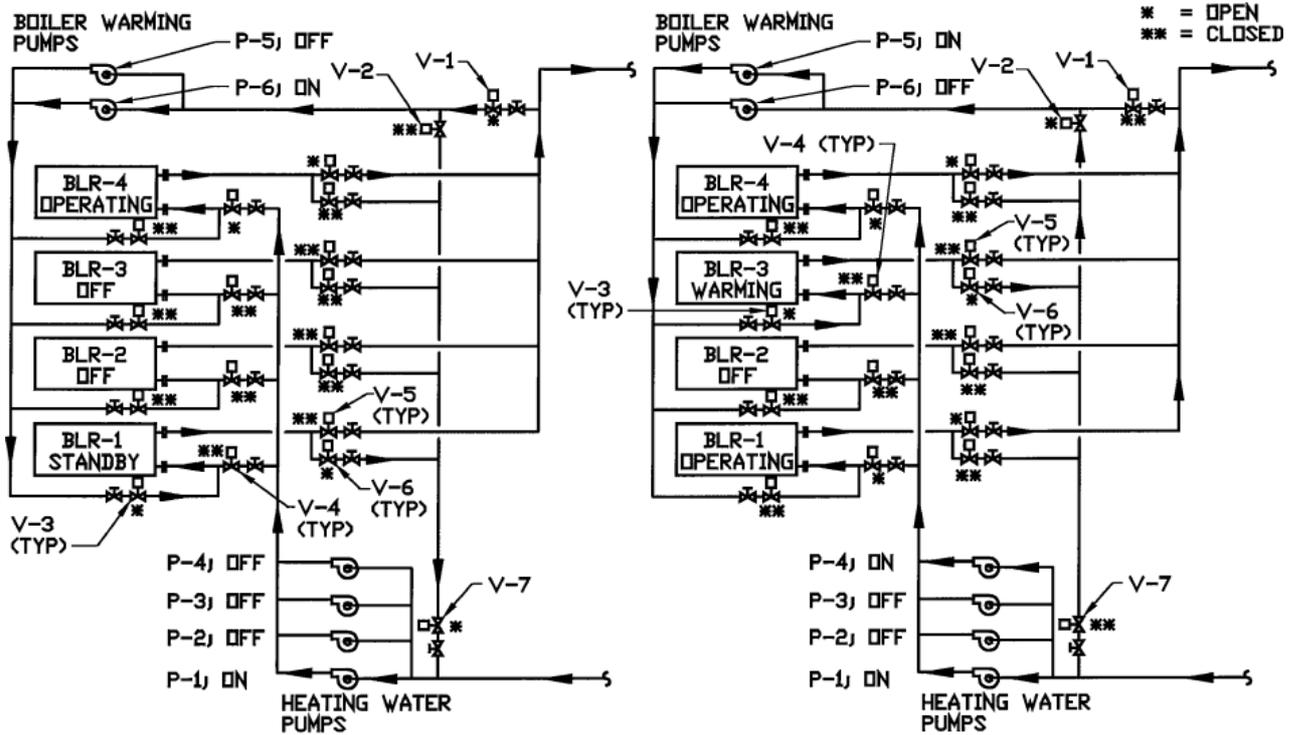
COUPLED PUMPS

BOILER WARMING OPERATION

COUPLED PUMPS

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Figure 31.7. BOILER STANDBY AND WARMING DIAGRAM—COUPLED PUMPS.



BOILER STANDBY OPERATION

HEADERED PUMPS

BOILER WARMING OPERATION

HEADERED PUMPS

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Figure 31.8. BOILER STANDBY AND WARMING DIAGRAM—HEADERED PUMPS.

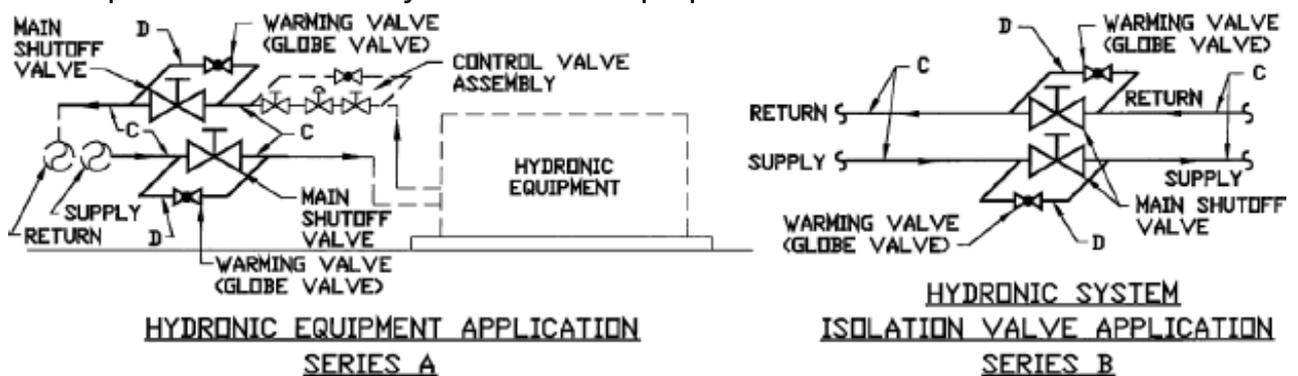
19. Boiler warming pumps should be selected for 0.1 GPM/BHP (range 0.05–0.1 GPM/BHP). At 0.1 GPM/BHP, it takes 45–75 minutes to completely exchange the water in the boiler. This flow rate is sufficient to offset the heat loss by radiation and stack losses on boilers when in standby mode of operation. In addition, this flow rate allows the system to keep the boiler warm without firing the boiler, thus allowing for more efficient system operation. For example, it takes 8–16 hours to bring a boiler online from a cold start. Therefore, the standby boiler must be kept warm to enable immediate startup of the boiler upon failure of an operating boiler.
20. Circulating hot water through a boiler which is not operating, to keep it hot for standby purposes, creates a natural draft of heated air through the boiler and up the stack, especially in natural draft boilers. Forced draft or induced draft boilers have combustion dampers that close when not firing and therefore reduce, but don't eliminate, this heat loss. Although this heat loss is undesirable, for standby boilers, circulating hot water through the boiler is more energy efficient than firing the boiler. Operating (firing) a standby boiler may be in violation of air permit regulations in many jurisdictions today.
21. To provide fully automatic heating water system controls, the controls must look at and evaluate the boiler metal temperature (water temperature) and the refractory temperature prior to starting the primary pumps or enabling the boiler to fire. First, the boiler system design must circulate system water through the boilers to keep the boiler water temperature at system temperature when the boiler is in standby mode, as discussed for boiler warming pump arrangements. Second, the design must look at the water temperature prior to starting the primary pumps to verify the boiler is ready for service. And third, the design must look at refractory temperature to prevent boiler from going to high fire if the refractory is not at the appropriate temperature. However, the refractory temperature is usually handled by the boiler control package.
22. Outside air temperature reset of low temperature heating water systems is recommended for energy savings and controllability of terminal units at low load conditions. However, care must be taken with the boiler design to prevent thermal shock by low return water temperatures, or to prevent condensation in the boiler due to low supply water temperatures and, therefore, a lower combustion stack discharge temperature.
23. Combustion air dampers must be extra heavy duty and should be low

leakage (10 CFM/sq.ft. @ 4" WC differential) or ultralow leakage (6 CFM/sq.ft. @ 4" WC differential) type.

24. When the system design requires the use of dual fuel boilers (natural gas, fuel oil), provide a building automation control system I/O point to determine whether the boiler is on natural gas or fuel oil. Boiler control panels generally have a fuel type switch (Gas/Off/Fuel Oil Switch) which can be connected to create this I/O point. Switching from natural gas to fuel oil (or vice versa) cannot be a fully automatic operation because the boiler operator must first turn the boiler burner to the "Off" position, then turn the fuel type switch to fuel oil, then put combustion air linkage into the fuel oil position, then slide the fuel oil nozzle into position, then put the fuel oil pump into "Hand" or "Auto" position, and then turn the boiler burner to the "On" position. Remember to interlock the fuel oil pumps with operation of the boiler on fuel oil. Do not forget to include diesel generator interlocks with fuel oil pumps when the generators are fed from the same fuel oil system.
25. Heating water system warm-up procedure:
- a. Heating water system startup should not exceed a 100°F temperature rise per hour, but boiler or heat exchanger manufacture limitations should be consulted.
 - b. It is recommended that no more than a 25°F temperature rise per hour be used when warming heating water systems. Slow warming of the heating water system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
 - c. Low temperature heating water systems (250°F and less) should be warmed slowly at a 25°F temperature rise per hour until the system design temperature is reached.
 - d. Medium- and high-temperature heating water systems (above 250°F) should be warmed slowly at a 25°F temperature rise per hour until a 250°F system temperature is reached. At this temperature, the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 350°F or the system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing

the system to settle for an hour before increasing the temperature or pressure to the next increment. When the system reaches 350°F and the design temperature is above 350°F, the system should be allowed to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 455°F or system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allow the system to settle for an hour before increasing the temperature or pressure to the next increment.

26. Provide heating water systems with warm-up valves for in-service startup as follows (see Fig. 31.9). This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when only opened a small amount in an attempt to control the system warm-up speed.



NOTES:

1. SERIES A WARMING VALVES COVER STEAM OR MEDIUM/HIGH-TEMPERATURE HEATING WATER SERVICE FOR WARMING UP EQUIPMENT BEFORE THE MAIN SHUTOFF VALVES ARE OPENED, AND FOR BALANCING PRESSURES WHERE LINES ARE OF LIMITED VOLUME.
2. SERIES B WARMING VALVES COVER LINES CONVEYING GASES OR LIQUIDS WHERE BYPASSING MAY FACILITATE THE OPERATION OF THE MAIN VALVE BY BALANCING THE PRESSURES ON BOTH SIDES OF THE MAIN VALVE.

MAIN VALVE SIZE (C)	WARMING VALVE SIZE (D)	
	SERIES A WARMING VALVES	SERIES B WARMING VALVES
4"	1/2"	1"
5", 6"	3/4"	1-1/4"
8"	3/4"	1-1/2"
10"	1"	1-1/2"
12", 14"	1"	2"
16", 18", 20"	1"	3"
24", 30"	1"	4"
36", 42"	1"	6"
48", 54"	1"	8"
60", 72"	1"	10"
84", 96"	1"	12"

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Figure 31.9. HYDRONIC SYSTEM WARMING VALVES.

BYPASS AND WARMING VALVES

Nominal Pipe Size

Main Valve Nominal Pipe Size	Series A Warming Valves	Series B Bypass Valves
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

- 1. Series A comprehends steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**

- 2. Series B comprehends lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

27. Heating water system warming valve procedure (see Fig. 31.9):
- a. Open the warming return valve slowly to pressurize the equipment without flow.
 - b. Once the system pressure has stabilized, slowly open the warming supply valve to establish flow and to warm the system.
 - c. Once the system pressure and temperature have stabilized, perform the following steps, one at a time:
 1. Slowly open the main return valve.
 2. Close the warming return valve.
 3. Slowly open the main supply valve.
 4. Close the warming supply valve.

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31.03. Steam Boilers

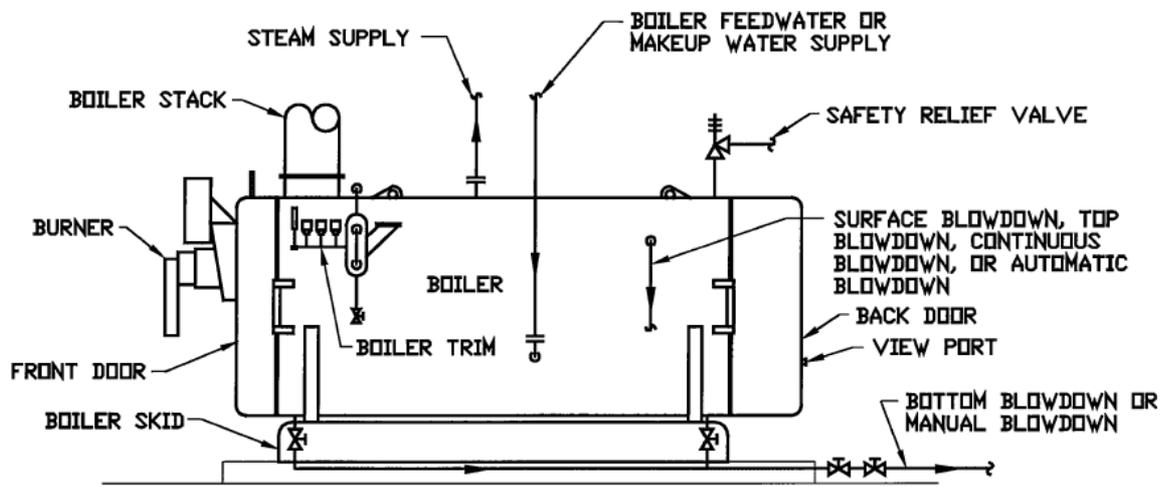
A. Boiler Types

1. Fire tube boilers:
 - a. 15–800 BHP.
 - b. 518–27,600 lbs./h
 - c. 15–300 psig.
2. Water tube boilers:
 - a. 350–2,400 BHP.
 - b. 12,075–82,800 lbs./h
 - c. 15–525 psig.
3. Flexible water tube boilers:
 - a. 30–250 BHP.
 - b. 10,000–82,000 lbs./h
 - c. 15–525 psig.
4. Cast-iron boilers:
 - a. 10–400 BHP.

- b. 1,035–8,625 lbs./h
 - c. 0–150 psig.
5. Electric boilers:
- a. 15–5,000 KW.
 - b. 51–17,065 MBH.
 - c. 0–300 psig.

B. Steam Boiler Plant Equipment

1. Pretreatment systems:
 - a. Filters.
 - b. Softeners.
 - c. Dealkalizers.
 - d. RO units.
2. Feedwater systems:
 - a. Deaerator:
 1. Spray type.
 2. Packed column type.
 - b. Feedwater tank.
 - c. Feedwater pumps.
3. Chemical feed systems:
 - a. Chemical pumps.
 - b. Chemical tanks.
 - c. Agitators.
4. Sample coolers.
5. Blowdown coolers.
6. Surface blowdown/feedwater preheater.
7. Flue gas economizers.
8. Boilers (see Fig. 31.10).



NOTES:

1. BOILER BURNER MAY BE FORCED DRAFT, INDUCED DRAFT, OR NATURAL DRAFT TYPE DEPENDING ON BOILER TYPE AND CONSTRUCTION, FORCED DRAFT TYPE SHOWN.
2. BOILER TRIM IS COMPRISED OF THE LOW WATER LEVEL LIMIT AND ALARM, HIGH WATER LEVEL LIMIT AND ALARM, FEEDWATER CONTROLLER INCLUDING LEVEL CONTROLLER, SAFETIES, FUEL CUTOUTS, SAFETY RELIEF VALVES, PRESSURE GAUGES, THERMOMETERS, HIGH AND LOW LIMIT BURNER CONTROLS, AND OTHER APPURTENANCES.

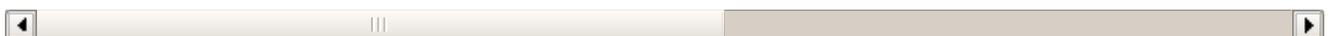
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Figure 31.10. STEAM SYSTEM AND BOILER TERMINOLOGY.

9. Condensate return units and pumps.
 10. Condensate receiver tank.
 11. Condensate pumps.
 12. Accumulators:
 - a. Type:
 1. Dry.
 2. Wet.
 - b. Service:
 1. Total system.
 2. Dedicated lines to specific equipment.
 13. Super heaters:
 - a. Internal.
 - b. External.
- C. Steam Capacities**
1. Approx. 1,000 Btuh/1 lb. steam.
 2. lbs. steam/h = lb. water/h

STEAM CAPACITY PER BOILER HORSEPOWER

Feed Water Temp.	Pounds of Dry Saturated Steam @ System Pressure (psig) vs. Feed									
	0	2	10	15	20	40	50	60	80	100
30	29.0	29.0	28.8	28.7	28.6	28.4	28.3	28.2	28.2	28.1
40	29.3	29.2	29.1	29.0	28.9	28.7	28.6	28.5	28.4	28.3
50	29.6	29.5	29.3	29.2	29.1	28.9	28.8	28.8	28.7	28.6
60	29.8	29.8	29.6	29.5	29.4	29.2	29.1	29.0	28.9	28.8
70	30.1	30.0	29.9	29.8	29.7	29.5	29.4	29.3	29.2	29.1
80	30.4	30.3	30.1	30.0	30.0	29.8	29.6	29.6	29.5	29.3
90	30.6	30.6	30.4	30.3	30.2	30.0	29.9	29.8	29.7	29.6
100	30.9	30.8	30.6	30.6	30.5	30.3	30.2	30.1	30.0	29.8
110	31.2	31.2	30.9	30.8	30.8	30.6	30.4	30.3	30.2	30.0
120	31.5	31.4	31.2	31.2	31.1	30.8	30.7	30.6	30.5	30.4
130	31.8	31.7	31.5	31.4	31.4	31.1	31.0	30.9	30.8	30.7
140	32.1	32.0	31.8	31.7	31.6	31.4	31.3	31.2	31.1	31.0
150	32.4	32.4	32.1	32.0	31.9	31.7	31.6	31.5	31.4	31.2
160	32.7	32.7	32.4	32.4	32.3	32.0	31.9	31.8	31.7	31.5
170	33.0	33.0	32.7	32.6	32.6	32.3	32.2	32.1	32.0	31.8
180	33.4	33.3	33.0	33.0	32.9	32.6	32.5	32.4	32.3	32.2
190	33.8	33.7	33.4	33.3	33.2	32.9	32.8	32.7	32.6	32.5
200	34.1	34.0	33.7	33.6	33.5	33.2	33.1	33.0	32.9	32.8
212	34.5	34.4	34.2	34.1	33.9	33.6	33.5	33.4	33.3	33.2
220	34.8	34.7	34.4	34.3	34.2	33.9	33.8	33.7	33.5	33.4
227	35.0	34.9	34.7	34.5	34.4	34.1	34.0	33.9	33.8	33.7
230	35.2	35.0	34.8	34.7	34.5	34.2	34.1	34.0	33.9	33.8



D. Steam Boiler Drums

1. Top drum: steam drum.
2. Bottom drum: mud or blowdown drum.

E. System Types

1. Low-pressure steam:	0-15 psig.
2. Medium-pressure steam:	16-100 psig.
3. High-pressure steam:	101 psig and greater.

F. Steam Carryover

1. Steam carryover is the entrainment of boiler water with the steam.
2. Causes of carryover:
 - a. Mechanical:
 1. Poor boiler design.
 2. Burner misalignment.
 3. High water level.
 - b. Chemical:
 1. High total dissolved solids (TDS).
 2. High total suspended solids (TSS).
 3. High alkalinity.
 4. High amine levels.
 5. Presence of oils or other organic materials.
3. Problems caused by carryover:
 - a. Deposits minerals on valves, piping, heat transfer surfaces, and other steam-operated equipment.
 - b. Causes thermal shock to the system.
 - c. Contaminates process or products that have direct steam contact.
 - d. If steam is used for humidification, a white dust is often left on the air handling unit components, ductwork surfaces, and furniture and other equipment within the space.

4. Carryover control:
 - a. Install steam separation devices.
 - b. Maintain the proper steam space in the steam drum and boiler.
 - c. Maintain proper water chemistry—TDS, TSS, alkalinity, etc.

G. Design, Layout, and Clearance Requirements/Considerations

1. Design conditions:
 - a. Boiler load: Btu/h, or MBH.
 - b. Steam pressure and flow rate.
 - c. Fuel input: gas, fuel oil, electric, etc.
 - d. Overall boiler efficiency.
 - e. Fouling factor.
 - f. Electrical data:
 1. Unit kW, blower hp, compressor hp, and fuel oil pump hp.
 2. Full load, running load, and locked rotor amps.
 3. Voltage-phase-hertz.
2. Multiple steam boilers should be used to prevent complete system or building shutdown upon failure of 1 steam boiler in all steam systems over 70 boiler horsepower or 2,400,000 Btu/h (i.e., 2 @ 50 percent, 2 @ 67 percent, 2 @ 70 percent, 3 @ 34 percent, 3 @ 40 percent).
3. Show tube clean/pull clearances and location.
4. The minimum recommended clearance around boilers is 36 in. Maintain minimum clearances for tube pull and the cleaning of the tubes as recommended by the equipment manufacturer. This is generally equal to the length of the boiler. Maintain minimum clearance as required to open access and control doors on boilers for service, maintenance, and inspection.
5. Mechanical room locations and placement must take into account how boilers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.
6. Maintain minimum electrical clearances as required by the NEC.

7. Show the location of the boiler starter, disconnect switch, and the control panel.
8. Show gas train and/or fuel oil train location.
9. Show the boiler relief piping.
10. Show sanitary drain locations and boiler drain connections.
11. Design and locate combustion air louvers and motorized dampers or an engineered combustion air system. What happens if the engineered combustion air system malfunctions? Is a standby available? Verify that items that might freeze are not located in front of the combustion air intake.
12. Coordinate the height of the boiler with overhead clearances and obstructions. Is a beam required above the boiler for lifting components? Is a catwalk required to service the boiler.
13. Boiler stack and breeching. Coordinate routing in the boiler room, through the building, and the discharge height above building with architect and structural engineer.
14. Provide a stop check valve (located closest to the boiler) and an isolation valve with a drain between these valves on the steam supply connections to all steam boilers.
15. Combustion air dampers must be extra heavy duty and should be low leakage (10 CFM/sq.ft. @ 4" WC differential) or ultralow leakage (6 CFM/sq.ft. @ 4" WC differential) type.
16. When the system design requires the use of dual fuel boilers (natural gas, fuel oil), provide a building automation control system I/O point to determine whether the boiler is on natural gas or fuel oil. Boiler control panels generally have a fuel type switch (gas/off/fuel oil switch) that can be connected to create this I/O point. Switching from natural gas to fuel oil (or vice versa) cannot be a fully automatic operation because the boiler operator must first turn the boiler burner to the "Off" position, then turn the fuel type switch to fuel oil, then put the combustion air linkage into the fuel oil position, then slide the fuel oil nozzle into position, then put the fuel oil pump into the "Hand" or "Auto" position, and then turn the boiler burner to the "On"

position. Remember to interlock the fuel oil pumps with operation of the boiler on fuel oil. Do not forget to include diesel generator interlocks with fuel oil pumps when the generators are fed from the same fuel oil system.

17. Steam system warm-up procedure:

- a. Steam system startup should not exceed a 100°F temperature rise per hour (50 psig per hour); boiler or heat exchanger manufacture limitations should be consulted.
- b. It is recommended that no more than a 25°F temperature rise per hour (15 psig per hour) be used when warming steam systems. Slow warming of the steam system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
- c. Low-pressure steam systems (15 psig and less) should be warmed slowly at a 25°F temperature rise per hour (15 psig per hour) until the system design pressure is reached.
- d. Medium- and high-pressure steam systems (above 15 psig) should be warmed slowly at a 25°F temperature rise per hour (15 psig per hour) until a 250°F-15 psig system temperature-pressure is reached. At this temperature-pressure, the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature-pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 120 psig or the system design pressure in 25 psig pressure increments, and allow the system to settle for an hour before increasing the pressure to the next increment. When the system reaches 120 psig and the design pressure is above 120 psig, the system should be allowed to settle for at least 8 hours or more (preferably overnight). The pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 300 psig or the system design pressure in 25 psig pressure increments, and then must be permitted to settle for an hour before increasing the pressure to the next increment.

18. Provide steam systems with warm-up valves for in-service startup, as shown in the following table. This will allow operators to warm these systems slowly and prevent a sudden shock or catastrophic system failure when large

system valves are opened. Providing warming valves also reduces wear on large system valves when only opened a small amount in an attempt to control the system warm-up speed.

BYPASS AND WARMING VALVES

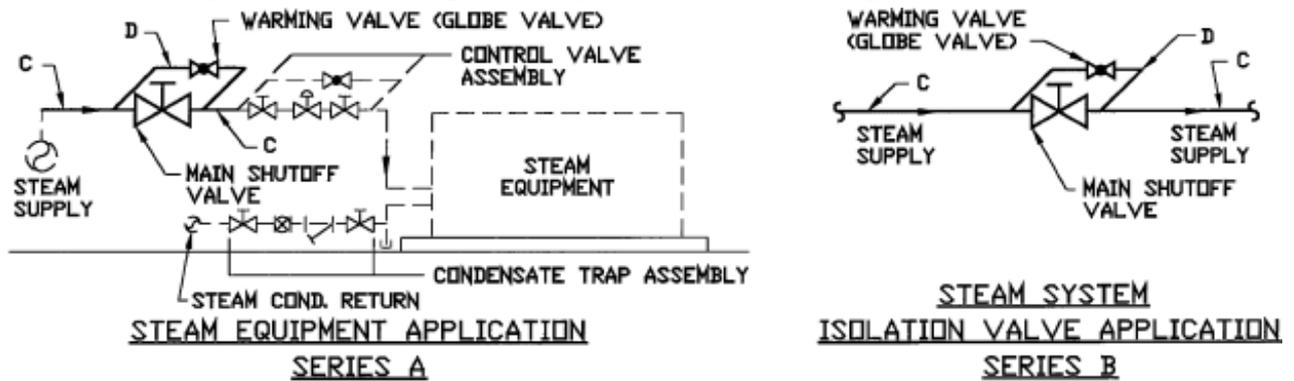
Nominal Pipe Size

Main Valve Nominal Pipe Size	Series A Warming Valves	Series B Bypass Valves
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

- 1. Series A comprehends steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**
- 2. Series B comprehends lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

19. The steam system warming valve procedure (see Fig. 31.11):



NOTES:

1. SERIES A WARMING VALVES COVER STEAM OR MEDIUM/HIGH-TEMPERATURE HEATING WATER SERVICE FOR SYSTEM OR EQUIPMENT WARM-UP BEFORE THE MAIN SHUTOFF VALVE TO THE SYSTEM OR DEVICE IS OPENED. WARMING VALVES ARE ALSO USED FOR BALANCING PRESSURES WHERE LINES ARE OF LIMITED VOLUME.
2. SERIES B WARMING VALVES COVER LINES CONVEYING GASES OR LIQUIDS WHERE BYPASSING MAY FACILITATE THE OPERATION OF THE MAIN VALVE BY BALANCING THE PRESSURES ON BOTH SIDES OF THE MAIN VALVE.

MAIN VALVE SIZE (C)	WARMING VALVE SIZE (D)	
	SERIES A WARMING VALVES	SERIES B WARMING VALVES
4"	1/2"	1"
5", 6"	3/4"	1-1/4"
8"	3/4"	1-1/2"
10"	1"	1-1/2"
12", 14"	1"	2"
16", 18", 20"	1"	3"
24", 30"	1"	4"
36", 42"	1"	6"
48", 54"	1"	8"
60", 72"	1"	10"
84", 96"	1"	12"

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Figure 31.11. STEAM SYSTEM WARMING VALVES.

- a. Slowly open the warming supply valve to establish flow and to warm the system.
 - b. Once the system pressure and temperature have stabilized, perform the following items one at a time:
 1. Slowly open the main supply valve.
 2. Close the warming supply valve.
20. If isolators are required for the boiler, has isolator height been considered in clearance requirements? If isolators are required for the boiler, has piping isolation been addressed?

H. Low Water Cutoffs

1. Primary: Float type.
2. Auxiliary: Probe type.
3. Low water cutoffs should be tested by using an evaporation test:
 - a. Take the boiler to low fire.
 - b. Shut off the feedwater to the boiler.

- c. Operate the boiler until the low water cutoff shuts down the boiler or the water level in the gauge glass falls below the low water cutoff activation point but still remains visible in glass.
 - d. Conduct an evaporation test at least every 30 days; once a week is recommended.
4. Class I boilers. Low water cutoff is 3" above the top row of tubes in fire tube boilers.
 5. Class IV boilers. Low water cutoff is 0"-1/4" above the top row of tubes in fire tube boilers.
 6. Water should always be visible in gauge glass. If water is not visible in gauge glass, immediately perform the following two steps one after another in any order:
 - a. Shut off the boiler burner.
 - b. Shut off the boiler feedwater.
 - c. Then allow the boiler to cool and inspect it for damage.

I. Deaerator or Feedwater Tank

1. The deaerator or the feedwater tank purpose is to remove oxygen, carbon dioxide, hydrogen sulfide, and other noncondensable gases and to heat boiler feedwater.
2. They also preheat the feedwater prior to being pumped to the boiler. Cold feedwater temperatures may cause:
 - a. Thermal shock.
 - b. Oxygen-rich feedwater, which causes corrosion.
3. This equipment should remove oxygen in the water to levels measured in parts per billion (ppb).
4. Steam vent on the deaerator or feedwater tank. Steam should appear 12"-18" above the top of vent. If steam appears below 12", the deaerator or feedwater tank is not removing all the oxygen, carbon dioxide, hydrogen sulfide, and other noncondensable gases.
5. Deaerators should be used when:
 - a. The system pressure is 75 psig and higher.

- b. Steam systems are employed with little or no standby capacity.
- c. The system depends on continuous operation.
- d. The system requires 25 percent or more of makeup water.

J. Sizing Boiler Feed Pumps, Condensate Return Pumps, and Condensate Receivers

1. If the boiler is under 50 psi, the designer should size the boiler feed pumps or condensate return pumps so that they discharge at 5 psi above the working pressure of the boiler.
2. If the boiler is over 50 psi, the designer should size boiler feed pumps or condensate return pumps so that they discharge at 10 psi above the working pressure of the boiler.
3. The designer should size condensate receivers for 1 minute of net capacity based on the condensate return rate.
4. Size boiler feedwater system receivers for system capacity (normally estimated at 10 minutes):
 - a. Deaerator systems: 10-minute supply.
 - b. Feedwater tank systems: 15-minute supply.
5. Size condensate pumps at three times the condensate return rate.
6. Size boiler feedwater pumps and transfer pumps at:
 - a. Turbine pumps, intermittent operation: Two times the boiler maximum evaporation rate or 0.14 GPM per boiler hp.
 - b. Centrifugal pumps, continuous operation: 1.5 times the boiler maximum evaporation rate or 0.104 GPM per boiler hp.
 - c. Boiler feedwater and transfer pump selection criteria:
 1. Continuous or intermittent operation.
 2. Temperature of feedwater or condensate.
 3. Flow capacity (GPM).
 4. Discharge pressure required: Boiler pressure plus piping friction loss.
 5. NPSH requirement.

7. Boiler feedwater control types:
 - a. On/Off feedwater control is generally used with single boiler systems or in multiple boiler systems when one feedwater pump is dedicated to each boiler and is typically accomplished with a turbine pump.
 - b. Level control is generally used with multiple boiler systems where feedwater pumps serve more than one boiler and is typically accomplished with a centrifugal pump.
8. Vacuum type steam condensate return units: 0.1 GPM/1,000 lbs./h of connected load.
9. Pumped steam condensate return units: 2.4 GPM/1,000 lbs./h.

K. Boiler Blowdown Systems

1. Bottom blowdown. Bottom blowdown, sometimes referred to as manual blowdown, functions to remove suspended solids and sediment that have settled out of the water and deposited on the bottom of the boiler. Bottom blowdown is most effective with several short discharges in lieu of one long discharge because the solids settle out between discharges; this results in the greatest removal of suspended solids with the least amount of water.
2. Surface blowdown. Surface blowdown, sometimes referred to as automatic blowdown, continuous blowdown, or periodic blowdown, depending on how the blowdown is controlled, functions to remove dissolved solids, surface water scum, and foam to maintain proper conductivity levels.
 - a. Automatic:
 1. Conductivity probe.
 2. Timer.
 - b. Continuous.
 - c. Periodic (manual) by time.

L. Boiler Blowdown Separator Makeup

1. Noncontinuous blowdown (bottom blowdown): 5.0 GPM/1,000 lbs./h.
2. Continuous blowdown (surface blowdown): 0.5 GPM/1,000 lbs./h.

M. Blowdown Separator Drains: 10 GPM/1000 lbs./h Boiler Output

N. Steam Boiler Water Makeup

1. Boilers: 4.0 GPM/1,000 lbs./h each.

2. Deaerator/feedwater unit: 4.0 GPM/1,000 lbs./h each.
3. Makeup water for the steam system is only required at one of the boilers or one of the feedwater units at any given time for system sizing.

O. Chemical Feed Systems for Steam Boilers. Chemical feed systems are designed to control the following.

1. System pH, normally between 8 and 9.
2. Oxygen level, less than 0.007 PPM (7 ppb).
3. Water conditioning level.
4. Carbon dioxide level.
5. Scale.
6. Corrosion.

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31.04. Fuel Systems and Types

A. Fuel System Design Guidelines

1. Natural gas pressure reducing valves (NGPRV):
 - a. Use multiple NGPRVs when system natural gas capacity exceeds 2 NGPRV size, when normal operation calls for 10 percent of design load for sustained periods, or when there are two distinct load requirements (e.g., summer/winter) that are substantially different. Provide the number of NGPRVs to suit the project.
 - b. If system capacity for a single NGPRV exceeds the 2 NGPRV size but is not larger than the 4 NGPRV size, use 2 NGPRVs with 33 percent and 67 percent or 50 percent and 50 percent capacity split.
 - c. If system capacity for a single NGPRV exceeds 4 NGPRV size, use 3 NGPRVs with 25 percent, 25 percent, and 50 percent or 15 percent, 35 percent, and 50 percent capacity split to suit the project.
 - d. Provide natural gas pressure regulating valves with positive shutoff ability to prevent the natural gas system from becoming equal to the gas utility system pressure when the building natural gas system is not using gas.
2. Natural gas meters should be provided as follows:

- a. Coordinate equipment, building, or site meter requirements with the local utility company. If the project budget permits, these meter readings should be logged and recorded at the building facilities management and control system.
 - b. Meter for a campus or site of buildings. A site meter is generally provided by the utility company.
 - c. Meter for individual buildings on a campus. If fed from a site meter, design documents should provide a meter for each building. This meter will assist in tracking energy use at each building and for troubleshooting system problems.
 - d. Meter for individual buildings. A building meter will generally be provided by the utility company.
 - e. Meters for individual boilers. A meter should be provided by the design documents for each and every boiler; environmental air permit requirements insist natural gas be monitored at each boiler.
 - f. Meters for other major users. A meter should be provided by the design documents for each major user within the building (emergency generators, gas-fired AHUs, domestic water heaters, unit heaters, kitchens).
3. Boiler fuel oil pump flow rates and generator day tank pump flow rates are generally 2.5–3.0 times the boiler and generator consumption rates. Confirm with the manufacturer or the electrical engineer that the information received is the consumption rate of the boiler/generator or fuel oil pumping rate of the boiler/generator. When boilers are located above the fuel oil tanks, a method of preventing back siphoning through the return line must be provided. This may be accomplished by providing the return line with a pressure regulator or with an operated valve interlocked with the fuel oil pump. Also, the fuel oil pumps must be provided with a check valve in the discharge, or if large height differentials are required, a motorized discharge isolation valve interlocked with the pump may be required because check valves will leak.
4. Fuel oil meters should be provided as follows:
- a. If the fuel oil system is a circulating system with a fuel oil return line, meters must be provided in both the supply and return to determine the fuel oil consumed. Most manufacturers provide fuel oil meters with this

capability with controls and software to automatically calculate the fuel oil consumed. If the project budget permits, these meter readings should be logged and recorded at the building facilities management and control system. All fuel oil meters must be shown on the design documents. Environmental regulations require the fuel oil purchased versus fuel oil consumed be recorded and tracked for determining when leaks may be occurring in the system.

- b. Meters for each group of site distribution pumps are located at the pumps.
- c. Meters for individual buildings on a campus are located at each building. This meter will assist in tracking energy use at each building and for troubleshooting system problems.
- d. Meters for individual boilers. A meter should be provided for each and every boiler; environmental air permit requirements require fuel oil to be monitored at each boiler.
- e. Meters for other major users. A meter should be provided for each major user within the building (emergency generators, oil-fired AHUs, domestic water heaters, and unit heaters).

B. Natural Gas

- 1. 900–1200 Btu/cu.ft.
- 2. 1,000 Btu/cu.ft. average.

C. Fuel Oil

- 1. #2: 138,000 Btu/gal.
- 2. #4: 141,000 Btu/gal.
- 3. #5: 148,000 Btu/gal.
- 4. #6: 152,000 Btu/gal.

D. LP Gas

- 1. Butane:
 - a. 21,180 Btu/lbs.
 - b. 3,200 Btu/cu.ft.
- 2. Propane:
 - a. 21,560 Btu/lbs.

b. 2,500 Btu/cu.ft.

E. Electric

1. 3,413 Btuh/KW.
2. 3,413 Btuh/watt.

F. Coal

1. Anthracite: 14,600–14,800 Btu/lb.
2. Bituminous: 13,500–15,300 Btu/lb.

G. Wood

1. 8,000–10,000 Btu/lb.

H. Kerosene

1. 135,000 Btu/gal.

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 31: Boilers, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 32: Motors and Motor Controllers

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32. Part 32: Motors and Motor Controllers

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32.01. Motors

A. Motor Types. Items 1, 2, and 3 are the most common HVAC motor types.

1. Open drip proof (ODP): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance. Use indoors and in moderately clean environments.
2. Totally enclosed fan cooled (TEFC): A fan on the motor shaft, outside the stator housing and within the protective shroud, blows air over the motor. Use in damp, dirty, corrosive, or contaminated environments.
3. Explosion proof (EXPRF): Totally enclosed with enclosure designed to withstand internal explosion of a specific gas-air or dust-air mixture to prevent escape of ignition products. Motors are approved for a specific Hazard Classification as covered by the NEC. Class I Explosion Proof and Class II Dust Ignition Resistant are the two most common types of hazardous location motors.
4. Open drip proof air over (ADAO): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance. Use indoors and in moderately clean environments. Rated for motor cooling by airflow from a driven device.
5. Totally enclosed non-ventilated (TENV): No ventilation openings in housing. Motor rated for cooling by airflow from a driven device. TENV motors are usually under 5 horsepower.

6. Totally enclosed air over (TEAO): No ventilation openings in housing. Motor rated for cooling by airflow from a driven device. TEAO motors frequently have dual horsepower ratings depending on speed and cooling air temperature.

B. Motor Horsepowers, Voltage, Phase, and Operating Guidelines:

1. Suggested horsepower and phase:
 - a. Motors 1/2 horsepower and larger: 3 Phase.
 - b. Motors less than 1/2 horsepower: Single Phase.
 - c. Considering first cost economics only, it is less costly, on average, to have motors smaller than 1 hp to be single-phase. At 3/4 hp, single-phase and three-phase motors cost about the same, but branch circuits and control equipment for three-phase motors are usually more expensive.
 - d. When life cycle owning and operating costs are considered, it is often more economical to provide motors as specified in lines a. and b. earlier.
2. Do not start and stop motors more than six times per hour.
3. Motors of 5 horsepower and larger should not be cycled; they should run continuously.
4. Specify energy-efficient motors—EPA motors as a minimum; preferred premium efficiency motors. Premium efficiency motors are a higher efficiency motor than the EPA motors.
5. Do not use energy-efficient motors with variable speed/frequency drives.
6. For best motor life and reliability, do not select motors to run within the service factors. Specify motors with a minimum 1.15 service factor.
7. For every 50°F (28°C) increase in motor operating temperature, the life of the motor is cut in half. Conversely, for every 50°F (28°C) decrease in motor operating temperature, the life of the motor is doubled.
8. Energy-efficient motors have a higher starting current than their standard efficiency counterparts.
9. The best sign of motor trouble is smoke and/or paint discoloration.
10. In general, motors can operate with voltages plus or minus 10 percent of their rated voltage.

11. Motors in storage should be turned by hand every 6 months to keep the bearings from drying out.

12. Available motor voltages are given in the following table:

Phase	Nominal Voltage	Nameplate Voltage
Single-Phase	120	115
	240	230
	277	265
Three-Phase	208	200
	240	230
	480	460
	600	575

C. Standard motor sizes are given in the following table:

Motor Sizes (hp)	Recommended Starter Type	Standard Service Factors
1/8; 1/10; 1/12; 1/15; 1/20; 1/25; 1/30; 1/60; 1/100	SPC or PSC	1.40
1/6	SPC or PSC	*
1/4; 1/3	CS	*
1/2; 3/4; 1	MS	*
1-1/2; 2	MS	*
3; 5; 7-1/2; 10; 15; 20; 25; 30; 40; 50; 60; 75; 100; 125; 150; 200; 250	MS	*
350; 400; 450; 500; 600; 700; 750; 800; 900; 1000; 1250; 1500; 1750; 2000; 2250; 2500; 3000; 3500	MS	*

Notes:
SPC: Split phase capacitor start.
PSC: Permanent split capacitor start.
CS: Capacitor start.

3500, 4000, 4500, 5000, 5500, 6000** Motor Sizes (hp)	Recommended Starter Type	Standard Service Factors
Notes:		
SPC: Split phase capacitor start.		
PSC: Permanent split capacitor start.		
CS: Capacitor start.		
MS: Magnetic start; polyphase induction motors (squirrel cage).		
1/2 hp through 50 hp across-the-line starter.		
60 hp and larger reduced-voltage starter.		
*See paragraph E below for motor service factors for these motors.		
**Motors generally not used in HVAC applications.		

D. **Standard Motor RPM: 3600, 1800, 1200, 900, 720, 600, and 514.**

E. **NEMA motor service factors are given in the following table:**

hp	3600 RPM	1800 RPM	1200 RPM	900 RPM
1/6-1/3	1.35	1.35	1.35	1.35
1/2	1.25	1.25	1.25	1.15
3/4	1.25	1.25	1.15	1.15
1	1.25	1.15	1.15	1.15
1-1/2-250	1.15	1.15	1.15	1.15
300-2500	1.15	1.15	1.15	1.15

F. **NEMA locked rotor indicating code letters are given in the following table:**

NEMA Locked Rotor Indicating Code Letters

Code Letter	KVA/hp	Code Letter	KVA/hp
A	0-3.14	L	9.00-9.99
B	3.15-3.54	M	10.00-11.19
C	3.55-3.99	N	11.20-12.49
D	4.00-4.49	O	Not used
E	4.50-4.99	P	12.50-13.99
F	5.00-5.59	Q	Not used
G	5.60-6.29	R	14.00-15.99
H	6.30-7.09	S	16.00-17.99
I	Not used	T	18.00-19.99
J	7.10-7.99	U	20.00-22.39
K	8.00-8.99	V	22.40 and up

1. Standard three-phase motors often have these NEMA starting locked rotor codes:

a. 1 horsepower and smaller:	Locked Rotor Code L.
b. 1-1/2-2 horsepower:	Locked Rotor Code K.
c. 3 horsepower:	Locked Rotor Code J.
d. 5 horsepower:	Locked Rotor Code H.
e. 7-1/2-10 horsepower:	Locked Rotor Code G.
f. 15 horsepower and larger:	Locked Rotor Code F.

2. Standard single-phase motors often have these locked rotor codes:

Factor	Motor Insulation Class Temperature Rise											
4. Motors with Enclosed Windings and with 1.0 Service, All Enclosures	65	A	149	85	B	185	110	F	230	-	H	-
Motor Type	°C		°F	°C		°F	°C		°F	°C		°F

Notes:

- 1. Abnormal deterioration of insulation may be expected if the ambient temperature of 40°C/104°F is exceeded in regular operation.**
- 2. Temperature rise based on 40°C/104°F ambient. Temperature rises are based on operation at altitudes of 3300 feet or less.**
- 3. Class A Motors: Fractional hp motors, small appliances; maximum operating temperature 105°C/221°F.**
- 4. Class B Motors: Motors for HVAC applications, high-quality fractional hp motors; maximum operating temperature 130°C/266°F.**
- 5. Class F Motors: Inverter duty motors, industrial motors; maximum operating temperature 155°C/311°F.**
- 6. Class H Motors: High temperature, high reliability, high ambient; maximum operating temperature 180°C/356°F.**

H. NEMA Motor Design Designations

- Design A motors are built with high pullout torque and are used on injection molding machines.
- Design B motors are built with high starting torque with reasonable starting current and are used with fans, pumps, air handling units, and other HVAC equipment. They are the most common HVAC motor.
- Design C motors are built with high starting torque and used with hard-to-start loads and with conveyors.
- Design D motors are built with high starting torque, low starting current, and

high slip and are used with cranes, hoists, and low-speed presses.

I. Clearance Requirements

1. The minimum recommended clearance around the motors is 24 inches.
2. Mechanical room locations and placement must take into account how motors can be moved into and out of the building during the initial installation and after construction for maintenance, repair, and/or replacement.

J. Motor Efficiencies

1. *ASHRAE Standard 90.1-2013*: NEMA Design A and B; Single Speed; 3600, 1800, or 1200 RPM; Open Drip Proof (ODP) or Totally Enclosed Fan-Cooled (TEFC) motors 1 hp and larger shall meet the following minimum nominal efficiencies:

Motor Horsepower	Minimum Nominal Efficiency (%)					
	Open Motors			Enclosed Motors		
	Number of Poles			Number of Poles		
	2	4	6	2	4	6
	Synchronous Speed (RPM)			Synchronous Speed (RPM)		
	3600	1800	1200	3600	1800	1200
1	-	82.5	80.0	75.5	82.5	80.0
1.5	82.5	84.0	84.0	82.5	84.0	85.5
2	84.0	84.0	85.5	84.0	84.0	86.5
3	84.0	86.5	86.5	85.5	87.5	87.5
5	85.5	87.5	87.5	87.5	87.5	87.5
7.5	87.5	88.5	88.5	88.5	89.5	89.5
10	88.5	89.5	90.2	89.5	89.5	89.5
15	89.5	91.0	90.2	90.2	91.0	90.2
20	90.2	91.0	91.0	90.2	91.0	90.2
25	91.0	91.7	91.7	91.0	92.4	91.7
Note:	91.0	92.4	92.4	91.0	92.4	91.7

Motor Horsepower	Open Motors			Enclosed Motors		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
40	91.7	93.0	93.0	91.7	93.0	93.0
50	92.4	93.0	93.0	92.4	93.0	93.0
60	93.0	93.6	93.6	93.0	93.6	93.6
75	93.0	94.1	93.6	93.0	94.1	93.6
100	93.0	94.1	94.1	93.6	94.5	94.1
125	93.6	94.5	94.1	94.5	94.5	94.1
150	93.6	95.0	94.5	94.5	95.0	95.0
200	94.5	95.0	94.5	95.0	95.0	95.0

Note:

- Nominal efficiencies shall be established in accordance with NEMA MG1.

MOTOR DIMENSIONS AND WEIGHTS—EPAct MOTORS

Motor Horsepower	Open Drip Proof— EPAct			Totally Enclosed Fan-Cooled—EPAct		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
1	9	11	67	9	13	70
1.5	11	13	88	11	15	90
2	11	14	97	11	16	101
3	12	16	132	12	18	139
5	12	18	158	12	20	165
7.5	14	21	211	14	24	257
10	14	23	260	14	25	295
15	15	23	343	15	26	414
20	15	25	392	15	28	473
25	16	27	529	16	33	626
30	16	28	573	16	34	763
Notes:	18	29	726	18	35	822

Motor Horsepower	Open Drip Proof—EPAct			Totally Enclosed Fan-Cooled—EPAct		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
50	18	30	803	18	35	933
75	20	33	1105	20	35	1485
100	22	39	1166	22	47	1671
125	22	41	1276	22	48	1775
150	22	41	1364	22	48	1897
200	22	44	1810	22	54	2730
250	22	49	2160	22	59	3240

Notes:

1. The motor dimensions and weights are based on 1,200-rpm motors. Motors above the 1,200 rpm rating are lighter and smaller in size.
2. Motor dimensions are rounded to the nearest inch.

MOTOR DIMENSIONS AND WEIGHTS—PREMIUM EFFICIENCY MOTORS

Motor Horsepower	Open Drip Proof— Premium			Totally Enclosed Fan- Cooled—Premium		
	Dia. Inches	Length Inches	Weight lbs.	Dia. Inches	Length Inches	Weight lbs.
1	9	11	67	9	14	70
1.5	11	13	88	11	16	90
2	11	14	97	11	16	101
3	12	16	132	12	20	200
5	12	18	158	12	20	220
7.5	14	21	260	14	26	315
10	14	23	310	14	26	350
15	15	24	394	15	29	460
20	15	26	436	15	29	510

25	16	27	580	18	33	700
30	16	28	639	18	34	765
40	18	29	770	19	35	1030
50	18	30	838	20	35	1070
60	20	33	1090	22	40	1480
75	20	35	1150	22	40	1540
100	22	39	1494	24	47	2060
125	22	41	1715	24	48	2130
150	22	44	2100	24	52	2860
200	22	50	2150	24	54	3070
250	22	54	2632	24	59	3440

Notes:

1. The motor dimensions and weights are based on 1,200-rpm motors. Motors above the 1,200 rpm rating are lighter and smaller in size.
2. Motor dimensions are rounded to the nearest inch.



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32.02. Starters, Disconnect Switches, and Motor Control Centers

A. Starter Types

1. Manual starters (manual control):
 - a. Reversing/nonreversing.
 - b. Push button/toggle switch.
 - c. Available for single-phase or three-phase electrical power.
2. Magnetic starters (automatic control):
 - a. Full voltage/across the line.
 - b. Reversing/nonreversing.
 - c. Reduced voltage:

1. Reactor.
 2. Resistance.
 3. Auto transformer.
 4. Wye-delta/star delta.
 5. Full voltage part winding.
 6. Reduced voltage part winding.
 7. Solid state.
- d. Two-speed starting:
1. One winding. Full speed; half speed.
 2. Two winding. Full speed; 2/3 speed.
 3. Constant torque.
 4. Variable torque.
 5. Constant horsepower.
- e. Available for single-phase or three-phase electrical power.
3. Combination starter disconnect switch: see "magnetic starters":
- a. Fused.
 - b. Nonfused.
 - c. Disconnect switches (locking/nonlocking—recommend locking switches).
 - d. Available for three-phase electrical power only, but a three-phase starter can be used with a single-phase motor (although expensive).

B. Starter Accessories

1. Pilot lights: green, run; red, off.
2. Switches (locking/nonlocking—recommend locking switches).
 - a. Hand-off-auto (HOA).
 - b. Push button.
 - c. Toggle switch.

3. Control transformer.

4. Overload protection:

a. Fused.

b. Nonfused.

c. Motor circuit protector.

d. Molded case circuit breaker.

e. Circuit fuse protection: size based on circuit ampacity and wire size.

f. Overload heaters: size based on motor overload capacity.

g. Two levels of overload protection:

1. Type 1: Considerable damage occurs to the contactor and overload relay when an overload happens but the enclosure remains externally undamaged. Parts of the starter or the entire starter may need to be replaced after an overload.

2. Type 2: No damage occurs to the contactor or overload relay except light contact burning is permitted when an overload happens.

h. The choice between circuit breakers and fuses is purely a matter of user preference.

5. Auxiliary contacts (NO-Normally Open/NC-Normally Closed).

6. Relays.

C. **Disconnect switch sizes and accepted fuse sizes are given in the following table:**

Safety Switch Size Amps	Acceptable Fuse Sizes Amps	Safety Switch Size Amps	Acceptable Fuse Sizes Amps
30	15, 20, 25, 30	1600	1600
60	35, 40, 45, 50, 60	2000	2000
100	70, 80, 90, 100	2500	2500
200	110, 125, 150, 175, 200	3000	3000
400	225, 250, 300, 350, 400	4000	4000
600	450, 500, 600	5000	5000
800	700, 800	6000	6000
1,200	1000, 1200	-	-

D. Standard Fuse and Circuit Breaker Sizes (Amperes): 1, 3, 6, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, and 6000

E. Single-Phase Starter Types

SINGLE-PHASE MOTOR CHARACTERISTIC TABLE

Characteristics	Motor Type				
	Split Phase, Capacitor Start (SPC)	Permanent-Split Capacitor (PSC)	Capacitor Start, Induction Run (CSIR)	Capacitor Start, Capacitor Run (CSCR)	Shaded Pole (SP)
Starting Control	Speed switch	None	Speed switch	Speed switch	None
Ratings (Horsepower)	1/25-1/2	1/20-5	1/20-5	1/20-5	1/10-1/4
Full Load Speeds (RPM @ 60 Hz)	3450 1725	3450 1725	3450 1725	3500 1750	3100 1550 1000
Locked Rotor Torque (Percent @ Full Load)	125-150%	250%	250-350%	250%	250%
Breakdown Torque (Percent @ Full Load)	250-300%	250-300%	250-300%	250%	125%
Speed Classification	Constant	Constant or variable	Constant	Constant	Constant or variable
Full Load Power Factor	60%	95%	65%	95%	60%
Efficiency	Medium	High	Medium	High	Low

F. Three-phase starter types by starting method are given in the following table:

THREE-PHASE STARTERS

Starting Method	Inrush Current % LRA	Starting Torque % LRT
Across-the-Line	100	100
Auto-Transformer		
80% Tap	71	64
65% Tap	48	42
50% Tap	28	25
Primary Resistor or Reactor		
80% Applied Voltage	80	64
65% Applied Voltage	65	42
58% Applied Voltage	58	33
50% Applied Voltage	50	25
Star Delta	33	33
Part Winding	60	48
Part Winding w/Resistors	60-30	48-12
Wound Rotor (Approx.)	25	150
Solid State	3 × RLA	-
Notes:		
1. % LRA = Percent full voltage locked rotor current (amps).		
2. % LRT = Percent full voltage locked rotor torque.		
3. RLA = Rated load amps or running load amps.		

G. Disconnect Switches

1. Fused disconnect switches should be used whenever the equipment manufacturer requires fused disconnect switches or when more than one motor or piece of equipment is on a single electrical circuit. Fused disconnect switches are generally required with packaged air conditioning equipment, and some chillers. Fusing means it may be either a fuse or a

circuit breaker. Circuit breakers are preferred; however, some equipment will require fuses because they have not been tested or rated with circuit breakers.

a. Fuses shall be Class RK5 Time Delay, Dual Element Fuses.

b. Circuit breakers shall be Thermal Magnetic Circuit Breakers.

2. Nonfused disconnect switches should be used whenever fused disconnects are not required by the equipment manufacturer. Most fans, pumps, and air-handling units do not require fused disconnect switches.

H. Motor Size, Starter and Disconnect Switch Size, and Fuse and Circuit Breaker Size are given in the following tables. The following notes are applicable to all schedules.

1. Starters and/or disconnect switches. Fuses shall be Class RK5 Time Delay, Dual Element Fuses. Circuit breakers shall be Thermal Magnetic Circuit Breakers.

2. Motor data, starters, disconnect switches, and fuses based on *2014 NEC* and Square D Company.

115 Volt (120 Volt) Single-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps Per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/8	1	3.0	30	4.5	15
1/6	1	4.4	30	7	15
1/4	1	5.8	30	9	15
1/3	1	7.2	30	12	15
1/2	1	9.8	30	15	20
3/4	1	13.8	30	20	25
1	1	16.0	30	25	30
1.5	1	20.0	30	30	40
2	1	24.0	30	30	50
3	2	34.0	60	50	70
5	3	56.0	100	80	90
7.5	4	80.0	100	100	110
10	-	-	-	-	-

230 Volt (240 Volt) Single-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps Per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/8	1	1.7	30	2.5	15
1/6	1	2.2	30	3.5	15
1/4	1	2.9	30	4.5	15
1/3	1	3.6	30	5.6	15
1/2	1	4.9	30	8	15
3/4	1	6.9	30	10	15
1	1	8.0	30	12	15
1.5	1	10.0	30	15	20
2	1	12.0	30	17.5	25
3	1	17.0	30	25	35
5	2	28.0	60	40	60
7.5	2	40.0	60	60	80
10	3	50.0	60	60	90

200 Volt (208 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	2.5	30	3.5	15
3/4	1	3.7	30	5	15
1	1	4.8	30	6.25	15
1.5	1	6.9	30	10	15
2	1	7.8	30	12	15
3	1	11.0	30	17.5	20
5	1	17.5	30	25	35
7.5	1	25.3	60	40	50
10	2	32.2	60	50	60
15	3	48.3	60	60	90
20	3	62.1	100	90	100
25	3	78.2	100	100	110
30	4	92.0	200	125	125
40	4	120.0	200	175	175
50	5	150.0	200	200	200
60	5	177.0	400	250	250
75	5	221.0	400	300	300
100	6	285.0	400	400	400
125	6	359.0	600	500	600
150	6	414.0	600	600	600
200	7	552.0	-	-	800

230 Volt (240 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	2.2	30	3.2	15
3/4	1	3.2	30	4.5	15
1	1	4.2	30	5.6	15
1.5	1	6.0	30	8	15
2	1	6.8	30	10	15
3	1	9.6	30	15	20
5	1	15.2	30	25	30
7.5	1	22.0	30	30	45
10	2	28.0	60	40	60
15	2	42.0	60	60	80
20	3	54.0	100	80	90
25	3	68.0	100	100	100
30	3	80.0	100	100	110
40	4	104.0	200	150	150
50	4	130.0	200	200	200
60	5	154.0	200	200	225
75	5	192.0	400	300	250
100	5	248.0	400	350	350
125	6	312.0	400	400	450
150	6	360.0	600	500	600
200	6	480.0	600	600	800
250	7	600.0	800	800	800
300	7	720.0	1200	1000	1000
400	-	-	-	-	-

460 Volt (480 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	1.1	30	1.6	15
3/4	1	1.6	30	2.25	15
1	1	2.1	30	2.8	15
1.5	1	3.0	30	4	15
2	1	3.4	30	5.6	15
3	1	4.8	30	8	15
5	1	7.6	30	12	15
7.5	1	11.0	30	17.5	20
10	1	14.0	30	20	25
15	1	21.0	30	30	40
20	1	27.0	60	40	60
25	2	34.0	60	50	70
30	2	40.0	60	60	80
40	3	52.0	100	80	90
50	3	65.0	100	100	100
60	3	77.0	100	100	110
75	4	96.0	200	150	125
100	4	124.0	200	175	200
125	5	156.0	200	200	225
150	5	180.0	400	250	250
200	5	240.0	400	350	350
250	6	302.0	600	500	500
300	6	361.0	600	600	600
400	6	477.0	800	700	700
500	7	590.0	1200	800	800

575 Volt (600 Volt) Three-Phase Motor Starter Schedule

Motor hp	NEMA Starter Size	Full Load Amps per Phase	Disc. Switch Size	Fuse Size Amperes	Circuit Breaker Size Amperes
1/2	1	0.9	30	1.25	15
3/4	1	1.3	30	1.6	15
1	1	1.7	30	2.25	15
1.5	1	2.4	30	3.5	15
2	1	2.7	30	4.5	15
3	1	3.9	30	6.25	15
5	1	6.1	30	10	15
7.5	1	9.0	30	15	15
10	1	11.0	30	17.5	20
15	2	17.0	30	25	35
20	2	22.0	30	30	45
25	2	27.0	60	40	60
30	3	32.0	60	50	60
40	3	41.0	60	60	80
50	3	52.0	100	80	90
60	4	62.0	100	90	100
75	4	77.0	100	110	110
100	4	99.0	200	150	150
125	5	125.0	200	175	200
150	5	144.0	200	200	200
200	5	192.0	400	300	250
250	6	242.0	600	350	350
300	6	289.0	600	400	400
400	6	382.0	600	500	500
500	7	472.0	800	800	700

I. Motor Control Centers (MCCs)

1. NEMA Class I, Type A:

- a. No terminal boards for load or control connections are provided.

- b. Numbered terminals for field-wired power and control connections are provided on the starter.
- c. Starter unit mounted pilot devices are internally wired to starter.

2. NEMA Class I, Type B:

- a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on starter.
- b. Unit control terminal boards for each combination motor controller are provided for field wiring.
- c. Both terminal boards are factory-wired and mounted on, or adjacent to, the unit.
- d. No load terminal boards for feeder tap units are provided.
- e. Starter unit mounted pilot devices are internally wired to the starter.
- f. NEMA Class I, Type B will be suitable for most HVAC applications.

3. NEMA Class I, Type C:

- a. Factory-wired master section terminal board, mounted on the stationary structure, is provided for each section.
- b. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on the starter.
- c. Unit control terminal boards for each combination motor controller are provided for field wiring.
- d. Complete wiring between combination controllers or control assemblies and their master terminal boards is factory installed. No wiring between sections or between master terminals is provided. No interconnections between combination controllers and control assemblies.
- e. No load terminal boards for feeder tap units are provided.

4. NEMA Class II, Type B:

- a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on the starter.

- b. Unit control terminal boards for each combination motor controller are provided for field wiring.
 - c. Both terminal boards are factory-wired and mounted on, or adjacent to, unit.
 - d. Complete wiring between combination controllers or control assemblies in the same and other sections is factory-wired.
 - e. No load terminal boards for feeder tap units are provided.
5. NEMA Class II, Type C:
- a. A factory-wired master section terminal board, mounted on the stationary structure, is provided for each section.
 - b. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field-wired power connections are provided on the starter.
 - c. Unit control terminal boards for each combination motor controller are provided for field wiring.
 - d. Complete wiring between combination controllers or control assemblies and their master terminal boards in the same section and other sections is factory-wired.
 - e. No load terminal boards for feeder tap units are provided.
6. MCCs are available in NEMA enclosure types 1, 2, 3R, and 12.

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32.03. Variable Frequency Drives

A. Variable Frequency Drives have many names and acronyms.

1. Variable frequency drives (VFDs)—Used within this text.
2. Adjustable frequency drives (AFDs).
3. Variable frequency controllers (VFCs).
4. Adjustable frequency controllers (AFCs).

B. VFD Components (from power side to load side)

1. Rectifier section: Silicon-controlled rectifiers (SCRs) or diodes change single- or three-phase AC power to DC power.
2. DC bus section: Capacitors and an inductor smooth the rippled DC power supplied by the rectifier.
3. Inverter section: An inverter converts the DC bus power to three-phase variable frequency power.
4. Controller section: The controller turns the inverter on and off to control the output frequency and voltage.

C. VFD Types

1. Variable voltage inverters (VVI) use an SCR to convert incoming AC power to a varying DC power and then use an inverter to convert the DC power to three-phase variable voltage and variable frequency power. The disadvantages of VVIs are:
 - a. Incoming line notching, which requires isolation transformers.
 - b. The power factor is proportional to speed, which may require power factor correction capacitors.
 - c. Torque pulsations are experienced at low speeds.
 - d. Non-sinusoidal current waveforms produce additional heating in the motor.
2. Current source inverters (CSIs) use SCRs in the rectifier and inverter sections and only an inductor in the DC bus section. The disadvantages of CSIs are:
 - a. Incoming line notching, which requires isolation transformers.
 - b. The power factor is proportional to the speed, which may require power factor correction capacitors.
 - c. Motor drive matching is critical to proper operation.
 - d. Non-sinusoidal current waveforms produce additional heating in the motor.
3. Pulse width modulated (PWM) drives use a full wave diode bridge rectifier to convert the incoming AC power to DC power. Most PWM drives use a six-pulse converter, while some offer a 12-pulse converter in the rectifier section. The DC bus section consists of capacitors, and in some cases an inductor. The inverter section uses Insulated Gate Bipolar Transistors

(IGBTs), Bipolar Junction Transistors (BJTs), or Gate Turn off Thyristors (GTOs) to convert the DC bus power to a three-phase variable voltage and variable frequency power. PWM drives are the most common VFD in use in the HVAC industry today despite the fact it can punish motors electrically, especially 460 and 575 volt motors.

a. The advantages of PWM drives are:

1. Minimal line notching.
2. Better efficiency.
3. Higher power factor.
4. Larger speed ranges.
5. Lower motor heating.

b. The disadvantages of the PWM drives are:

1. Higher initial cost.
2. Regenerative braking is caused because power is allowed to flow in both directions and can act as a drive or a brake.

D. VFD Design Guidelines

1. Provide VFDs with the following:

a. VFDs serving motors:

1. 10 hp and smaller: six-pulse VFD with a 3 percent impedance input line reactor.
2. 15–40 hp: six-pulse VFD with a 5 percent impedance input line reactor.
3. 50 hp and larger: 18-pulse VFD.

b. NEMA-rated controller enclosure.

c. Push-button stations, pilot lights, and selector switches: NEMA-ICS-2, heavy-duty type.

d. Stop and lockout push-button station: Momentary-break, push-button station with a factory-applied hasp arranged so the padlock can be used to lock the push button in the depressed position with the control circuit open.

e. Lockable disconnect switch.

- f. Control relays: Auxiliary and adjustable time-delay relays.
 - g. Standard displays:
 - 1. Output frequency (Hz).
 - 2. Setpoint frequency (Hz).
 - 3. Motor current (amperes).
 - 4. DC-link voltage (VDC).
 - 5. Motor torque (percent).
 - 6. Motor speed (rpm).
 - 7. Motor output voltage (V).
 - h. Historical logging information and displays:
 - 1. Real-time clock with current time and date.
 - 2. Running log of total power versus time.
 - 3. Total runtime.
 - 4. Fault log, maintaining the last four faults with the time and date stamp for each.
 - i. Current-sensing, phase-failure relays for bypass controller: A solid-state sensing circuit with isolated output contacts for hard-wired connections; arranged to operate on phase failure, phase reversal, current unbalance of from 30 to 40 percent, or loss of supply voltage; with adjustable response delay.
- 2. For best motor life and reliability, do not operate motors run by VFDs into their service factor and do not select motors to run within the service factors.
 - 3. Do not run motors below 25 percent of their rated speed or capacity.
 - 4. Use inverter duty motors whenever possible. Inverter duty motors are built with winding thermostats that shut down the motor when elevated temperatures are sensed inside it. In addition, these motors are built with oversized frames and external blowers to cool the motor through the full range of speeds.

5. Motors that are operated with VFDs should be specified with phase insulation, should operate at a relatively low temperature rise (most high efficiency motors fit this category), and should use a high class of insulation (either insulation class F or H).
6. Generally, VFDs do not include disconnect switches; therefore, the engineer must include a disconnect switch in the project design. The disconnect switch should be fused with the fuse rated for the drive input current rating.
7. Multiple motors can be driven with one VFD.
8. All control wiring should be run separately from VFD wiring.
9. Most VFDs include the following features as standard:
 - a. Overload protection devices.
 - b. Short circuit protection.
 - c. Ground fault protection.
10. Provide VFDs with a manual bypass in the event the drive fails.
 - a. Manual bypasses may not be required when standby equipment is provided.
 - b. Manual bypasses may not be required when multiple pieces of equipment are headered together, especially if three or more pieces of equipment are headered together.
11. Coordinate harmonic mitigation requirements with an electrical engineer.
 - a. Line reactors.
 - b. Active harmonic filters.

E. VFDs produce nonlinear loads, which cause the following unwanted effects.

1. AC system circuits containing excessive currents and unexpectedly higher or lower voltages.
2. Conductor, connector, and component heating, which is unsafe.
3. Loss of torque on motors.
4. Weaker contactor, relay, and solenoid action.
5. High heat production in transformers and motors can be destructive.

6. Poor power factor.

32.04. NEMA Enclosures

A. NEMA Type 1:	Indoor General Purpose, Standard
B. NEMA Type 2:	Indoor Drip-Proof
C. NEMA Type 3R:	Outdoor, Rain Tight, Water Tight, Dust Tight
D. NEMA Types 4, 4X, 5:	Outdoor Rain Tight, Water Tight, Dust Tight, Corrosion Resistant
E. NEMA Type 7X:	Explosion-Proof
F. NEMA Type 12:	Indoor Oil and Dust Tight

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Part 33: Humidifiers

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33.01. Humidifiers

A. The number of humidifier manifolds required is given in the following table:

Duct Height	Number of Manifolds
Less than 37"	1
37"-58"	2
59"-80"	3
81"-100"	4
101" and Over	5

A. Humidifier Installation Requirements

1. Humidifiers shall be installed a minimum of 3'0" from any duct transformation, elbow, fitting, or outlet.
2. Consideration must be given to the length of the vapor trail and air handling unit, and ductwork design must provide sufficient length to prevent the vapor trail from coming in contact with items downstream of the humidifier before the vapor has had time to completely evaporate.

B. Humidifier Makeup Requirements

1. Steam humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
2. Electric humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
3. Evaporative humidifiers:	5.0 GPM/1,000 lbs./h.
4. Spray coil humidifiers:	5.0 GPM/1,000 lbs./h.

C. Humidifier Makeup Water Types

1. Potable (untreated) water.
2. Softened water.
3. Deionized water (DI).
4. Reverse osmosis water.

D. Residential Humidifier Types

1. Pan humidifiers:
 - a. Basic pan.
 - b. Electrically heat pan.
 - c. Pan with wicking plates.
2. Wetted element humidifiers:
 - a. Fan type.
 - b. Bypass type.
 - c. Duct mounted type.
3. Atomizing humidifiers:
 - a. Spinning disk.
 - b. Spray nozzles—water pressure.
 - c. Spray nozzles—compressed air.
 - d. Ultrasonic.
4. Portable or non-ducted humidifiers.

E. Industrial Humidifier Types

1. Heated pan humidifiers:
 - a. Steam.
 - b. Hot water.
2. Direct steam injection humidifiers:
 - a. Single or multiple steam jacketed humidifiers.
 - b. Nonjacketed manifold or panel-type distribution humidifiers.
3. Electrically heated, self-contained steam humidifiers:
 - a. Electrode type humidifier.
 - b. Resistance type humidifiers.
4. Atomizing humidifiers:
 - a. Ultrasonic humidifiers.
 - b. Centrifugal humidifiers.
 - c. Compressed air nozzle humidifiers.
5. Wetted media humidifiers:
 - a. Rigid media humidifiers.
6. Evaporative cooling.

Citation

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Part 34: Filters

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34. Part 34: Filters

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34.01. Minimum Efficiency Reporting Value (MERV)

- A. **MERV reports a filter's ability to capture particles between 0.3 and 10 microns.**
- B. **MERV values are used in comparing the performance of different filters.**
- C. **MERV ratings are derived from an ASHRAE test method.**
- D. **The higher the MERV rating, the better the filter is at removing particulates from the air.**
- E. **MERV Values.**

MERV RATINGS

MERV Rating	Average Particle Size in Microns	Efficiency	Filter Types
1-4	3.0-10.0	Less than 20%	Roll filters Flat or panel filters Electronic air cleaners Carbon filters (not designed to remove)

MERV Rating	Average Particle Size in Microns	Efficiency	remove particulates) Filter Types
5	3.0-10.0	20-34.9%	Flat or panel filters Pleated media filters Cartridge filters
6	3.0-10.0	35-49.9%	
7	3.0-10.0	50-69.9%	
8	3.0-10.0	70% or greater	
9	3.0-10.0 1.0-3.0	85% or greater Less than 50%	Bag filters Box filters
10	3.0-10.0 1.0-3.0	85% or greater 50-64.9%	
11	3.0-10.0 1.0-3.0	85% or greater 65-79.9%	
12	3.0-10.0 1.0-3.0	90% or greater 80% or greater	
13	3.0-10.0 1.0-3.0 0.30-1.0	90% or greater 90% or greater Less than 75%	Bag filters Box filters HEPA filters ULPA filters
14	3.0-10.0 1.0-3.0 0.30-1.0	90% or greater 90% or greater 75-84.9%	
15	3.0-10.0 1.0-3.0 0.30-1.0	90% or greater 90% or greater 85-94.9%	
16	3.0-10.0 1.0-3.0 0.30-1.0	95% or greater 95% or greater 95% or greater	

34.02. Flat or Panel Filters

A. **Efficiency: 20-35% (dust spot)**

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop: 0.25" W.G.**

D. **Final Pressure Drop: 0.50" W.G.**

E. **Nominal Sizes**

1. 1" Thick: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 16 × 25; 16 × 20

2. 2" Thick: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24

F. **Test Method: *ASHRAE 52.2-2012*, Atmospheric**

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34.03. Pleated Media Filters

A. **Efficiency (dust spot)**

1. 25-35%

2. 60-65%

3. 80-85%

4. 90-95%

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop**

1. 25-35%:	0.25-0.45" W.G.
2. 60-65%:	0.50" W.G.
3. 80-85%:	0.60" W.G.
4. 90-95%:	0.70" W.G.

D. **Final Pressure Drop**

1. 25–35%:	1.20" W.G.
2. 60–65%:	1.20" W.G.
3. 80–85%:	1.20" W.G.
4. 90–95%:	1.20" W.G.

E. Nominal Sizes

1. Thicknesses (inches):

a. 25–35%:	1; 2; 4.
b. 60–65%:	4; 6; 12.
c. 80–85%:	4; 6; 12.
d. 90–95%:	4; 6; 12.

2. Face sizes:

a. 25–35%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.
b. 60–65%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.
c. 80–85%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.
d. 90–95%:	24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24.

F. Test Method: *ASHRAE 52.2-2012*, Atmospheric

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34.04. Bag Filters

A. Efficiency (dust spot)

1. 40–45%

2. 50-55%
3. 60-65%
4. 80-85%
5. 90-95%

B. Face Velocity: 500 FPM

C. Initial Pressure Drop

1. 40-45%:	0.25" W.G.
2. 50-55%:	0.35" W.G.
3. 60-65%:	0.40" W.G.
4. 80-85%:	0.50" W.G.
5. 90-95%:	0.60" W.G.

D. Final Pressure Drop

1. 40-45%:	1.00" W.G.
2. 50-55%:	1.00" W.G.
3. 60-65%:	1.00" W.G.
4. 80-85%:	1.00" W.G.
5. 90-95%:	1.00" W.G.

E. Nominal Sizes

1. Thicknesses (inches):

a. 40-45%:	12; 15.
b. 50-55%:	21; 22; 30; 37.
c. 60-65%:	21; 22; 30; 37.
d. 80-85%:	21; 22; 30; 37.
e. 90-95%:	21; 22; 30; 37.

2. Face sizes:

a. 40–45%:	24 × 24; 24 × 20; 20 × 25; 20 × 24; 20 × 20; 16 × 25; 16 × 20; 12 × 24.
b. 50–55%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.
c. 60–65%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.
d. 80–85%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.
e. 90–95%:	24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24.

F. Test Method: *ASHRAE 52.2-2012*, Atmospheric

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34.05. HEPA (High Efficiency Particulate Air) Filters

A. Efficiency: 99.97% for 0.3 micron particles and larger

B. Face Velocity: 250 FPM maximum

C. Initial Pressure Drop

1. 95%:	0.50" W.G.
2. 99.97–99.995%:	1.00" W.G.

D. Final Pressure Drop

1. 95%:	2.00" W.G.
2. 99.97–99.995%:	3.00" W.G.

E. Nominal Sizes

1. Thicknesses (inches):	3; 5; 6; 12.
2. Face sizes:	8 × 8; 12 × 12; 12 × 24; 16 × 20; 20 × 20; 24 × 12; 24 × 24; 24 × 30; 24 × 36; 24 × 48; 24 × 60; 24 × 72; 30 × 24; 30 × 30; 30 × 36; 30 × 48; 30 × 60; 30 × 72; 36 × 24; 36 × 30; 36 × 36; 36 × 48; 36 × 60; 36 × 72.

F. Test Method: D.O.P. or Polystyrene Latex (PSL) Spheres (PSL preferred)

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34.06. ULPA (Ultra Low Penetrating Air) Filters

A. Efficiency: 99.9997% for 0.12 micron particles and larger

B. Face Velocity: 250 FPM maximum

C. Initial Pressure Drop

1. 99.997–99.9999%:	1.00" W.G.
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D. Final Pressure Drop

1. 99.997–99.9999%:	3.00" W.G.
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E. Nominal Sizes

1. Thicknesses (inches):	3; 5; 6; 12.
2. Face sizes:	8 × 8; 12 × 12; 12 × 24; 16 × 20; 20 × 20; 24 × 12; 24 × 24; 24 × 30; 24 × 36; 24 × 48; 24 × 60; 24 × 72; 30 × 24; 30 × 30; 30 × 36; 30 × 48; 30 × 60; 30 × 72; 36 × 24; 36 × 30; 36 × 36; 36 × 48; 36 × 60; 36 × 72.

F. Test Method: D.O.P. or Polystyrene Latex (PSL) Spheres (PSL preferred)

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34.07. Roll Filters

A. **Efficiency: 20-25% (dust spot)**

B. **Face Velocity: 500 FPM**

C. **Initial Pressure Drop**

1. 20%:	0.20" W.G.
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D. **Final Pressure Drop**

1. 20%:	0.45" W.G.
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E. **Nominal Sizes**

1. Thicknesses:	2.
2. Face sizes:	
a. Height:	5'0-15'0" by increments of 4".
b. Width:	3'0-30'0" by increments of 1'0".

F. **Test Method: *ASHRAE 52.2-2012*, Atmospheric**

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34.08. Carbon Filters

A. **Front/Back Access**

1. Face velocity:	500 FPM
a. Pressure drop:	0.35–0.45" W.G.
b. Nominal sizes:	24 × 24 × 24: 90 lbs. of carbon per 2,000 CFM. 24 × 12 × 24: 45 lbs. of carbon per 1,000 CFM.
c. Tray size:	24 × 24.
2. Face velocity:	250 FPM
a. Pressure drop:	0.30–0.40" W.G.
b. Nominal sizes:	24 × 24 × 8: 30 lbs. of carbon per 1,000 CFM. 24 × 24 × 8: 15 lbs. of carbon per 500 CFM.
c. Tray size:	24 × 8.

B. Side Access

1. Face velocity:	500 FPM
a. Pressure drop:	0.35–0.45" W.G.
b. Nominal sizes:	24 × 24 × 24: 108 lbs. of carbon per 2,000 CFM.
c. Tray size:	12 × 24.

C. Test Method: *ASHRAE 52.2-2012, Atmospheric*

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34.09. Electronic Air Cleaners

A. Efficiency: 30–40% (dust spot)

B. Face Velocity: 625 FPM

C. Initial Pressure Drop

1. 90%:	0.26" W.G.
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D. Final Pressure Drop

1. 90%:	0.50" W.G.
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E. Nominal Sizes

1. Thicknesses:	2'0-4'0".
2. Face sizes:	
a. Height:	2'4-15'8" by increments of 4".
b. Width:	2'8-18'8" by increments of 1'0".

F. Test Method: *ASHRAE 52.2-2012, Atmospheric*

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34.10. Filter Characteristics

A. Filter Removal Capabilities

1. Fine mode	< 2.5 microns.
2. Coarse mode	2.5 microns.
3. Respirable	< 10.0 microns.
4. Nonrespirable	10.0 microns.

B. Filter Design Factors

1. Degree of air cleanliness required.
2. Particulate/contaminate size and form (solid or aerosols).
3. Concentration.
4. Cost (initial and maintenance).
5. Space requirements.
6. Pressure loss/energy use.

C. Filter Characteristics

1. *Efficiency*. Ability of the filter to remove particulates/contaminates.
2. *Airflow Resistance*. Static pressure drop of the filters.

3. *Dust Holding Capacity.* Amount of particulates/contaminates the filter will hold before efficiency drops drastically.

D. Filter Classes

1. Class 1 Filters: Filters that, when clean, do not contribute fuel when attacked by flame and emit only negligible amounts of smoke.
2. Class 2 Filters: Filters that, when clean, burn moderately when attacked by flame or emit moderate amounts of smoke, or both.
3. However, dust, trapped by filters, will support combustion and will produce smoke more than the filter itself.
4. 2015 IMC:
 - a. Media-type air filters shall comply with UL-900.
 - b. High-efficiency particulate air filters shall comply with UL-586.
 - c. Electrostatic-type air filters shall comply with UL-867.
 - d. Ducts and systems shall be designed to allow even distribution of air over the entire filter.
 - e. Filters shall be either Class 1 or Class 2.
5. NFPA 90A-2015: Filters shall comply with UL-900.

E. Filter Test Methods

1. ASHRAE "test dust." ASHRAE test dust is composed of 72 percent standardized air cleaner test dust, fine; 23 percent powdered carbon; and 5 percent cotton linters.
2. Arrestance test:
 - a. Uses ASHRAE test dust.
 - b. Tests the ability of the filter to remove the larger atmospheric dust particles.
 - c. Measures the concentration of the dust leaving the filter.
3. Atmospheric dust spot efficiency test:
 - a. Measures the change in light transmitted by HEPA filter media targets.
 - b. Intermittent flow method. Airflow upstream and downstream of the tested filter is drawn through separate target filters. Upstream airflow is

intermittently drawn and the downstream airflow is continuously drawn. The test takes more time for higher efficiency filters.

- c. Constant flow method. Airflow upstream and downstream of the tested filter is drawn through separate target filters at a constant flow. Test takes the same time for high- and low-efficiency filters.
4. Dust holding capacity test. The amount of dust held by the filter when the filter pressure drop reaches its maximum or final pressure drop, or when arrestance tests drop below 85 percent for two consecutive readings, or below 75 percent for one reading.
5. DOP (dioctyl phthalate) test:
 - a. High-efficiency filter tests (HEPA and ULPA).
 - b. DOP or BEP (Bis-[2-Ethylhexyl] Phthalate). Test aerosols are used.
 - c. A cloud of DOP or BEP is passed through the test filter, and the amount passing through the filter is measured by a light-scattering photometer.
6. Polystyrene latex (PSL) spheres test:
 - a. High-efficiency filter tests (HEPA and ULPA).
 - b. Filter media thickness 20 mL.
 - c. Media is tested at 10.5 feet per minute with PSL.
 - d. Filters are tested at 70–100 feet per minute.
 - e. PSL test material is selected to allow 90 percent of the mean size to be between 0.1 and 0.3 microns.
 - f. The minimum number of PSL particles in the filter test challenge will be a minimum of 10 million particles per cubic foot.
 - g. The particle test challenge is monitored in accordance with the Institute of Environmental Sciences (IES) standards *IES-RP-C001* for HEPA filters and *IES-RP-C007* for ULPA filters.
7. Leak scan tests:
 - a. Used with HEPA and ULPA filters.
 - b. The DOP Test is used while scanning the face of the filter for air leakage through or around the filters.

8. Particle size tests. No standard exists; depends heavily on the type of aerosol used.

Citation

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Part 35: Insulation

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35. Part 35: Insulation

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35.01. Insulation Materials and Properties

A. General

1. Insulation, adhesives, mastics, sealants, and coverings shall have a flame spread rating of 25 or less and a smoke developed rating of 50 or less as determined by an independent testing laboratory in accordance with *NFPA 255* and *UL 728* as required by *ASHRAE 90A* and *90B*. Coatings and adhesives applied in the field shall be nonflammable in the wet state.
2. Hangers on chilled water and other cold piping systems should be installed on the outside of the insulation to prevent hangers from sweating.
3. Cold surfaces: Normal operating temperatures less than 75°F.
4. Hot surfaces: Normal operating temperatures of 100°F or higher.
5. Dual-temperature surfaces: Normal operating temperatures that vary from hot to cold.
6. Thermal conductivity:
 - a. K-values.
 - b. Thermal conductivity values express the rate of heat loss of a homogenous substance in Btu-in./h sq.ft.°F.
7. Thermal conductance:
 - a. C-values.

- b. Thermal conductance values express the rate of heat loss of a homogenous substance in Btu-in./h sq.ft.°F.
8. Thermal resistance:
- a. R-values.
 - b. Thermal resistance values express the resistance of heat loss of a homogenous substance in °F sq.ft. h/Btu.
9. Overall heat transfer coefficients:
- a. U-values.
 - b. Overall heat transfer coefficient values express the rate of heat loss of a nonhomogenous substance in Btu/h sq.ft.°F.

$$R = \frac{1}{C} = \frac{1}{K} \times \text{Thickness}$$

$$U = \frac{1}{\sum R}$$

B. Materials

1. Calcium silicate temperature range:	0 to +1200°F.
2. Fiberglass temperature range:	-20 to +1000°F.
3. Mineral wool temperature range:	+200 to +1900°F.
4. Urethane, styrene, beadboard temperature range:	-350 to +250°F.
5. Cellular glass temperature range:	-450 to +850°F.
6. Ceramic fiber temperature range:	0 to +3000°F.
7. Flexible tubing and sheets temperature range:	-40 to +250°F.

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35.02. Pipe Insulation

- A. **Insulation shall be sectional molded glass fiber, minimum 3.0 lbs. per cubic foot density, with a thermal conductivity not greater than 0.24 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a white factory-applied flame-retardant vapor barrier jacket of 0.001"**

aluminum foil laminated to Kraft paper reinforced with glass fibers, or all service jacket.

- B. Insulation shall be flexible foamed plastic, minimum 5.0 lbs. per cubic foot density, with a thermal conductivity not greater than 0.28 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F.**
- C. Insulation shall be cellular glass, with a thermal conductivity not greater than 0.40 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F.**
- D. Insulation shall be foamglass, minimum 8.5 lbs. per cubic foot density, with a thermal conductivity not greater than 0.35 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F.**
- E. Code Required Pipe Insulation Thickness.
ASHRAE STANDARD 90.1-2013 AND 2015 IECC**

Fluid Design Operating Temperature **Conductivity Btu-in./h ft.² °F** **Nominal Pipe or Tube Diameter**

<1" 1-1-1/2" >1-1/2-4" >4-8" ≥8"

Heating Systems—Hot Water and Steam Condensate						
>350°F	0.32–0.34	4.5	5.0	5.0	5.0	5.0
251–350°F	0.29–0.32	3.0	4.0	4.5	4.5	4.5
201–250°F	0.27–0.30	2.5	2.5	2.5	3.0	3.0
141–200°F	0.25–0.29	1.5	1.5	2.0	2.0	2.0
105–140°F	0.22–0.28	1.0	1.0	1.5	1.5	1.5
Heating Systems—Steam						
>350°F >120 psig	0.32–0.34	4.5	5.0	5.0	5.0	5.0
251–350°F 16–120 psig	0.29–0.32	3.0	4.0	4.5	4.5	4.5
212–250°F 0–15 psig	0.27–0.30	2.5	2.5	2.5	3.0	3.0
Cooling Systems—Chilled Water, Glycol, Brine, and Refrigerant						
40–60°F	0.22–0.27	0.5	0.5	1.0	1.0	1.0
<40°F	0.20–0.26	0.5	1.0	1.0	1.0	1.5

F. Recommended pipe insulation thicknesses are provided in the following table:

Piping System (7)	Pipe Sizes	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Chilled Water 40–60°F (3)	1-1/2" and smaller	1.0	1.5	2.0	1.5
	2" and larger	1.5	2.0	2.5	2.5
Notes:	1" and	1.0	1.5	2.0	1.5
1/2" Type A: Fiberglass insulation			2.0	2.5	2.5

Water Piping System (7)	Smaller Pipe Sizes 1-1/4-6" and larger	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Chilled Water Below 32°F (3)	2" and smaller 2-1/2-6" 8" and larger	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.5 4.5	2.5 3.0 4.0
Condenser Water	All sizes	(2)	(2)	(2)	(2)
Condenser Water—Waterside Economizer	1-1/2" and smaller 2" and larger	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
Heating Water—Low Temperature 100-140°F (4)	1-1/2" and smaller 2" and larger	1.0 2.0	1.5 2.5	2.0 3.5	1.5 3.0
Heating Water—Low Temperature 141-200°F (4)	1-1/2" and smaller 2" and larger	1.5 2.0	1.5 2.5	2.0 3.5	1.5 3.0
Heating Water—Low Temperature 201-250°F (4)	1-1/4" and smaller 1-1/2" and larger	2.5 3.0	2.0 2.5	2.5 3.5	2.5 3.0
Heating Water—Medium Temperature 251-350°F (4)	3/4" and smaller 1-1-1/4" 1-1/2" and larger	3.0 4.0 4.5	(10)	2.5 4.5 5.0	2.5 4.0 4.5

Heating Piping System (7) Water—High Temperature 351-450°F (4)	Pipe Sizes 3/4" and smaller 1-3" 4" and larger	Insulation Thickness vs. Type (1, 8)			
		A	B	C	D
Dual Temperature	All sizes	(9)	(9)	(9)	(9)
Heat Pump Loop	All sizes	(2)	(2)	(2)	(2)
Steam and Steam Condensate—Low Pressure (5) 15 psig and Lower 201-250°F	3" and smaller 4" and larger	2.5 3.0	2.0 4.0	2.5 5.0	2.5 4.5
Steam and Steam Condensate—Medium Pressure (5) 16-100 psig 251-350°F	3/4" and smaller 1-1-1/4" 1-1/2" and larger	3.0 4.0 4.5	(10)	2.5 4.5 5.0	2.5 4.0 4.5
Steam and Steam Condensate—High Pressure (5) 101-300 psig >350°F	3/4" and smaller 1" and larger	4.5 5.0	(10)	4.5 6.5	4.0 6.0
Notes: 1. Type A: Fiberglass insulation. 2. Type B: Flexible foamed plastic insulation. 3. Type C: Cellular glass insulation. 4. Type D: Foamed glass insulation.	1" and smaller 1-1/4" 1-1/2" and larger	1.0 1.5 2.0	1.5 2.0	2.0 2.5 3.5	1.5 2.5 3.0

Refrigerant Piping System (67)	All Pipe Sizes	0.75	1.0	1.5	1.0
Insulation Thickness vs. Type (1, 8)					
Air Conditioning Condensate	All sizes	0.5 A	0.5 B	1.0 C	0.75 D

Notes:

1. **Type A: Fiberglass insulation.**
Type B: Flexible foamed plastic insulation.
Type C: Cellular glass insulation.
Type D: Foamglass insulation.
2. **Insulation is not required on systems with temperatures between 60°F and 105°F, unless insulating the pipe for freeze protection—in which case, use chilled water (40°F and above) thicknesses. Remember to include insulation on condenser water systems used for waterside economizer operation.**
3. **Chilled water system piping is often insulated with fiberglass insulation; although, cellular glass and flexible foamed plastic may be more appropriate for moisture condensation protection. Other types of insulation may be used.**
4. **Heating water system piping is generally insulated with fiberglass pipe insulation. Other types of insulation may be used.**
5. **Steam system piping and steam condensate system piping are generally insulated with fiberglass pipe insulation. Other types of insulation may be used.**
6. **Refrigerant system piping is generally insulated with flexible foamed plastic. Other types of insulation may be used. Normally, only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem, and hot gas lines should be insulated where personal injury from contact may pose a problem.**
7. **Table meets or exceeds ASHRAE Standard 90.1-2013 and the 2015 IECC.**
8. **For piping exposed to ambient temperatures, increase the insulation thickness by 1 in.**

9. For dual temperature systems, usually the heating system.

10. The system temperature exceeds the temperature rating of the insulation.

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35.03. Duct Insulation

A. Internal Duct Liner

1. 1-1/2 pounds per cubic foot density amber color glass fiber blanket with smooth coated matte facing to conform to *TIMA Standard AHC-101, NFPA 90A, NFPA 90B, NFPA 255, UL 181, and UL 723*. Duct lining shall have a thermal conductivity (k) not greater than 0.24 Btu/sq.ft./°F/h at a mean temperature difference of 75°F. Vinyl spray face shall not be permitted.
2. Thicknesses: 1", 1-1/2", 2".

B. External Duct Insulation

1. Duct wrap: Insulation shall be a flexible glass fiber blanket, minimum 3/4 lb. per cubic foot density, with a thermal conductivity (k) not greater than 0.29 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a factory-applied jacket of minimum 0.001" aluminum foil reinforced with glass fiber bonded to flame-resistant Kraft paper vapor barrier. Thicknesses: 1", 1-1/2", 2".
2. Duct board: Insulation shall be glass fiber, minimum 3.0 lbs. per cubic foot density, with a thermal conductivity (k) not greater than 0.23 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a white factory-applied flame-retardant vapor barrier jacket of 0.001" aluminum foil reinforced with glass fibers bonded to flame-resistant Kraft paper. Thicknesses: 1", 1-1/2", 2", 3", 4".
3. Duct board: Insulation shall be rigid glass fiber board, minimum 6.0 lbs. per cubic foot density, with a thermal conductivity (k) not greater than 0.22 Btu-in./sq.ft./°F/h at a mean temperature difference of 75°F and a white factory-applied flame-retardant vapor barrier jacket of 0.001" aluminum foil reinforced with glass fibers bonded to flame-resistant Kraft paper. Thicknesses: 1", 1-1/2", 2".

C. Code Required Duct Insulation Thickness

1. 2015 IECC:

- a. Supply and return air ducts and plenums located in unconditioned spaces: R-6 insulation minimum.
- b. Supply and return air ducts and plenums located outside: R-8 insulation minimum in Climate Zones 1 through 4, and R-12 insulation minimum in Climate Zones 5 through 8.
- c. Ducts or plenums shall be separated from the building exterior or unconditioned or exempt spaces by R-8 insulation minimum in Climate Zones 1 through 4, and R-12 insulation minimum in Climate Zones 5 through 8.
- d. Duct insulation is not required where located within equipment.
- e. Duct insulation is not required when the design temperature difference between the interior and exterior of the duct or plenum does not exceed 15°F. This exception will apply to most return air ducts except when located outside.

2. ASHRAE Standard 90.1-2013

Climate Zone	Duct Location				
	Exterior	Ventilated Attic	Unvented Attic above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space
Heating-Only Ducts					
1, 2	None	None	None	None	None
3	R-3.5	None	None	None	None
4	R-3.5	None	None	None	None
5	R-6	R-3.5	None	None	None
6	R-6	R-6	R-3.5	None	None
7	R-8	R-6	R-6	None	R-3.5
8	R-8	R-8	R-6	None	R-6
Cooling-Only Ducts					

1	R-6	R-6	R-8	Duct Location R-3.5	R-3.5
2	R-6	R-6	Unvented Attic R-6	Unvented R-3.5	R-3.5
Climate Zone 3	Exterior R-6	Ventilated Attic R-6	above Insul. Ceiling R-6	Attic w/Roof Insulation R-3.5	Unconditio Space R-1.9
4	R-3.5	R-3.5	R-6	R-1.9	R-1.9
5, 6	R-3.5	R-1.9	R-3.5	R-1.9	R-1.9
7, 8	R-1.9	R-1.9	R-1.9	R-1.9	R-1.9
Combined Heating and Cooling Ducts					
1	R-6	R-6	R-8	R-3.5	R-3.5
2	R-6	R-6	R-6	R-3.5	R-3.5
3	R-6	R-6	R-6	R-3.5	R-3.5
4	R-6	R-6	R-6	R-3.5	R-3.5
5	R-6	R-6	R-6	R-1.9	R-3.5
6	R-8	R-6	R-6	R-1.9	R-3.5
7	R-8	R-6	R-6	R-1.9	R-3.5
8	R-8	R-8	R-8	R-1.9	R-6
Return Ducts					
1-8	R-3.5	R-3.5	R-3.5	None	None

D. Recommended duct insulation R-values and insulation thicknesses are provided in the following table:

**Climate
Zone**

Duct Location

Exterior	Ventilated Attic	Unvented Attic above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditione Space
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Heating Ducts Only

Notes:	R-8	R-8	R-8	R-5	R-6
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1. The duct liner represented in the table has a K-value of 0.24 and a

Climate Zone				Duct Location	
Duct Liner	2"	2"	2"	1.5"	1.5"
Duct Wrap	3" Exterior	Ventilated Attic	3" Attic above Insul.	2" Attic w/Roof Insulation	Unconditioned Space
Duct Board	2"	2"	2" Ceiling	1.5"	1.5"
Cooling Ducts Only					
All Climate Zones	R-8	R-8	R-8	R-5	R-6
Duct Liner	2"	2"	2"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"
Cooling and Heating Ducts					
All Climate Zones	R-8	R-8	R-8	R-5	R-6
Duct Liner	2"	2"	2"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"
Return Ducts					
All Climate Zones	R-8	R-8	R-8	None	None
Notes:	2"	2"	2"	None	None

Liner Climate						
Zone	3"	3"	3"	Duct Location	None	None
Wrap			Unvented	Unvented	None	None
Duct Board	2" Exterior	2" Ventilated Attic	2" Attic above Insul. Ceiling	None Attic w/Roof	None Unconditione Space	
Notes:						
1. The duct liner represented in the table has a K-value of 0.24 and a						
2. The duct wrap represented in the table has a K-value of 0.29 and a						
3. The duct board represented in the table has a K-value of 0.22 and a						

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35.04. Insulation Protection

- A. **Aluminum roll jacketing and fitting covers produced from ASTM-B-209, 3003 Alloy, 0.016 in. thickness, H-14 temper with a smooth finish. Install in accordance with the manufacturer's recommendations.**
- B. **Stainless steel roll jacketing and fitting covers produced from ASTM-A-167, Type 304 or 316, 0.10-in. thick, No. 2B finish, and factory cut and rolled to indicated sizes. Install in accordance with the manufacturer's recommendations.**
- C. **Prefabricated PVC fitting covers and jacketing produced from 20-mil-thick, high-impact, ultra-violet-resistant PVC with the same insulation and thickness as specified. Install in accordance with the manufacturer's recommendations.**
- D. **Bands: 3/4-in. wide, in one of the following materials compatible with jacket.**
 1. Aluminum: 0.007-in. thick.
 2. Stainless steel: Type 304, 0.020-in. thick.

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Part 36: Fire-Stopping and Through-Penetration Systems

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36. Part 36: Fire-Stopping and Through-Penetration Systems

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36.01. Fire-Stopping and Through-Penetration Protection Systems

- A. **All openings in fire-rated and smoke-rated building construction must be protected from fire and smoke by systems that seal these openings to resist the passage of fire, heat, smoke, flames, and gases. These openings include passages for mechanical and electrical systems, expansion joints, seismic joints, construction joints, control joints, curtain wall gaps, the space between the edge of the floor slab and the exterior curtain wall and columns, and other openings or cracks.**
- B. **Terms**
1. *Firestopping*. Firestopping is noncombustible building materials or a system of lumber pieces installed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through small concealed spaces. The term *firestopping* is used with all types of building construction, except for noncombustible and fire-resistive construction.
 2. *Through-Penetration Protection Systems (TPPS)*. TPPS are building materials or assemblies of materials specifically designed and manufactured to form a system developed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through openings made in fire-rated

floors and walls to accommodate the passage of combustible and noncombustible items. The term *TPPS* is used with noncombustible and fire-resistive building construction.

3. *Combustible Penetrating Items*. Combustible penetrating items are materials such as plastic pipe and conduit, electrical cables, and combustible pipe insulation.
4. *Noncombustible Penetrating Items*. Noncombustible penetrating items are materials such as copper, iron, or steel pipe; steel conduit; EMT; electrical cable with steel jackets; and other noncombustible items.
5. *Annular Space Protection*. Annular space protection is the building materials or assembly of materials that protect the space between noncombustible penetrating items and the rated assembly. In concrete or masonry assemblies, the materials generally used for annular space protection are concrete, grout, or mortar. In all other assemblies, the materials must be tested and meet *ASTM E119* standard under positive pressure.
6. *Single-Membrane Protection*. Single-membrane protection is the building materials or assembly of materials that protect the opening through one side, or a single membrane, of a fire-resistive wall, roof/ceiling, or floor/ceiling to accommodate passage of combustible or noncombustible items. Materials protecting single membranes are annular space protection systems or TPPS.
7. *Shaft Alternatives*. A fire-rated shaft or enclosure is not required if a TPPS system with a flame rating (F-Rating) and a thermal rating (T-Rating) equal to the rating of the assembly is used to protect openings made in fire-rated floors and walls to accommodate the passage of combustible and noncombustible items.

C. System Ratings

1. F-Ratings define the period of time for which the fire-stopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly, in accordance with *ASTM E814*. To receive an F-Rating, the system must also pass the hose stream test. F-Ratings are needed for all applications, and must be equal to the rating of the assembly.
2. T-Ratings define the period of time for which the fire-stopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly (F-Rating), and must also restrict the temperature rise on

the unexposed surface to 325°F in accordance with *ASTM E814*. T-Ratings must be equal to the rating of the assembly and at least 1 hour. T-Ratings are rarely applied because most penetrations in commercial structures tend to be in noncombustible concealed spaces and are generally only applied where codes require open protectives.

D. **TPPS Materials**

1. Intumescent materials expand to form an insulating char.
2. Subliming materials pass from solid to vapor when heated without passing through the liquid phase.
3. Ablative materials char, melt, or vaporize when heated.
4. Endothermic materials, such as concrete and gypsum, absorb heat using chemically bounded water of the material.
5. Ceramic fibers are high-temperature refractory materials.

E. **Material Forms**

1. Caulks.
2. Putties.
3. Mixes.
4. Sheets, strips, or collars.
5. Kits.
6. Devices.

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Part 37: Makeup Water

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37. Part 37: Makeup Water

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37.01. Makeup Water Requirements

- A. **Hot Water System Makeup Connection: Minimum connection size shall be 10 percent of largest system pipe size or 1", whichever is greater (20" system pipe size results in a 2" makeup water connection).**
- B. **Chilled Water System Makeup Connection: Minimum connection size shall be 10 percent of largest system pipe size or 1", whichever is greater (20" system pipe size results in a 2" makeup water connection).**
- C. **Condenser Water Makeup to Cooling Tower**

1. Centrifugal:	40 GPM/1,000 tons.
2. Reciprocating:	40 GPM/1,000 tons.
3. Screw chillers:	40 GPM/1,000 tons.
4. Scroll chillers:	40 GPM/1,000 tons.
5. Absorption chillers:	80 GPM/1,000 tons.

- D. **Cooling Tower Blowdown and Drains**

- 1. Drains: Use two times the makeup water rate for sizing cooling tower drains.
- 2. Blowdown:

a. Centrifugal:	10 GPM/1,000 tons.
b. Reciprocating:	10 GPM/1,000 tons.
c. Screw:	10 GPM/1,000 tons.
d. Scroll:	10 GPM/1,000 tons.
e. Absorption:	20 GPM/1,000 tons.

E. Steam Boiler Water Makeup

1. Boilers:	4.0 GPM/1,000 lbs./h each
2. Deaerator/feedwater unit:	4.0 GPM/1,000 lbs./h each
3. Makeup water for the steam system is only required at one of the boilers or one of the feedwater units at any given time, for system sizing.	

F. Boiler Blowdown Separator Makeup

1. Noncontinuous blowdown (bottom blowdown):	5.0 GPM/1,000 lbs./h.
2. Continuous blowdown (surface blowdown):	0.5 GPM/1,000 lbs./h.

G. Blowdown Separator Drains: 10 GPM/1,000 lbs./h Boiler Output

H. Vacuum Type Steam Condensate Return Units: 0.1 GPM/1,000 lbs./h of Connected Load

I. Pumped Steam Condensate Return Units: 2.4 GPM/1,000 lbs./h

J. Humidifiers

1. Steam humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
2. Electric humidifiers:	5.6 GPM/1,000 kW input or 5.6 GPM/3413 MBH.
3. Evaporative humidifiers:	5.0 GPM/1,000 lbs./h.
4. Spray coil humidifiers:	5.0 GPM/1,000 lbs./h.

K. Air Conditioning Condensate

1. Unitary packaged AC equipment:	0.006 GPM/ton.
2. Air handling units (100% outdoor air):	0.100 GPM/1,000 CFM.
3. Air handling units (50% outdoor air):	0.065 GPM/1,000 CFM.
4. Air handling units (25% outdoor air):	0.048 GPM/1,000 CFM.
5. Air handling units (15% outdoor air):	0.041 GPM/1,000 CFM.
6. Air handling units (0% outdoor air):	0.030 GPM/1,000 CFM.

Citation

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Part 38: Water Treatment and Chemical Feed Systems

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38. Part 38: Water Treatment and Chemical Feed Systems

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38.01. Water Treatment and Chemical Feed Systems

A. General

1. Water treatment objectives:
 - a. Prevent hard scale and soft sludge deposits.
 - b. Prevent corrosion and pitting.
 - c. Protect boiler, piping, and equipment metal chemistry.
 - d. Prevent steam carryover.
2. Corrosion and scale/deposit control factors:
 - a. pH Level: As the pH of the system water increases (moves toward the alkaline side of the scale), the corrosiveness of the water decreases. However, as the pH of the system water increases, the formation of scale increases. Normal pH range is 6.5 to 9. A typical pH range is 7.8 to 8.8 (Acid pH = 1; Neutral pH = 7; Alkaline pH = 14).
 - b. Hardness: As the hardness of the system water increases, the corrosiveness of the water decreases. However, as the hardness of the system water increases, the formation of scale increases.
 - c. Temperature: As the temperature of the system water increases, the corrosiveness of the water increases. In addition, as the temperature of the system water increases, the formation of scale increases. Corrosion

rates double for every 20°F increase in water temperature.

- d. Foulants: The more scale-forming material and foulants in the system water, the greater the chances of scale and deposit formation. Foulants include calcium, magnesium, biological growth (algae, fungi, and bacteria), dirt, silt, clays, organic contaminants (oils), silica, iron, and corrosion by-products.

3. Water treatment limits:

- a. Oxygen: Less than 0.007 ppm (7 ppb).
- b. Hardness: Less than 5.0 ppm.
- c. Suspended matter: Less than 0.15 ppm.
- d. pH: 8 to 9.
- e. Silicas: Less than 150 ppm.
- f. Total alkalinity: Less than 700 ppm.
- g. Dissolved solids: Less than 7,000 mmho/cm.

4. Water source comparison:

- a. Surface water:
 - 1. High in suspended solids.
 - 2. High in dissolved gases.
 - 3. Low in dissolved solids.
- b. Well water:
 - 1. High in dissolved solids.
 - 2. Low in suspended solids.
 - 3. Low in dissolved gases.

5. Suspended solids:

- a. Dirt.
- b. Silt.
- c. Biological growth.
- d. Vegetation.

- e. Insoluble organic matter.
 - f. Undissolved matter.
 - g. Iron.
6. Hardness measures the amount of calcium and magnesium in the water.
 7. Alkalinity measures the water's ability to neutralize strong acid.
 8. Scale is the result of precipitation of hardness salts on heat exchange surfaces.
 9. Corrosion is the dissolving or wearing away of metals:
 - a. *General Corrosion*. General corrosion is caused by acidic conditions.
 - b. *Under-Deposit Corrosion*. Under-deposit corrosion is caused by foreign matter resting on a metal surface.
 - c. *Erosion*. Erosion is caused by turbulent water flow.
 - d. *Pitting Corrosion*. Pitting corrosion is caused by the presence of oxygen.
 - e. *Galvanic Corrosion*. Galvanic corrosion is an electrochemical reaction between dissimilar metals.
 10. Problems caused by poor water quality:
 - a. Scale and deposits.
 - b. Decreased efficiency/heat transfer.
 - c. Equipment failure/unscheduled shutdowns.
 - d. Corrosion.
 - e. Tube burnout or fouling.
 - f. Carryover in steam systems.
 11. Chemical Types:
 - a. Scale inhibitors. Scale inhibitors prevent scale formation:
 1. Phosphonate.
 2. Polyacrylate.
 3. Polymethacrylate.

4. Polyphosphate.
 5. Polymaleic acid.
 6. Sulfuric acid.
- b. Biocides. Biocides prevent biological growth:
1. Oxidizing:
 - a. Chlorine. Most common.
 - b. Chlorine dioxide.
 - c. Bromine. Most common.
 - d. Ozone.
 2. Non-Oxidizing:
 - a. Carbamate. Most common.
 - b. Organo-bromide.
 - c. Methylenebis-thiocyanate.
 - d. Isothiazoline.
 - e. Quaternary ammonium salts.
 - f. Organo-tin/quaternary ammonium salts.
 - g. Glutaraldehyde.
 - h. Dodecylguanidine.
 - i. Triazine.
 - j. Thiocyanates.
 - k. Quaternary ammonium metallics.
 3. Biocide treatment program should include alternate use of oxidizing and non-oxidizing biocides for maximum effectiveness (see the following table):

Biocide	Effectiveness Against			Comments
	Bacteria	Fungi	Algae	
Oxidizing Biocides				

Chlorine (Cl ₂) Biocide	Effectiveness Against			Comments range 5 to 8. Effective at neutral pH (pH = 7). Less effective at high pH. Reacts with -NH ₂ groups.
	Bacteria	Fungi	Algae	
Chlorine Dioxide (ClO ₂)	E	G	G	Insensitive to pH levels. Insensitive to presence of -NH ₂ groups.
Bromine	E	G	P	Usable pH range 5 to 10. Effective over broad pH range. Substitute for chlorine.
Ozone	E	G	G	pH range 7 to 9.
Non-Oxidizing Biocides				
Notes: 1. Table Abbreviations: E = Excellent Biocide Control G = Good Biocide Control P = Poor Biocide Control N = No Biocide Control	E	E	G	pH range of 5 to 9. Good in high suspended solids systems. Incompatible with chromate treatment

Biocide	Effectiveness Against			Comments
	Bacteria	Fungi	Algae	
Organic Bromide (DBNPA)	E	P	P	pH range 6 to 8.5.
Methylenebis-Thiocyanate (MBT)	E	P	P	Decomposes above a pH of 8.
Isothiazoline	E	G	G	Insensitive to pH levels. Deactivated by HS and-NH ₂ groups.
Quaternary Ammonium Salts	E	G	G	Tendency to foam. Surface active. Ineffective in organic-fouled systems.
Organo-Tin/Quaternary Ammonia Salts	E	G	E	Tendency to foam. Functions best in alkaline pH.
Glutaraldehyde	E	E	G	Effective over a broad pH range. Deactivated by-NH ₂ groups.
Dodecylguanidine (DGH)	E	E	G	pH range of 6 to 9.
Notes 1. Table Abbreviations: E = Excellent Biocide Control	N	N	E	pH range of 6 to 9. Specific for algae

Biocide	Effectiveness Against			Comments Must be used with other biocides.
	Bacteria	Fungi	Algae	
Notes:				
1. Table Abbreviations:				
E = Excellent Biocide Control				
G = Good Biocide Control				
P = Poor Biocide Control				
N = No Biocide Control				

c. Corrosion inhibitors. Corrosion inhibitors prevent corrosion:

1. Molybdate. Most common and most effective.

2. Nitrite. Most common.

3. Aromatic azoles.

4. Chromate.

5. Polyphosphate.

6. Zinc.

7. Orthophosphate.

8. Benzotriazole. Copper corrosion inhibitor.

9. Tolyltriazole. Copper corrosion inhibitor.

10. Silicate. Copper and steel corrosion inhibitor.

d. Dispersants. Dispersants prevent suspended and dissolved solids from settling out or forming scale in the system, remove existing deposits, and enhance biocide effectiveness:

1. Polyacrylate.

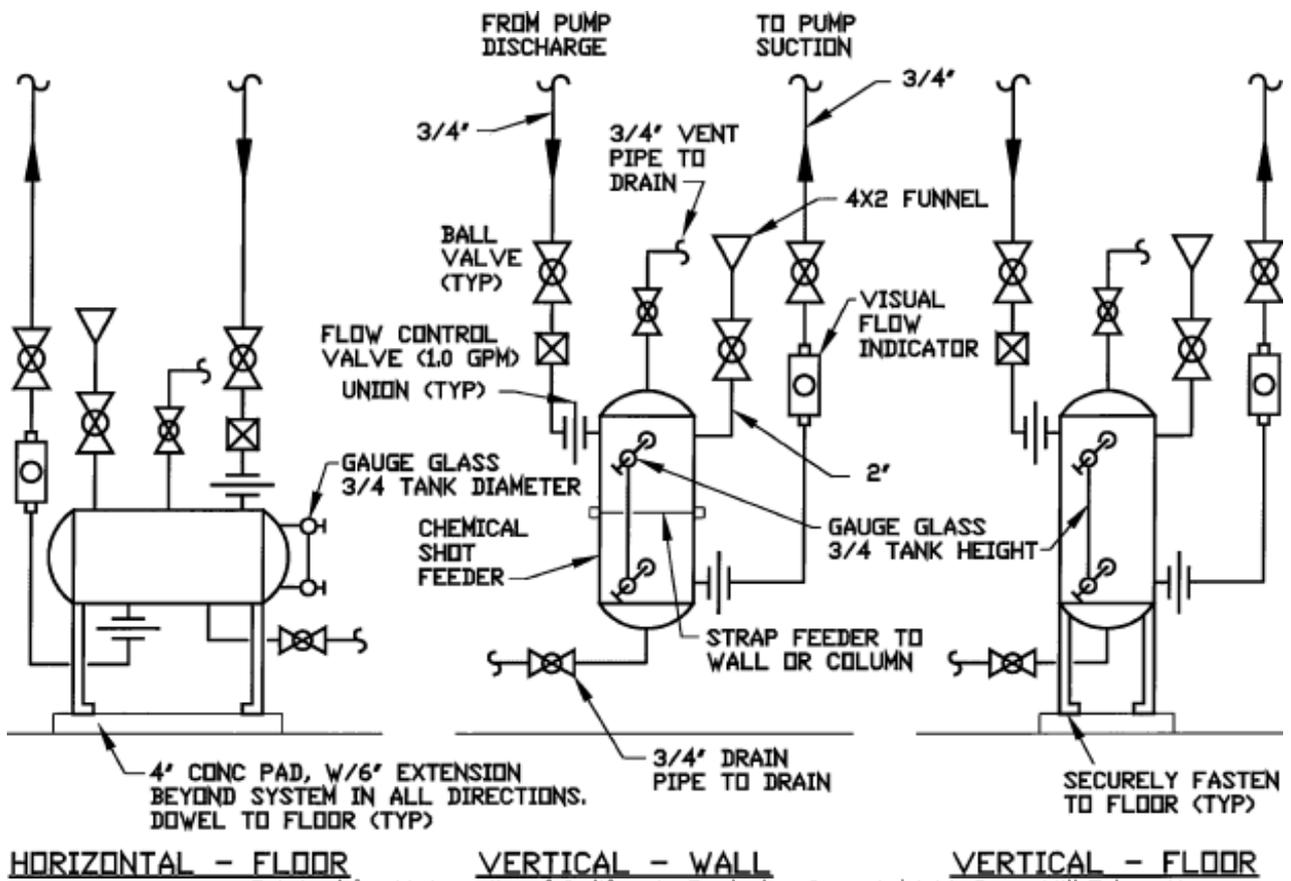
2. Polymethacrylate.

3. Polymaleic acid.
4. Surfactants.
12. Corrosion monitoring is recommended with the use of corrosion coupons for closed and open hydronic systems.
13. Side stream filtration is recommended to maintain system cleanliness. Filters should be sized to filter the entire volume of the system three to five times per day.

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38.02. Closed System Chemical Treatment (Chilled-Water Systems, Heating Water Systems)

- A. The chemical treatment objective is to prevent and control the following:**
 1. Scale formation.
 2. Corrosion. Major concern.
 3. System pH (between 8 and 9).
- B. Chemical Types Used in Closed Systems:**
 1. Scale inhibitors.
 2. Corrosion inhibitors.
 3. Dispersants.
- C. Most Common Chemicals Used:**
 1. Molybdate.
 2. Nitrite-based inhibitors.
- D. Water analysis should be conducted at least once a year, preferably semiannually or quarterly, depending on system water losses.**
- E. See Figs. 38.1 and 38.2 regarding the chemical treatment components used in a closed piping system.**



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Figure 38.1. CLOSED SYSTEM CHEMICAL SHOT FEEDER.



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Figure 38.2. PHOTOGRAPH OF A CLOSED SYSTEM CHEMICAL SHOT FEEDER.

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38.03. Open System Chemical Treatment (Condenser Water Systems)

- A. The chemical treatment objective is to prevent and control the following:**
1. Scale formation.
 2. Fouling:
 - a. Particulate matter.

b. Biological growth.

3. Corrosion.

4. System pH. Between 8 and 9.

B. Chemical Types Used in Open Systems:

1. Scale inhibitors.

2. Biocides.

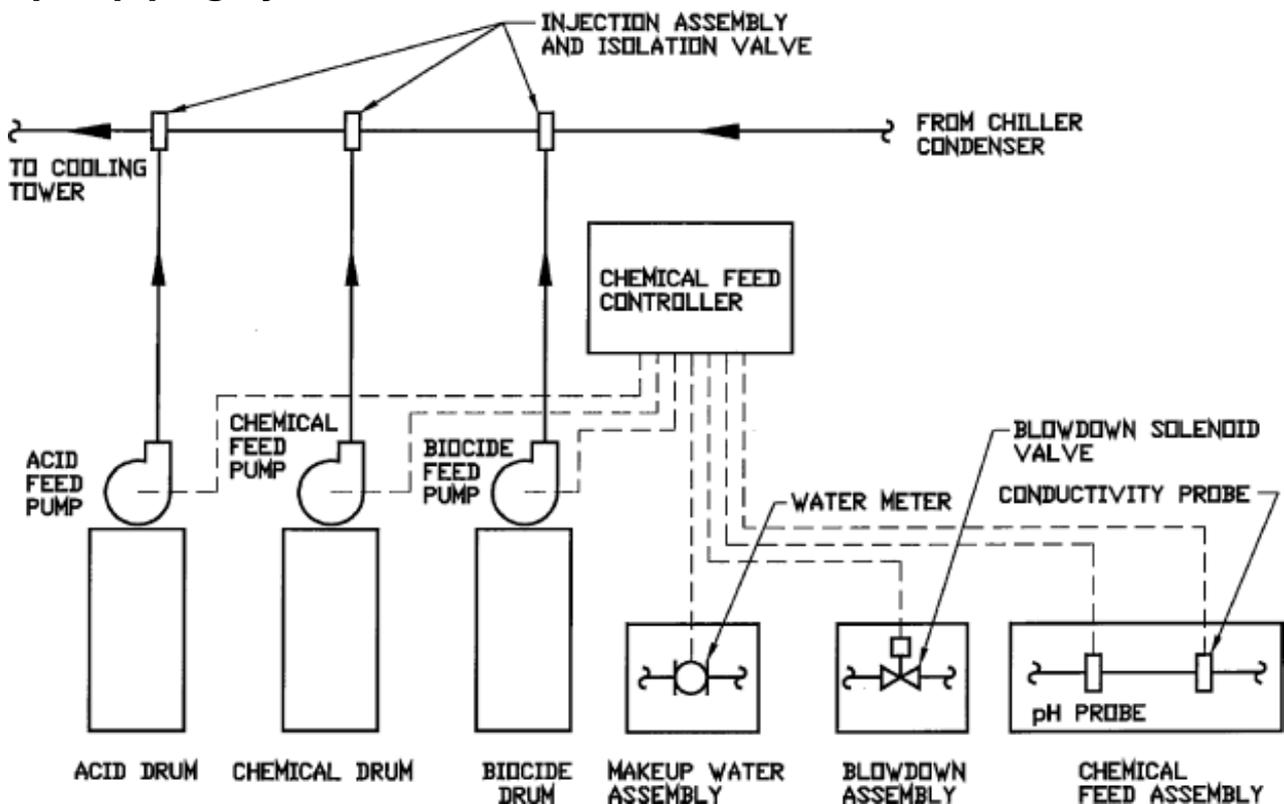
3. Corrosion inhibitors.

4. Dispersants.

C. Makeup water analysis should be conducted at least twice a year, preferably quarterly.

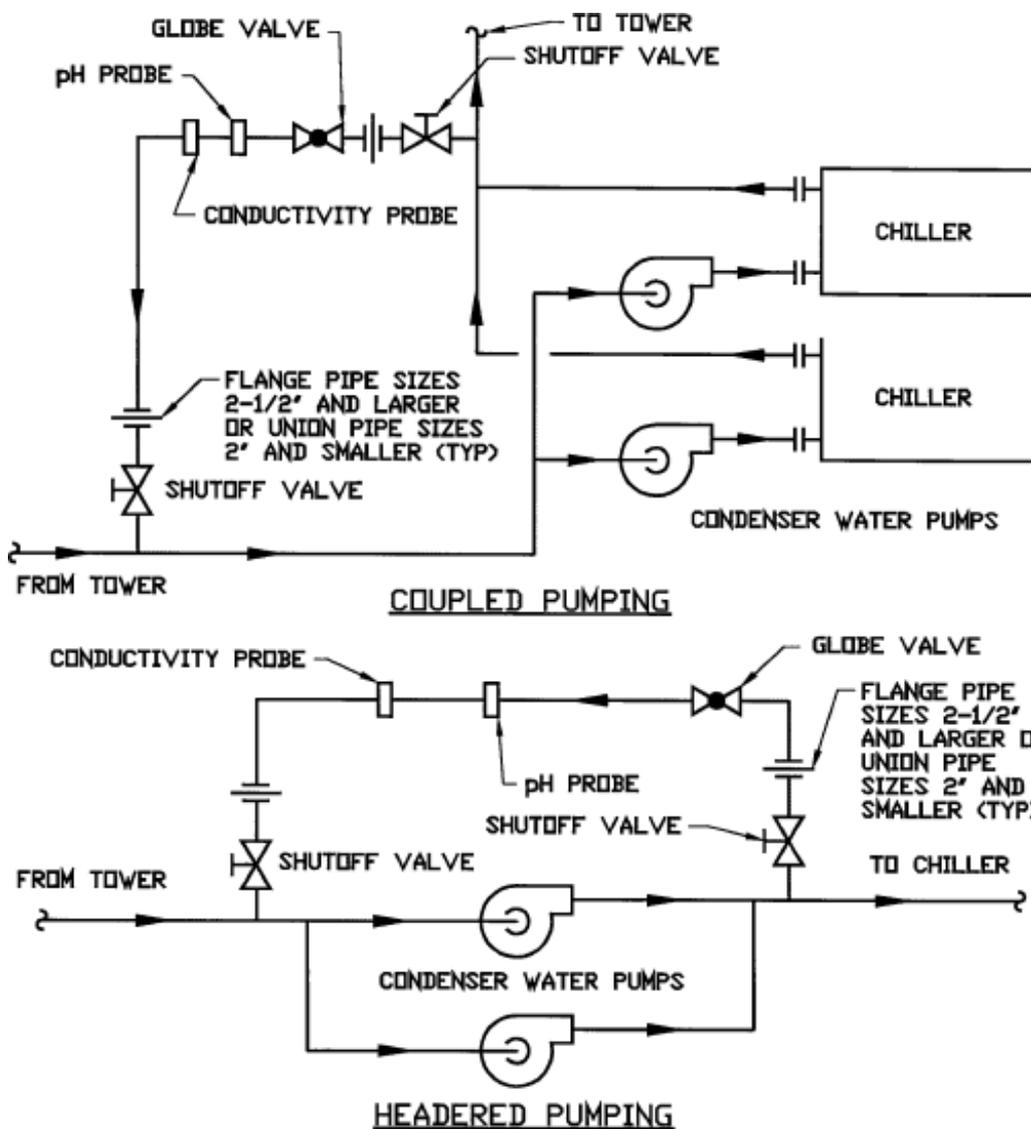
D. System water analysis should be conducted at least once a week.

E. See Figs. 38.3 and 38.4 for chemical treatment components used in an open piping system.



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Figure 38.3. OPEN SYSTEM CHEMICAL TREATMENT.



- NOTES:**
1. SHUTOFF VALVES SHALL BE:
 2" & SMALLER: BALL (FULL PORT) OR PLUG VALVES
 2-1/2" & LARGER: BUTTERFLY OR PLUG VALVES.

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Figure 38.4. OPEN SYSTEM CHEMICAL FEED CONTROL ASSEMBLY.

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38.04. Steam Systems

A. **The chemical treatment objective is to prevent and control the following:**

1. Scale formation.
2. Corrosion. Major concern.
3. System pH. Between 8 and 9.

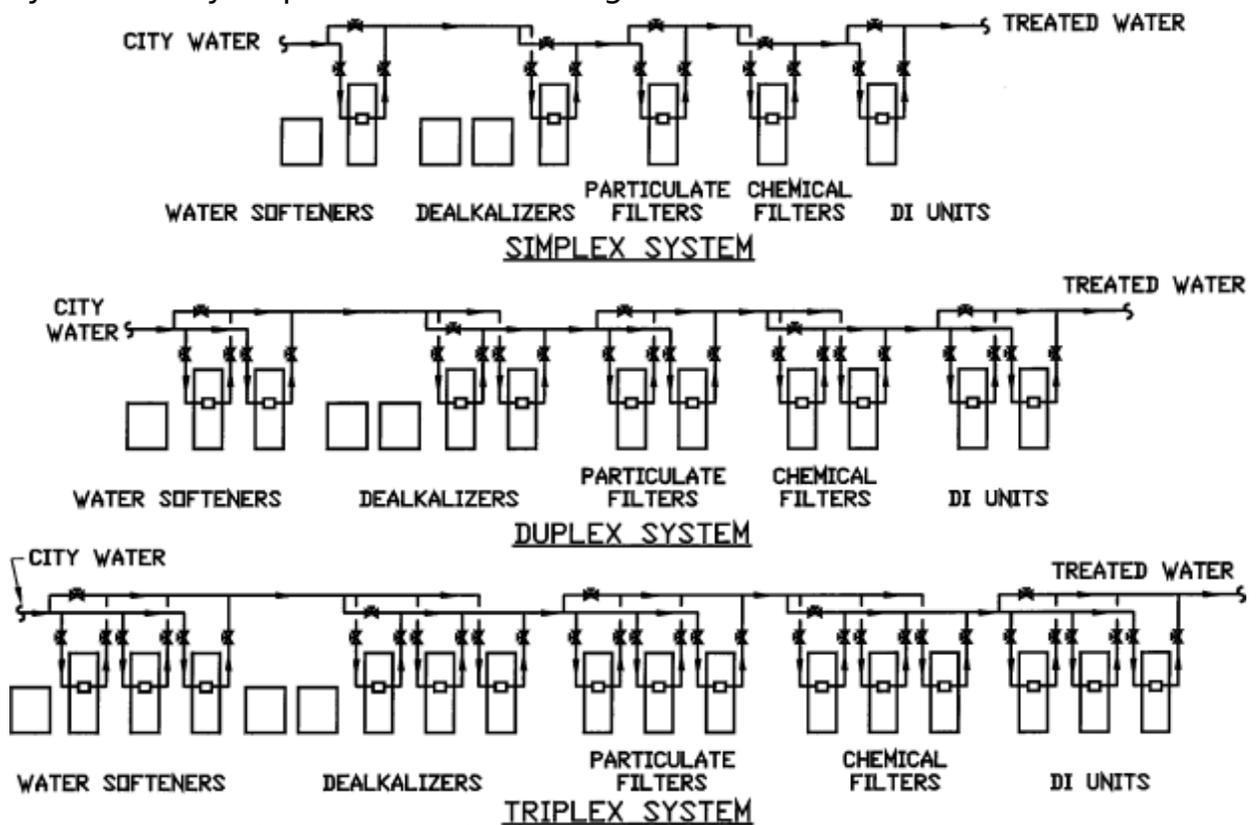
B. **Chemical Types Used in Steam Systems:**

1. Scale inhibitors.
2. Corrosion inhibitors.

3. Dispersants.

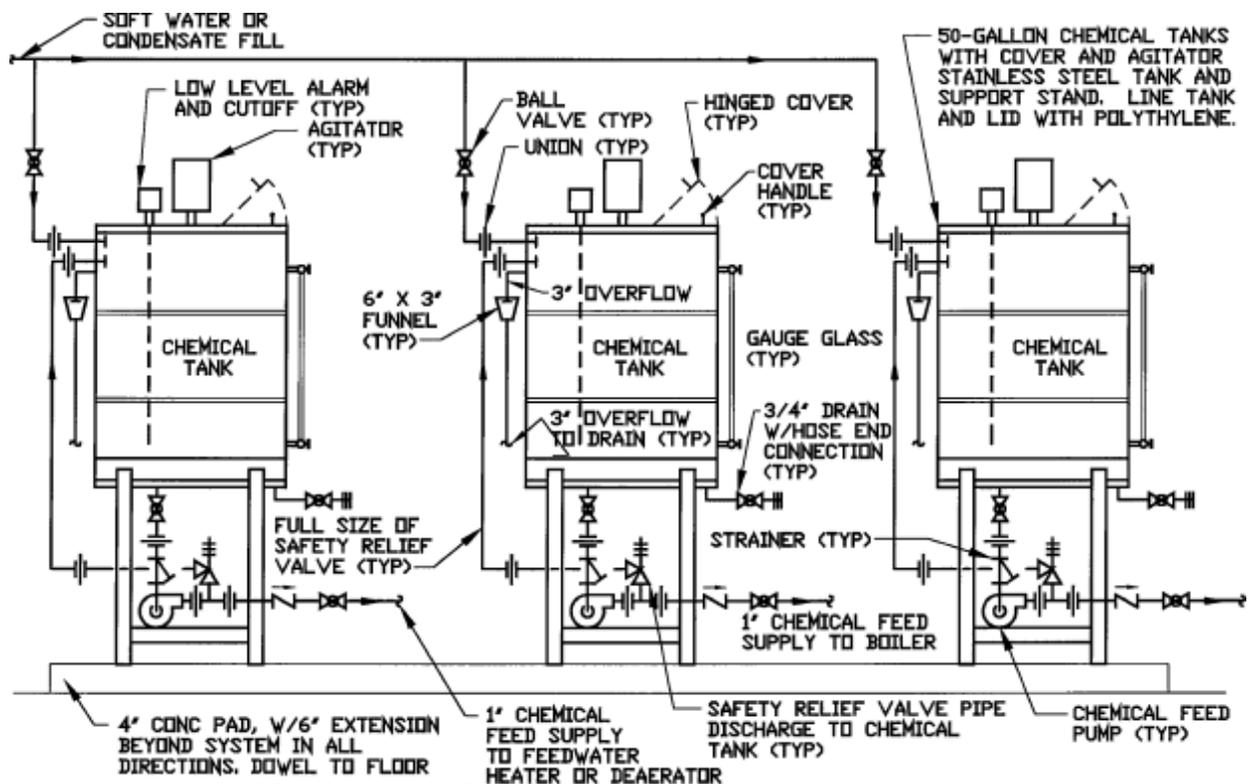
C. **Steam Boiler System Water Treatment Equipment:**

1. Pre-treatment: Most effective way to control steam boiler chemical treatment issues:
 - a. Softeners.
 - b. Filters.
 - c. Dealkalizers.
 - d. RO units.
 - e. See Figs. 38.5 and 38.6 for steam system chemical treatment. Figure 38.5 shows all the potential treatment equipment; however, many steam systems only require water softening.



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Figure 38.5. STEAM SYSTEM WATER TREATMENT.



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Figure 38.6. STEAM BOILER & FEEDWATER CHEMICAL TREATMENT SYSTEM.

2. Pre-boiler: Feedwater system treatment (deaerator, feedwater tank):
 - a. An oxygen scavenger should be injected into the storage tank. Injection into the storage tank is the ideal location. It provides the maximum reaction time and protects the feedwater tank, pumps, and piping.
 - b. An oxygen scavenger can be injected into the feedwater line, but is not recommended.
 - c. Oxygen scavenger chemicals (see the following table):
 1. Sodium sulfite. Low- and medium-pressure systems.
 2. Hydrazine. Medium- and high-pressure systems.

Oxygen Scavenger	Feedwater Levels	Boiler Levels
Sodium Sulfite	10 to 15 ppm	30 to 60 ppm
Hydrazine	0.05 to 0.1 ppm	0.1 to 0.2 ppm

3. Boiler: Organic treatment program:
 - a. Scale control chemicals should be injected directly into the boiler; however, they may be injected into the feedwater tank or feed water line as well.

b. Polymers. Most common.

c. Phosphonate.

4. After-boiler: Steam and Condensate Pipe Treatment:

a. Amines:

1. Neutralizing amines. Neutralize carbonic acid; may be injected into the boiler or steam header.
2. Filming amines. Injected into the steam header.

b. Injection location:

1. Steam header. Best location.
2. Boiler.
3. Feedwater. Worst location; not recommended.
4. These chemicals can be injected anywhere along the steam piping for better localized protection, especially in long piping runs.

D. Chemical Feed Methods

1. Shot feed or batch process. Not recommended.

2. Continuous:

a. Manual control:

1. Continuous.
2. Clock timer.
3. Percent timer.

b. Automated control:

1. Activated with feedwater pump.
2. Activated with makeup water flow control.
3. Activated with burner control.

E. Makeup water analysis should be conducted at least twice a year, preferably quarterly.

F. System water analysis should be conducted at least once a week.

Citation

EXPORT

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Part 39: Automatic Controls Building Automation Systems

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39. Part 39: Automatic Controls Building Automation Systems

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39.01. Automatic Controls and Building Automation Systems

A. Control Design Guidelines:

1. Today's automatic control systems and building automation systems should be designed to meet the following:
 - a. Open protocol design.
 - b. Web-based system design.
 - c. BACnet standards preferred.
 - d. Security—passwords for different levels.
 1. View only.
 2. View and modify setpoints.
 3. View, modify setpoints, and program.
 - e. BAS workstations.
 1. Computers:
 - a. Web-based systems—any computer connected to the network can be a workstation. However, it is good practice to provide a work station for facilities use.
 - b. Speed—the faster the better.

c. Provide laptop computers for facility maintenance staff to use on larger facilities or campus settings.

d. Items to specify:

Processor.

Memory.

Storage.

Media Drives.

Communication.

Modem.

Monitor.

Video.

Backup.

Ports.

Accessories—keyboard, mouse, UPS.

Operating system—industry standard, professional grade.

Data base—industry standard, professional grade, enterprise class.

2. Report printers:

a. LaserJet or Ink Jet

b. Paper sizes:

Letter—8.5" × 11".

Legal—8.5" × 14".

Tabloid—11" × 17" (for printing drawings).

3. Alarm printers:

a. LaserJet or Ink Jet.

b. Continuous paper feed is preferred; however, hard to find.

c. Paper sizes:

Letter—8.5" × 11".

f. Remote contact and alarm reporting:

1. E-mail.
2. Telephone.
3. Smart phone.
4. Other.

2. Two-way control valves should be installed upstream of equipment so that equipment is not subject to pump pressures.
3. *Proportional Band*. Throttling range over which the regulating device travels from fully closed to fully open.
4. *Drift or Offset*. Difference between the set point and the actual control point.
5. *Rangeability*. Ratio of maximum free area when fully open to the minimum free area.
6. Bypass valves should be plug valves, ball valves, or butterfly valves.
7. Control valves in HVAC systems should be the equal percentage type for output control, because equal percentage control valve flow characteristics are opposite of coil capacity characteristics.
 - a. Do not oversize control valves; most control valves are at least one to two sizes smaller than the pipe size.
 - b. The greater the resistance at design flow, the better the controllability.
 - c. Control Valve Pressure Drop:
 1. Minimum control valve pressure drop: 5 percent of total system pressure drop.
 2. Preferred control valve pressure drop: 10 to 15 percent of total system pressure drop.
 3. Maximum control valve pressure drop: 25 percent of total system pressure drop.
 - d. When specifying control valves include:
 1. Maximum design flow.
 2. Minimum design flow.

3. Internal pressure.
 4. Pressure drop at design flow.
 5. Pressure drop at minimum flow.
8. Two-way control valves:
- a. Two-way control valves should be selected for a resistance of 20 to 25 percent of the total system resistance at the valve location. This results in selecting the control valves for the available head at each location requiring a different pressure drop for each valve in direct return systems. In reverse return systems, control valves may be selected with equal pressure drop requirements. If control valves are selected for the pressure drop at each location, balancing valves are not required for external balancing of systems unless the pressure differential at the control valve location becomes excessive. Variable volume systems will be self-balancing.
9. Three-way control valves:
- a. Three-way control valves exhibit linear control characteristics that are not suited for output control at terminal units.
 - b. If three-way control action is desired to maintain minimum flow requirements, use two opposed-acting, equal percentage, two-way valves. A balancing valve must be installed in the bypass adjusted to equal the coil pressure drop. Operate valves sequentially in lieu of simultaneously, because if both valves are operated simultaneously, significant flow variations may occur.
 - c. The three-way valve pressure drop should be greater than the pressure drop (up to twice the pressure drop) of the coil it serves with a balancing valve in the bypass. The bypass valve pressure drop should be adjusted to equal to the coil pressure drop. A balancing valve or flow control device should be installed in the return downstream of the three-way valve.
10. Do not use on/off type control valves, except for small line sizes (1 inch and smaller).
11. Provide a fine mesh strainer ahead of each control valve to protect the control valve.

39.02. Control Definitions

The following control definitions were taken from the *Honeywell Control Manual* listed in Part 53:

A. *Algorithm.* A calculation method that produces a control output by operating on an error signal or a time series of error signals.

Operational logic affected by a control system usually resident in controlled hardware or software.

B. *Amplifiers.* Amplifiers condition the control signal, including linearization, and raise it to a level adequate for transmission and use by controllers.

C. *Analog.* Continuously variable (e.g., mercury thermometer, clock, faucet controlling water from closed to open).

D. *Authority.* The effect of the secondary transmitter versus the effect of the primary transmitter.

E. *Automatic Control System.* A system that reacts to a change or imbalance in the variable it controls by adjusting other variables to restore the system to the desired balance.

F. *Binary.* A distinct variable; a noncontinuous variable (e.g., digital clock, digital thermometer, digital radio dial); also related to computer systems and the binary numbering system (base 2).

G. *Closed Loop Control System.* Sensor is directly affected by the action of the controlled device, system feedback.

H. *Contactors.* Similar to relays, but are made with much greater current carrying capacity. Used in devices with high power requirements.

I. *Controls.* As related to HVAC, three elements are necessary to govern the operation of HVAC systems:

1. *Sensor.* A device or component that measures the value of the variable (e.g., temperature, pressure, humidity).
2. *Controller.* A device that senses changes in the controlled variable, internally or remotely, and derives the proper corrective action and output to be taken (e.g., receiver/controller, DDC panel, thermostat).

3. *Controlled Device*. That portion of the HVAC system that affects the controlled variable (e.g., actuator, damper, valve).

J. *Control Action*. Effect on a control device to create a response.

K. *Controlled Agent*. The medium in which the manipulated variable exists (e.g., steam, hot water, chilled water).

L. *Controlled Medium*. The medium in which the controlled variable exists (e.g., the air within the space).

M. *Controlled Variable*. The quantity or condition that is measured and controlled (e.g., temperature, flow, pressure, humidity, three states of matter).

N. *Control Point*. Actual value of the controlled variable (set point plus or minus set point).

O. *Corrective Action*. Control action that results in a change of the manipulated variable.

P. *Cycle*. One complete execution of a repeatable process.

Q. *Cycling*. A periodic change in the controlled variable from one value to another. Uncontrolled cycling is called "hunting."

R. *Cycling Rate*. The number of cycles completed per unit time, typically cycles per hour.

S. *Dampers*. Dampers are mechanical devices used to control airflow:

1. *Quick Opening*. Maximum flow is approached as the damper begins to open.
2. *Linear*. Opening and flow are related in direct proportion.
3. *Equal Percentage*. Each equal increment of opening increases flow by an equal percentage over the previous value.
4. *Opposed Blade*. Balancing, mixing, and modulating control applications. Half of the blades rotate in one direction, while the other half rotate in the other direction:
 - a. At low pressure drops, opposed blade dampers tend to be equal percentage.
 - b. At moderate pressure drops, opposed blade dampers tend to be linear.

- c. At high pressure drops, opposed blade dampers tend to be quick opening.
5. *Parallel Blade*. Two-position control applications. All the blades rotate in a parallel, or in the same, direction:
- a. At low pressure drops, parallel blade dampers tend to be linear.
 - b. At high pressure drops, parallel blade dampers tend to be quick opening.

T. *Deadband*. A range of the controlled variable in which no corrective action is taken by the controlled system and no energy is used.

U. *Discriminator*. A device that accepts a large number of inputs (up to 20) and selects the appropriate output signal (averaging relay, high relay, low relay).

V. *Deviation*. The difference between the set point and the value of the controlled variable at any moment. Also called *offset*.

W. *DDC*. Direct Digital Control.

X. *Differential*. The difference between the turn-on signal and the turn-off signal.

Y. *Digital*. Series of On and Off pulses arranged to carry messages (e.g., digital radio and TV dials, digital clock, computers).

Z. *Digital Control*. A control loop in which a microprocessor-based controller directly controls equipment based on sensor inputs and set point parameters. The programmed control sequence determines the output to the equipment.

AA. *Direct Acting*. Controller is direct acting when an increase in the level of the sensor signal results in an increase in the level of the controller output.

BB. *Droop*. A sustained deviation between the control point and the set point in a two-position control system caused by a change in the heating or cooling.

CC. *Dry Bulb Control*. Control of the HVAC system based on outside air dry bulb temperature (sensible heat).

DD. *Electric Control.* A control circuit that operates on line or low voltage and uses a mechanical means, such as temperature-sensitive bimetal or bellows, to perform control functions.

EE. *Electronic Control.* A control circuit that operates on low voltage and uses solid state components to amplify input signals and perform control functions.

FF. *Enthalpy Control.* Control of the HVAC system based on outside air enthalpy (total heat).

GG. *Fail Closed.* Position device will assume when system fails (e.g., fire dampers fail closed).

HH. *Fail Open.* Position device will assume when system fails (e.g., present coil valves fail open).

II. *Fail Last Position.* Position device will assume when system fails (e.g., process coding water valve fails in last position).

JJ. *Final Control Element.* A device such as a valve or damper that acts to change the value of the manipulated variable (e.g., controlled device).

KK. *Floating Action.* Dead spot or neutral zone in which the controller sends no signal but allows the device to float in a partly open position.

LL. *Gain.* Proportion of control signal to throttling range.

MM. *In Control.* Control point lies within the throttling range.

NN. *Interlocks.* Devices that connect HVAC equipment so operation is interrelated and systems function as a whole.

OO. *Lag.* A delay in the effect of a changed condition at one point in the system, or some other condition to which it is related. Also, the delay in response of the sensing element of a control due to the time required for the sensing element to sense a change in the sensed variable.

PP. *Lead/Lag.* A control method in which the selection of the primary and secondary piece of equipment is obtained and alternated to limit and equalize wear on the equipment.

QQ. *Manipulated Variable.* The quantity or condition regulated by the automatic control system to cause desired change in the controlled variable.

RR. *Measured Variable.* A variable that is measured and may be controlled.

SS. *Microprocessor-Based Control.* A control circuit that operates on low voltage and uses a microprocessor to perform logic and control functions. Electronic devices are primarily used as sensors. The controller often furnishes flexible DDC and energy management control routines.

TT. *Modulating Action.* The output of the controller can vary infinitely over the range of the controller.

UU. *Modulating Range.* Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.

VV. *Motor Starters.* Electromechanical device that utilizes the principle of electromagnetism to start and stop electric motors, often containing solenoid coil actuators, relays, and overload protective devices.

WW. *Normally Closed.* The device assumes the closed position when the control signal is removed (the device is in the closed position in the box prior to installation).

XX. *Normally Open.* The device assumes the open position when the control signal is removed (the device is in the open position in the box prior to installation).

YY. *Offset.* The difference between the control point and the set point.

ZZ. *On/Off Control.* A simple two-position control system in which the device being controlled is either full On or full Off with no intermediate operating positions available.

AAA. *Open Loop Control System.* The sensor is not directly affected by the action of the controlled device; no system feedback.

BBB. *Out of Control.* The control point lies outside of the throttling range.

CCC. *Pigtail.* A loop put in a sensing device to prevent the element from experiencing temperature or pressure extremes.

DDD. *Pneumatic Control.* A control circuit that operates on air pressure and uses a mechanical means, such as temperature-sensitive bimetal or bellows, to perform control functions.

EEE. *Proportional Control.* A control algorithm or method in which the final control element moves to a position proportional to the deviation of the value of the controlled variable from the set point. Cyclical control (sine/cosine).

FFF. *Proportional-Integral (PI) Control.* A control algorithm that combines the proportional (proportional response) and integral (reset response) control algorithms. Cyclical control, but automatically narrows the band between upper and lower points. Used most commonly in commercial building applications.

GGG. *Proportional-Integral-Derivative (PID) Control.* A control algorithm that enhances the PI control algorithm by adding a component that is proportional to the rate of change (derivative) of the deviation of the controlled variable. Compensates for system dynamics and allows faster control response. Cyclical control, but automatically narrows the band between upper and lower points and also calculates the time between peak high and peak low and adjusts accordingly. Used most commonly in industrial applications.

HHH. *Relays.* Electromagnetic devices for remote or automatic control actuated by variations in conditions of an electric circuit and operating, in turn, other devices (such as switches) in the same or different circuit. Carry low-level control voltages and currents.

III. *Reverse Acting.* Controller is reverse acting when an increase in the level of the sensor signal results in a decrease in the level of the controller output.

JJJ. *Sensing Element.* A device or component that measures the value of the variable.

KKK. *Sensitivity.* Proportion of the control signal to throttling range.

LLL. *Set Point.* Desired value of the controlled variable (usually in the middle of the throttling range).

MMM. *Snubber.* A component installed with a sensing device that prevents sporadic fluctuations from reaching the sensing device. These sporadic fluctuations often make the sensing device inoperative.

NNN. *Step Control.* Control method in which a multiple-switch assembly sequentially switches equipment as the controller input varies through the proportional band.

OOO. *Time Delay Relays.* Relays that provide a delay between the time the coil is energized and the time the contactors open and/or close.

PPP. *Thermistor.* A solid state device in which resistance varies with temperature.

QQQ. *Throttling Action.* Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.

RRR. *Throttling Range.* Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other. Also referred to as *proportional band*.

SSS. *Transducers.* Devices that change a pneumatic signal to an electric signal and vice versa. Pneumatic-Electric (PE) or Electric-Pneumatic (EP) switches (two-position transducer or analog to analog).

TTT. *Turndown Ratio.* The minimum flow or capacity of a piece of equipment expressed as a ratio of maximum flow/capacity to minimum flow/capacity. The higher the ratio, the better the control.

UUU. *Two-Position Control.* Control system in which the device being controlled is either full On or full Off with no intermediate operating positions available (On/Off; open/closed; also called *On/Off control*).

VVV. Valves. Valves are mechanical devices used to control the flow of steam, water, gas, and other fluids:

1. 2-Way: Temperature control, modulate flow to controlled device, variable flow system.
2. 3-Way mixing: Temperature control, modulate flow to controlled device, constant flow system; two inlets and one outlet.
3. 3-Way diverting: Used to divert flow; generally cannot modulate flow—two positions; one inlet and two outlets.
4. Quick opening control valves: Quick opening control valves produce wide free port area with relatively small percentage of total valve stem stroke. Maximum flow is approached as the valve begins to open.
5. Linear control valves: Linear control valves produce free port areas directly related to valve stem stroke. Opening and flow are related in direct proportion.
6. Equal percentage control valves: Equal percentage control valves produce an equal percentage increase in the free port area with each equal increment of valve stem stroke. Each equal increment of opening increases flow by an equal percentage over the previous value (most common HVAC control valve).
7. Control valves are normally smaller than line size unless used in two-position applications (open/closed).
8. Control valves should normally be sized to provide 20 to 60 percent of the total system pressure drop:
 - a. Water system control valves should be selected with a pressure drop equal to two to three times the pressure drop of the controlled device.

OR

Water system control valves should be selected with a pressure drop equal to 10 ft. or the pressure drop of the controlled device, whichever is greater.

OR

Water system control valves for constant flow systems should be sized to provide 25 percent of the total system pressure drop.

OR

Water system control valves for variable flow systems should be sized to provide 10 percent of the total system pressure drop, or 50 percent of the total available system pressure.

- b. Steam control valves should be selected with a pressure drop equal to 75 percent of the inlet steam pressure.

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39.03. Types of Control Systems

A. Pneumatic:

1. Safe.
2. Reliable.
3. Proportional.
4. Inexpensive.
5. Fully modulating or two-position in nature.
6. Seasonal calibration required.
7. If there are more than a couple dozen control devices in a building, then pneumatic controls would be less expensive than electric or electronic controls.
8. Widely used in commercial, institutional, and industrial facilities.
9. Pneumatic control system pressure signals:
 - a. Typical heating: 0–7 psi.
 - b. Typical cooling: 8–15 psi.
 - c. Max. system pressure: 30 psi.
10. Compressor runtime should be 1/3 to 1/2 the operating time.

B. Electric:

1. Simple control systems.
2. Used on small HVAC systems.
3. Mostly used for starting and stopping equipment.

4. Electric control system signals:
 - a. 120 volts and less AC or DC.
 - b. Typically 120 volts or 24 volts.

C. Electronic:

1. Used widely in prepackaged control systems.
2. Fully modulating in nature.
3. Reasonably inexpensive.
4. Electronic control system signals:
 - a. 24 volts or less AC or DC.
 - b. Typical voltage signal range of 0 to 10 volts.
 - c. Typical amperage signal range of 4 to 20 milliamps.

D. Direct Digital Control (DDC):

1. Computerized control.
2. Fully modulating, start/stop and staged control.
3. Faster and more accurate than all other control systems.
4. Control systems can be adapted and changed to suit field conditions. Very flexible.
5. Able to communicate measured, control, input and output data over a network.
6. Fairly expensive.
7. Often DDC systems use DDC controllers and pneumatic actuators to operate valves, dampers, and other devices.
8. DDC system signals:
 - a. Typical voltage signal range of 0 to 10 volts DC.
 - b. Typical amperage signal range of 4 to 20 milliamps.
9. Most energy codes are forcing control system design to DDC.
10. Common names for DDC systems.

- a. BAS—Building Automation System.
- b. BMS—Building Management System.
- c. EMS—Energy Management System.
- d. FMS—Facility Management System.

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39.04. Control System Objectives

A. Define Control Functions:

1. Start/Stop—All control systems should be provided with the following types of start/stop control.
 - a. Manual—manual control at starter or variable frequency drive.
 - b. Remote manual—manual control through the building automation system.
 - c. Automatic control—automatic control through the building automation system.
2. Occupied/unoccupied/preparatory.
3. Fan capacity control:
 - a. Variable Frequency Drives (VFDs)—energy codes are forcing the use of VFDs.
 - b. Inlet Vanes.
 - c. Two-speed motors.
 - d. Discharge dampers—energy wasting; not typically permitted by energy codes.
 - e. Scroll volume control.
 - f. Supply air-, return air-, relief air-fan tracking.
4. Pump capacity control:
 - a. Variable Frequency Drives (VFDs)—energy codes are forcing the use of VFDs.
 - b. Two-speed motors.
 - c. Variable flow pumping systems (two-way control valves).

5. Damper control (OA, RA, RFA, Inlet Vanes).
6. Valve control (two-way, three-way).
7. Temperature.
8. Humidity.
9. Pressure.
10. Flow.
11. Temperature Reset (SA, Water).
12. Terminal unit control (room, discharge, submaster).
13. Modulate, sequence, cycling.
14. Monitoring systems:
 - a. HVAC systems.
 - b. Plumbing systems.
 - c. Medical gas, vacuum, and compressed air systems.
 - d. Laboratory gas, vacuum, and compressed air systems.
 - e. Fire protection systems.
 - f. Electrical systems.
 - g. Elevators.
 - h. Other.
15. Alarms.
16. Energy/utility consumption—natural gas, fuel oil, electric, water.
17. Lighting—time of day schedule, daylighting.

B. Define Interlock Functions:

1. Fans/AHUs.
2. Pumps/boilers/chillers.
3. Smoke control system interlocks.

C. Define Safety Functions:

1. Fire.
2. Smoke.
3. Freeze protection.
4. Low/high pressure limit.
5. Low/high temperature limit.
6. Low/high water.
7. Low/high flow.
8. Over/under electrical current.
9. Vibration.

D. Alarm Functions (most often safety alarms).

E. Typical Control Algorithms:

1. Occupied/unoccupied/preparatory (time of day scheduling).
2. Night/weekend/holiday (time of day/week/year scheduling).
3. AHU dry-bulb economizer.
4. AHU enthalpy economizer.
5. Boiler/heat exchanger OA reset.
6. AHU discharge air control.
7. AHU discharge air control with room reset.
8. AHU VAV pressure independent.
9. AHU VAV pressure dependent.
10. Chiller discharge water reset.
11. Daylight savings time adjustments.
12. Electrical demand limiting.
13. Start/stop optimization.

14. Energy-performance optimization.

15. Duty cycle.

16. Enthalpy optimization.

17. Smoke control.

18. Trending.

19. Alarm instructions.

20. Maintenance work order.

21. Runtime totalizing.

F. **Types of Controls:**

1. *Operating Controls.* Operating controls are used to control a device, system, or entire facility in accordance with the needs of the device, system, or facility.
2. *Safety Controls.* Safety controls are used to protect the device, system, or facility from damage should some operating characteristic get out of control; to prevent catastrophic failure of the device or system; and to prevent harm to the occupants of the facility. Most safety controls come in the form of high or low limits:
 - a. Automatic reset.
 - b. Manual reset.
3. *Operator Interaction Controls.* Controls the building occupant would normally be provided with to activate various HVAC equipment devices or systems.

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39.05. Building Automation and Control Networks (BACnet)

A. **BACnet is a communication protocol. A communication protocol is a set of rules governing the exchange of data between two computers. A protocol encompasses both hardware and software specifications, including the following:**

1. Physical medium.
2. Rules for controlling access to the medium.

3. Mechanics for addressing and routing messages.
4. Procedures for error recovery.
5. The specific formats for the data being exchanged.
6. The contents of the messages.

B. The BACnet goal is to enable building automation and control devices from different manufacturers to communicate.

C. BACnet Data Structures:

1. Analog input.
2. Analog output.
3. Analog value.
4. Binary input.
5. Binary output.
6. Binary value.
7. *Calendar*. Represents a list of dates that have special meaning when scheduling the operation of mechanical equipment.
8. Command.
9. *Device*. Contains general information about a particular piece of mechanical equipment (i.e., model, location).
10. *Device Table*. Shorthand reference to a list of devices.
11. *Directory*. Provides information on how to access other objects.
12. *Event Enrollment*. Provides a way to define alarms or other types of events.
13. File.
14. *Group*. Shorthand method to access a number of values in one request.
15. *Loop*. Represents a feedback control loop (PID).
16. Mailbox.
17. Multi-state input.

18. Multi-state output.

19. Program.

20. Schedule.

D. BACnet Object Properties:

1. Object identifier.

2. Object type.

3. Present value.

4. Description.

5. Status flags.

6. Reliability.

7. Override.

8. Out-of-service.

9. Polarity.

10. Inactive text.

11. Active text.

12. Change-of-state time.

13. Elapsed active time.

14. Change-of-state count.

15. Time of reset.

E. BACnet Applications:

1. Alarm and event services.

2. File access services (read, write).

3. Object access services (add, create, delete, read, remove, write).

4. Remove device management services.

5. Virtual terminal services (open, close, data).

F. **BACnet Conformance Classes:**

1. *Class 1.* Class 1 devices are the lowest level in BACnet system structure and consist of smart sensors.
2. *Class 2.* Class 2 devices consist of smart actuators.
3. *Class 3.* Class 3 devices consist of unitary controllers.
4. *Class 4.* Class 4 devices consist of general purpose local controllers.
5. *Class 5.* Class 5 devices consist of operator interface controllers.
6. *Class 6.* Class 6 devices are the highest level in the BACnet system structure and consist of head-end computers.

G. **BACnet Functional Groups:**

1. Clock.
2. Hand-held workstation.
3. Personal computer workstation.
4. Event initiation.
5. Event response.
6. Files.
7. Reinitialize.
8. Virtual operator interface.
9. Virtual terminal.
10. Router.
11. Device communications.
12. Time master.

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39.06. Control Points List

A. **Inputs:**

1. Analog:
 - a. Measured:

1. Temperature.
 - a. Air
 - b. Water
 - c. Steam
2. Relative humidity.
3. Dewpoint.
4. Pressure.
 - a. Air
 - b. Water
 - c. Steam
5. Differential pressure.
6. Airflow—CFM.
7. Water flow—GPM.
8. Steam flow—lbs./h.
9. Btu/hr.
10. Tons.
11. Gas flow—CFH.
12. Oil flow—GPH.
13. kW.
14. Current.
15. Voltage.
16. VFD speed.
17. CO₂ concentration.
18. CO sensor.
19. Refrigerant sensor.

20. Filter static.

21. Water or liquid level.

b. Calculated:

1. Relative humidity.

2. Dewpoint.

3. Specific humidity.

4. Wet bulb.

5. Enthalpy.

6. Steam consumption—lb.

7. Gas consumption—CF.

8. Oil consumption—gal.

9. Water consumption—gal.

10. Btu/h.

11. Tons.

12. kWh.

13. Runtime.

14. Efficiency.

15. Volume—gal.

2. Binary:

a. Run status—Flow Switch.

b. Run status—Differential Pressure Switch.

c. Run status—Current Switch.

d. Filter.

e. Smoke.

f. Freeze.

- g. Airflow.
- h. Water Flow.
- i. Steam Flow.
- j. Meter.
- k. Interlocks.
- l. Status.
- m. Extinguishing agent flow.

B. Outputs:

- 1. Digital:
 - a. Off-on.
 - b. Off-auto-on.
 - c. Off-high-low.
 - d. Off-auto-on (VFD).
 - e. Damper open-closed.
 - f. Valve open-closed.
 - g. Heating stages.
- 2. Analog:
 - a. Damper position.
 - b. Damper control.
 - c. Valve position.
 - d. Valve control.
 - e. Setpoint adjustment.
 - f. Load reset.
 - g. Temperature reset.
 - h. Electric heat—SCR.

C. System Features:

1. Alarms:

- a. High analog.
- b. Low analog.
- c. High-high digital.
- d. High digital.
- e. Low digital.
- f. Low-low digital.
- g. Run status.
- h. Filter.
- i. Smoke.
- j. Freeze.
- k. Pressure.
- l. Fire.
- m. Vibration.

2. Programs:

- a. Time scheduling.
- b. Demand limiting.
- c. Duty cycle.
- d. Start/stop optimization.
- e. Energy/performance optimization.
- f. Enthalpy optimization.
- g. Smoke control.
- h. Trends.
- i. Alarm instruction.

j. Maintenance work order.

D. General:

1. Color graphics.
2. Summary report.
3. Alarm reports.
4. Trends reports.
5. X-Y graphic plots.
6. Statistical reports.
7. Historical reports.
8. Custom reports.
9. Expansion capacity: 10 to 25 percent spare capacity in controller, panels, and computer systems.
10. PC, monitor, keyboard.
11. Alarm printer.
12. Report printer.
13. Laptop computers.

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39.07. DDC Control System Specification Outline

A. Part 1—General

1. Scope of work.
2. System description.
3. System performance.
 - a. Graphic display.
 - b. Graphic refresh.
 - c. Object command.
 - d. Object scan.

- e. Alarm response time.
 - f. Program execution frequency.
 - g. Performance.
 - h. Multiple alarm annunciation.
 - i. Reporting accuracy.
 - j. Stability of control.
4. Codes and standards.
5. Products furnished and installed under this contract.
- a. Thermostats.
 - b. Humidistats.
 - c. Air distribution system temperature sensors.
 - d. Air distribution system pressure and differential pressure sensors.
 - e. Air distribution system flow switches.
 - f. Refrigerant, CO₂, CO, and other gas detection systems.
 - g. Current switches.
 - h. All other devices not specifically mentioned in the following.
6. Products furnished but not installed under this contract.
- a. Piping temperature sensors, Wells, and Sockets.
 - b. Piping pressure and differential Pressure Sensors.
 - c. Piping flow switches.
 - d. Control valves—may be furnished and installed under another division.
 - e. Control dampers—may be furnished and installed under another division.
 - f. Water flow meters—may be furnished and installed under another division.
 - g. Airflow meters—may be furnished and installed under another division.
 - h. Energy meters—may be furnished and installed under another division.

- i. Terminal unit controls—may be furnished and installed under another division.
- j. Air terminal unit controls—often furnished by the control contractor and manufacturer; installed under another division.

7. Products installed but not furnished under this contract.

8. Products not furnished or installed but integrated with under this contract.

- a. Chiller control package.
- b. Boiler control package.
- c. Cooling tower basin heater and water level control package.
- d. Packaged air handling system controllers.
- e. Variable frequency controllers.
- f. Motor controllers and disconnect switches.
- g. Fire, smoke, and fire/smoke dampers.
- h. Duct mounted smoke detectors.
 - i. Control valves.
 - j. Control dampers.
 - k. Water flow meters.
 - l. Airflow meters.
- m. Energy meters.
- n. Terminal unit controls.
- o. Air terminal unit controls.
- p. Electrical distribution systems—normal power, emergency power, and UPS systems.
- q. Emergency generator control package.
- r. Lighting control systems.

9. Quality assurance.
10. Submittals.
11. Warranty.
12. Ownership of proprietary material.

B. Part 2—Products

1. Approved control system contractors/manufacturers.
2. Materials.
3. Communication.
 - a. Network arrangement.
 - b. Workstation communication.
 - c. Controller communication.
 - d. Secondary bus communication.
 - e. System architecture.
 - f. Communication performance.
 - g. Communication protocols.
 1. Interoperability.
 2. Network communications.
4. Integrating a proprietary system with an open protocol system.
5. Operator interface.
 - a. Number of work stations.
 - b. System connection.
 - c. System hardware.
 1. Fixed operator work stations:
 - a. Computer terminal—computer, keyboard, monitor, mouse, modem, backup method.
 - b. Report printer.
 - c. Alarm printer.

2. Portable operator work stations—laptop computers.

- d. System software:

1. Operating system.

2. System graphics.

3. System applications:

- a. General.

- b. Automatic and manual system database save and restore.

- c. System configuration.

- d. Online help.

- e. Security.

- f. System diagnostics.

4. Alarm processing.

5. Trend, alarm, and event logs.

6. Object and property status and control.

7. Clock synchronization.

8. Reports and logs.

9. Custom reports.

- a. Tenant override reports.

- b. Electrical, gas, water, utility, and weather reports.

- c. ASHRAE Guideline 3 Report—large chillers.

10. Workstation application editors.

11. Controller.

12. Scheduling.

13. Custom application programming.

6. Controller software.

- a. System security.

- b. Scheduling.
- c. Grouping.
- d. Alarm processing.
- e. Remote communications.
- f. Standard application programs.
- g. Demand limiting.
- h. Maintenance management.
- i. Sequencing.
- j. PID control.
- k. Staggered start.
- l. Energy calculations.
- m. Anti-short cycling.
- n. On/off control with differential.
- o. Runtime totalization.

7. Building controllers.

- a. General.
- b. Background.
- c. Internal software.
- d. Modularity.
- e. Operator software.
- f. Inputs and outputs.
- g. Power supplies, including UPS.
- h. Listings.
- i. Distribution of controllers—limits the number of systems on any one controller.

8. Custom application controllers.
 - a. General.
 - b. Internal software.
 - c. Modularity.
 - d. Operator software.
 - e. Inputs and outputs.
 - f. Power supplies, including UPS.
 - g. Listings.
 - h. Distribution of controllers—limits the number of systems on any one controller.
9. Application specific controllers.
 - a. General.
 - b. Background.
10. Input/output interface.
11. Power supplies and line filtering.
12. Auxiliary control devices.
 - a. Motorized control dampers.
 - b. Damper/valve actuators.
 1. Electric.
 2. Pneumatic.
 - c. Control valves.
 - d. Temperature devices.
 - e. Humidity devices.
 - f. Flow switches.
 - g. Relays.
 - h. Override timers.

- i. Power monitoring.
 - 1. Current.
 - 2. Voltage.
 - 3. Power sensing.
 - j. Equipment status sensing.
 - k. Pressure devices.
 - l. Electro-pneumatic transducers.
 - m. Local control panels.
13. Wiring and raceways.
14. Fiber optic cable system.
15. Compressed air supply—pneumatic actuation.
 - a. Air compressor.
 - b. Air dryer.
 - c. Air filters.
 - d. Pressure reducing valves.
 - e. Relief valves.
 - f. Condensate drains.
 - g. Pneumatic tubing.

C. Part 3—Execution

- 1. General installation.
- 2. Examination.
- 3. Protection.
- 4. Coordination.
- 5. General workmanship.
- 6. Field quality control.

7. Existing equipment.
8. Wiring.
9. Communication wiring.
10. Fiber optic cable.
11. Pneumatic systems installation.
12. Control air tubing installation.
13. Installation of sensors.
14. Flow switch installation.
 - a. Airflow.
 - b. Water flow.
15. Flow meter installation.
16. Control valve installation.
17. Control damper installation.
18. Valve and damper actuators.
19. Warning labels.
20. Identification of hardware and wiring.
21. Controllers—controller loading—spare capacity.
22. Programming.
 - a. Project specific programming.
 1. Text-based programming.
 2. Graphic-based programming.
 3. Menu-driven programming.
 - b. Point naming.
 - c. Other programming and database setup.
23. Control system checkout and testing.

24. Control system demonstration and acceptance.
25. Commissioning.
26. Cleaning.
27. Training.
28. Sequences of operation—sequences of operation may be contained in a separate specification section.
29. I/O points lists—I/O points lists may be contained in a separate specification section or in a graphical matrix form.

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Part 40: Sustainability Guidelines Relating to HVAC Systems

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40. Part 40: Sustainability Guidelines Relating to HVAC Systems

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40.01. Introduction

- A. Sustainability is a term used in the building industry to describe the focus on the design, construction, and operation of buildings in a manner that reduces their impact on the natural environment.**
- B. There are many aspects of sustainability in the building industry including site selection; water efficiency; use of recycled, renewable, and regional materials; energy efficiency; and indoor environmental quality. These aspects have been defined by the U.S. Green Building Council (USGBC) through its Leadership in Energy and Environmental Design (LEED) rating system.**
- C. The LEED rating system was started in 1993 to meet the need in the building industry for a system to define and measure "green buildings." Since that time, the LEED rating system has been expanded to cover all sectors of the building industry including new construction, existing buildings, commercial interiors, and others. The USGBC periodically updates the LEED rating system to refine its guidelines and incorporate emerging sustainability concepts.**
- D. Energy Star is an international standard for energy efficient consumer products that was created in 1992 by the U.S. Environmental Protection Agency. Products carrying the Energy Star service mark**

are generally 20 to 30 percent more energy efficient than what is required by federal standards. The program also includes labeling for residential HVAC equipment, such as air conditioning and heat pump units, furnaces, and boilers; lighting products; new homes; and commercial and industrial buildings.

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40.02. Sustainable HVAC System Design

- A. This chapter presents sustainability guidelines relating to HVAC systems. These guidelines focus mainly on energy efficiency, commissioning, refrigerant management, and indoor environmental quality.**
- B. Energy Efficiency**
1. The minimum energy efficiency requirements for buildings and their associated energy systems are established by ANSI/ASHRAE/IESNA Standard 90.1-2013 *Energy Standard for Buildings Except Low-Rise Residential Buildings*. This standard prescribes the minimum energy efficiency requirements for all building envelope, electrical, and HVAC systems.
 2. Increases in the energy efficiency of buildings can be achieved through improvements to the building envelope, reduction in lighting power densities, increases in motor efficiencies, and incorporation of energy-efficient HVAC systems.
 3. Improvements in the energy efficiency of HVAC systems can be made in a number of ways, depending upon the system:
 - a. Energy-efficient equipment.
 1. High-efficiency boilers and chillers.
 - a. Select higher-efficient central heating and cooling equipment, such as boilers and chillers, in lieu of central HVAC equipment that meets the minimum energy efficiency requirements of ASHRAE Standard 90.1-2013. For example, condensing boilers which extract the latent heat of vaporization from hot flue gases are more energy-efficient than noncondensing boilers which must keep stack temperatures high in order to avoid condensation of moisture in the flue gases. Recent chiller technologies, such as variable speed compressors and magnetic bearings, have greatly increased the energy efficiency of this equipment.

2. High-efficiency air conditioning equipment.
 - a. Select air conditioning and heat pump equipment that exceeds the minimum energy efficiency requirements of ASHRAE Standard 90.1-2013.
 3. NEMA premium efficiency motors.
 - a. For motors 1 horsepower and larger, specify NEMA premium efficiency motors as defined by NEMA Standards Publication MG 1-2014 Table 52 in lieu of motors classified as energy efficient by NEMA Standards Publication MG 1-2014 Table 51.
- b. HVAC system configuration.
1. Variable flow systems.
 - a. Variable flow water and air systems are inherently more energy-efficient than constant flow water and air systems. Variable frequency drives for pumps and fans can reduce energy use considerably when there are fluctuations in the loads this equipment serves.
 2. Heat reclaim systems.
 - a. Systems which reclaim heat that would otherwise be rejected to the outdoors improve the energy efficiency of HVAC systems. Heat is most often reclaimed from building exhaust airstreams and mechanical refrigeration equipment. Heat reclaimed from exhaust airstreams can be used to preheat/precool outdoor air, and heat reclaimed from mechanical refrigeration equipment is often used to preheat domestic hot water. Heat reclaim can also be used to provide dehumidification in some cases where humidity control is required by the space usage.
 3. Thermal storage systems.
 - a. Thermal storage systems can reduce energy costs by operating central cooling systems during off-peak hours when energy is less expensive. (The downside to thermal storage systems is that the central cooling equipment actually uses more, albeit less expensive, energy than the same central cooling equipment in nonthermal storage systems.)
- c. HVAC system control strategies.
1. Water and air temperature reset.

- a. Reset of water and air temperatures based on outdoor air temperature improves energy efficiency by more closely matching the HVAC systems' capacities to the building HVAC loads.
2. Demand-control ventilation.
 - a. Adjusting the outdoor air ventilation delivered by the HVAC systems to meet the ventilation requirements of the building occupants (referred to as demand-control ventilation, or DCV) is an energy-efficient strategy that only delivers the outdoor air ventilation that is necessary for acceptable indoor air quality. DCV is usually applied to HVAC systems which serve densely occupied spaces (those with a design occupant density greater than or equal to 25 people per 1,000 sq.ft.), such as conference rooms and auditoriums. Space CO₂ sensors located within the breathing zone (between 3 in. and 72 in. above the floor) of these spaces are used to control the amount of outdoor air ventilation delivered by the HVAC system. A CO₂ concentration that is about 700 ppm above outdoor air levels will satisfy a substantial majority of visitors entering a space with respect to human bioeffluents (body odor) according to ASHRAE Standard 62.1-2013, Appendix C. CO₂ concentrations in acceptable outdoor air range from 300 to 500 ppm. Therefore, the CO₂ setpoint for the space CO₂ sensors for DCV systems should be between 1,000 and 1,200 ppm.
3. Night setback.
 - a. Night setback control of the space temperature setpoint reduces energy use during unoccupied periods.
4. Economizers.
 - a. Airside and waterside economizers reduce energy use by utilizing outdoor air for cooling instead of mechanical refrigeration when the outdoor air conditions are suitable for this use. Airside economizers compare the enthalpy or dry bulb temperature of the outdoor air and return air and increase the outdoor airflow beyond the minimum value when the outdoor air has a lower enthalpy or dry bulb temperature and cooling is required by the HVAC system. Dry bulb economizers are often disabled above an outdoor air temperature of approximately 60°F in order to prevent the possibility of increasing the indoor space relative humidity above an acceptable limit. Waterside economizers can only be incorporated into central chilled

water systems which utilizes water-cooled chillers. When the outdoor air wet bulb temperature is low enough for the cooling tower(s) to cool the returning chilled water, the returning chilled water is diverted to a plate and frame heat exchanger where it is cooled by the cooling tower water. Thus, the outdoor air is used to cool (or precool) the chilled water loop through the cooling tower(s) instead of (or in addition to) using mechanical refrigeration to cool the chilled water loop through the chiller(s).

d. Architectural components.

1. Close coordination with the architectural design can improve energy efficiency by increasing the insulating quality of walls (above and below grade), roofs, partitions, and the edges of slabs on grade or below grade. Other areas of consideration include building orientation, window-to-wall ratio, glazing properties, and both internal and external shading of windows.

C. Commissioning

1. The commissioning process is defined by ASHRAE Guideline 0-2013 *The Commissioning Process* as "a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets the defined objectives and criteria."
2. Commissioning of HVAC systems ensures that the energy-efficient features of the project that are desired by the owner and intended by the design are actually implemented by the completed facilities, systems, and assemblies.
3. Commissioning begins in the predesign phase with stated goals called the Owner's Project Requirements (OPRs), continues during the design phase by meeting the OPRs with the Basis of Design (BOD) and the construction documents, moves into the construction phase with submittal review, installation checklists, issues log, startup checklists, prefunctional checklists, functional testing, and training in the operation and maintenance of the commissioned systems. Commissioning should continue at least through the warranty period with ongoing monitoring of the commissioned systems. Ideally, commissioning should continue throughout the life of the building.
4. When implemented properly throughout the course of design, construction, and operation, commissioning plays a key role in ensuring that the intended sustainability initiatives are fully implemented.

5. The commissioning process is defined in detail by ASHRAE Guideline 0-2013 *The Commissioning Process* and ASHRAE Guideline 1.1-2007 *HVAC&R Technical Requirements for the Commissioning Process*.

D. Refrigerant Management

1. From a sustainability standpoint, the two characteristics of a refrigerant that are of the greatest concern are the refrigerant's ozone-depletion potential (ODP) and its global warming potential (GWP). The types of refrigerants most commonly used in HVAC equipment are hydrochlorofluorocarbon (HCFC)-based refrigerants and hydrofluorocarbon (HFC)-based refrigerants. Chlorofluorocarbon (CFC)-based refrigerants, such as R-11 and R-12, are no longer produced because of their ODP.
2. The LEED rating system requires zero use of chlorofluorocarbon (CFC)-based refrigerants, such as R-11 and R-12, in new base building heating, ventilating, air conditioning, and refrigeration (HVAC&R) systems.
3. The LEED rating system discourages the use of hydrochlorofluorocarbon (HCFC)-based refrigerants, such as R-22 and R-123, because of their ODP. Although these refrigerants have a lesser ODP than CFC-based refrigerants, they are scheduled to cease production in the year 2030 due to their ODP.
4. Hydrofluorocarbon (HFC)-based refrigerants, such as R-134a and R-410A, do not have any ODP and are therefore not scheduled to cease production. However, both HCFC- and HFC-based refrigerants have GWPs that need to be considered in sustainable HVAC system design. The LEED rating system is concerned with the lifecycle direct global warming potential (LCGWP) of refrigerants used in HVAC&R systems. The LCGWP of a piece of HVAC&R equipment is a function of the refrigerant's GWP, the equipment's life and refrigerant leakage rate, the end-of-life refrigerant loss, and the equipment's refrigerant charge.
5. Small HVAC units (defined as containing less than 0.5 pounds of refrigerant) are not considered part of the base building system and are not subject to the requirements of the LEED rating system.

E. Indoor Environmental Quality

1. Many factors contribute to the quality of the indoor environment. From an HVAC standpoint, indoor air quality, thermal comfort, and acoustic quality need to be considered. Other factors, such as interior lighting, daylight, and

quality views of the outdoors also contribute to the quality of the indoor environment but are not HVAC-related.

2. Indoor air quality.

- a. Some indoor air contaminants which must be controlled in order to ensure acceptable indoor air quality are airborne particulates, formaldehyde and volatile organic compounds (VOCs) from building materials, and ozone which is generated by copying and printing equipment. Airborne particulates are suspended in the air and can be removed through air filtration. Formaldehyde, VOCs, and ozone, on the other hand, cannot be removed through air filtration, but must be controlled through dilution ventilation and exhaust at their source.

1. Air filtration.

- a. The minimum level of air filtration efficiency recommended for commercial HVAC systems is a minimum efficiency reporting value (MERV) of 8, as determined by ASHRAE Standard 55.2-2012 *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*.
- b. For superior air filtration, MERV 13 air filters may be used, but at the expense of higher installed and maintenance costs and increased energy use of the air handling equipment.
- c. All inlets for air handling equipment used during construction should be protected with air filters having a minimum efficiency of MERV 8 to keep the air handling equipment and ductwork free from airborne particulates generated by the construction activities.
- d. Ductwork should also be kept clean during construction in accordance with the recommended control measures of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) *IAQ Guidelines for Occupied Buildings under Construction*, 2nd edition, 2007, ANSI/SMACNA 008-2008, Chap. 3. These measures include covering all openings of air handling equipment and ductwork with plastic until the systems are operational.

2. Dilution ventilation.

- a. The concentration of indoor air contaminants can be reduced to acceptable levels for human occupancy by introducing outdoor air to the building through the air handling equipment. The Ventilation Rate Procedure in Section 6.2 of ASHRAE Standard 62.1-2013 *Ventilation*

for Acceptable Indoor Air Quality describes the procedure for determining the minimum rates of outdoor ventilation for various types of occupancy.

3. Source control of contaminants through exhaust.
 - a. Where indoor air contaminants are generated within a building, these contaminants should be captured at their source and exhausted to the outdoors. Areas such as toilet rooms, copying and printing rooms, janitor's closets, garages, and storage closets where hazardous chemicals are stored should be exhausted at the rate required by the applicable mechanical code (minimum of 0.50 cfm per sq.ft.). These rooms should also be kept at under negative air pressurization with respect to adjacent spaces when the doors are closed.
4. Testing airborne pollutant levels.
 - a. The best way to demonstrate that indoor pollutants have been reduced to acceptable levels after construction has been completed is to test for pollutants in accordance with the California Department of Public Health (CDPH) Standard Method v1.1. Air testing includes measurements of the concentrations of formaldehyde; particulate matter (PM) up to 10 microns in diameter (PM10); PM up to 2.5 microns in diameter (PM2.5); ozone; total VOCs, target chemicals listed in CDPH Standard Method v1.1, Table 4-1, except formaldehyde; and carbon monoxide (CO).
5. Building flush-out.
 - a. Another acceptable means of reducing indoor pollutants after construction has been completed is to flush the building (or project area) with a minimum of 14,000 cu.ft. of outdoor air per sq.ft. of gross floor area. This amounts to operating a typical HVAC system at 100 percent outdoor air for approximately 2 weeks. For optimum results, the space temperature should be maintained at a minimum of 60°F and a maximum of 80°F. Space relative humidity during the flush-out process should be no higher than 60 percent.
6. Thermal comfort.
 - a. Comfort conditions for humans are subject to six primary variables: surface temperature, air temperature, relative humidity, air movement, metabolic rate, and clothing. Comfort conditions are also a matter of personal preference and a certain percentage of

dissatisfied building occupants can be expected for any indoor environmental condition. Minimizing this percentage of building occupants is the goal of sustainable HVAC design as it relates to thermal comfort. Providing occupants with the ability to control air temperature, relative humidity, air speed, and radiant temperature for their individual spaces or shared group spaces can reduce the percentage of dissatisfied building occupants. Since it is not possible to achieve an indoor environmental condition that is acceptable for all building occupants, *ASHRAE Standard 55-2013 Thermal Comfort Conditions for Human Occupancy* has defined an acceptable indoor environment as one in which 80 percent of occupants are satisfied. Achieving acceptable thermal comfort conditions in buildings is a part of sustainable HVAC system design because workers' satisfaction and productivity increase with improved thermal comfort in buildings.

7. Acoustic performance.

- a. Background noise of HVAC systems is the only acoustic performance consideration of the LEED rating system that is related to building HVAC systems.
- b. Building HVAC systems are to be designed to meet the background noise levels specified in 2011 *ASHRAE Handbook—HVAC Applications*, Chapter 48, Table 1; *AHRI Standard 885-2008*, Table 15; or a local equivalent. Noise levels are to be calculated or measured.

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Part 41: New Technologies for HVAC Systems

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41.01. Variable Refrigerant Flow Systems

A. Introduction

1. Variable refrigerant flow (or VRF) systems utilize refrigerant as the working fluid to provide heating and cooling in the same way that conventional refrigeration systems do, with the exception that the refrigerant flow within the system can be modulated through a variable speed drive on the compressor motor. This modulation of refrigerant flow enables VRF systems to closely match the refrigeration system capacity to the heating or cooling load on the system. Variable speed condenser fan motors also improve the load matching capabilities of these systems. VRF systems also utilize circuiting manifolds which enable multiple indoor fan-coil units to be connected to a single outdoor unit. For some manufacturers, one outdoor unit can serve up to 50 indoor fan-coil units.

B. VRF Heat Pump and Energy Recovery Systems

1. VRF heat pump systems.
 - a. VRF heat pump systems can provide either heating or cooling to all of the indoor fan-coil units served by a single outdoor unit.
2. VRF energy recovery systems.
 - a. VRF energy recovery systems can simultaneously provide heating to some indoor fan-coil units and cooling to other indoor fan-coil units, all of which are served by the same outdoor unit. This exchange of energy from spaces requiring heating to spaces requiring cooling, and vice versa, reduces the use of purchased energy for the system.

C. Equipment Configurations

1. Indoor fan-coil units.

- a. Indoor fan-coil unit configurations include: ceiling-recessed cassettes, wall-mounted, ceiling-suspended, ceiling-concealed ducted, and vertical ducted units. Figures 41.1 through 41.6 illustrate these fan-coil unit configurations.



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Figure 41.1. CEILING-RECESSED CASSETTE, FOUR-WAY BLOW. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)



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Figure 41.2. CEILING-RECESSED CASSETTE, ONE-WAY BLOW. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)



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Figure 41.3. WALL-MOUNTED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)



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Figure 41.4. CEILING-SUSPENDED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)



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Figure 41.5. CEILING-CONCEALED DUCTED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

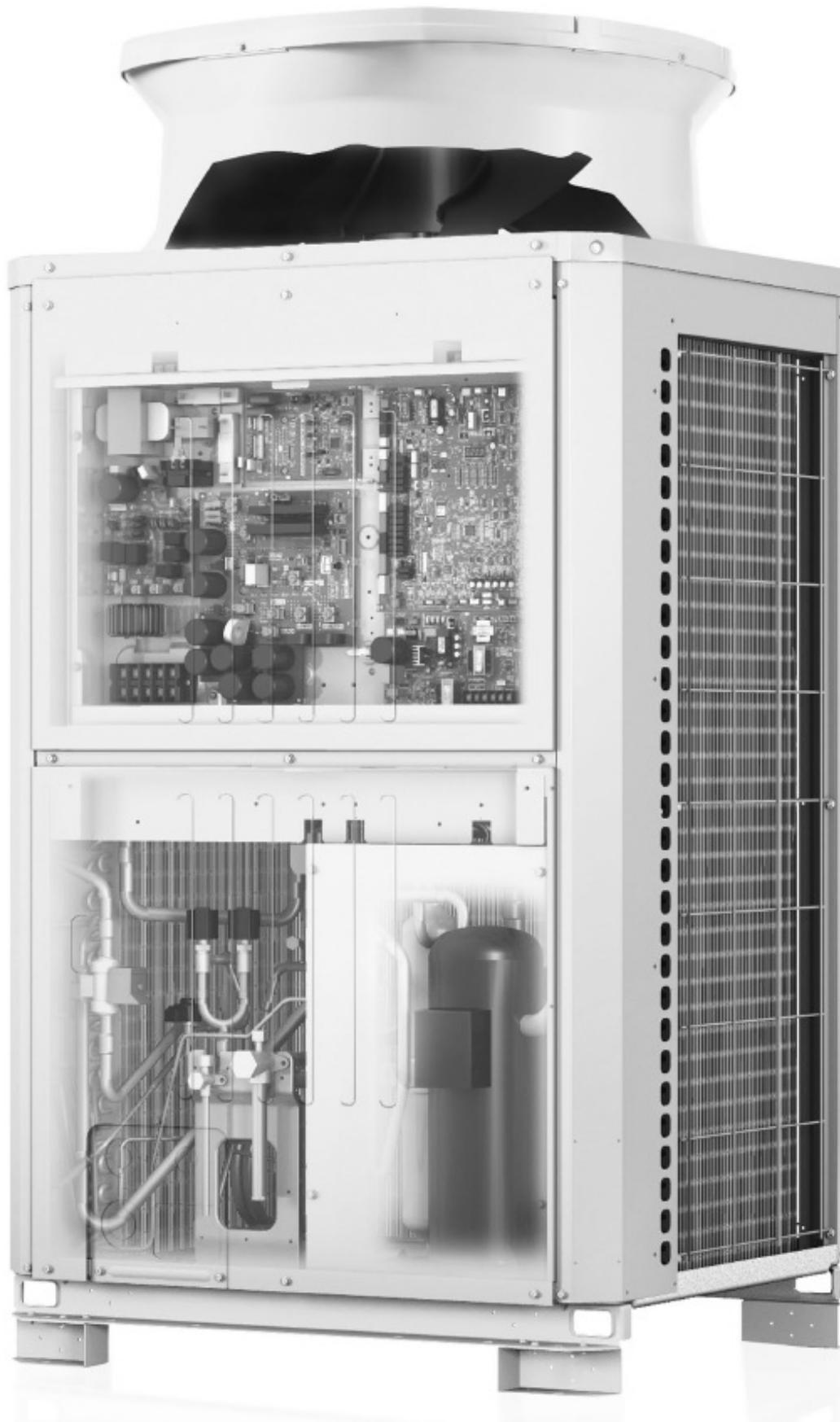


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Figure 41.6. VERTICAL DUCTED FAN-COIL UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

2. Outdoor units.

- a. The capacity of a single outdoor module is limited to about 25 tons; however, two or three modules can be combined through the use of a twinning kit in order to increase the capacity of the outdoor unit. Figure 41.7 illustrates a typical outdoor unit.

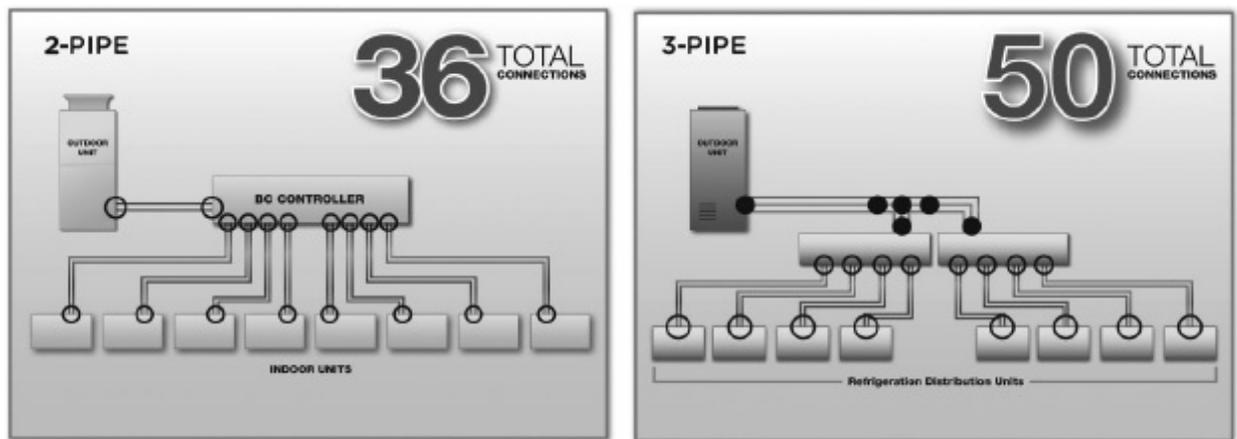


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Figure 41.7. TYPICAL VRF OUTDOOR UNIT. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

3. Refrigerant piping.

- a. Some manufacturers utilize three pipes between the refrigerant piping manifold and the outdoor unit, while other manufacturers utilize two pipes. Figure 41.8 illustrates the two-pipe and three-pipe configurations.



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Figure 41.8. TWO-PIPE AND THREE-PIPE CONFIGURATIONS. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

4. Air-source and water-source heat rejection/absorption
- a. Heat rejection/absorption can be accomplished through air-source equipment located outdoors, or through water-source equipment located indoors that receives cooling/heating water from an external heat rejection/absorption system. Figure 41.9 illustrates a water-source heat exchanger.



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Figure 41.9. WATER-SOURCE HEAT EXCHANGER. ((c) 2015 Mitsubishi Electric US. All Rights Reserved.)

- b. Manufacturers have improved the heating capabilities of the outdoor air-source heat pump units so that approximately 85 percent of the heating capacity at 47°F is available at -13°F. High heating capacity heat pump units are also available which provide 100 percent of the heating capacity at -4°F.
5. Air conditioning condensate.
- a. Condensate that is formed on the cooling coil of the indoor fan-coil units

and in the circuiting manifolds must be drained to the outdoors or to the building storm water system. Indoor fan-coil units are equipped with condensate pumps which are capable of between 20 and 33 inches of lift.

6. Controls.

- a. Wireless or hardwired room temperature sensors are available to control the indoor fan-coil units. (One temperature sensor is required for each fan-coil unit.) These controls can be networked to a central, stand-alone, proprietary, web-interface control system. The VRF control system can also be connected to a building automation system through a LonWorks or BACnet gateway.

7. System efficiency.

- a. VRF energy recovery systems are capable of obtaining an integrated energy efficiency ratio (IEER) rating as high as 22.1 (based on AHRI 1230 test method). Actual system efficiency will depend upon the level of energy recovery that can be achieved. Care must be taken during the design of VRF energy recovery systems to ensure that simultaneous heating and cooling is required by the zones served by the VRF system in order to maximize the system efficiency.

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41.02. Variable Frequency Drives for Chillers

- A. Variable frequency drives (VFDs), also called variable speed drives (VSDs), adjustable frequency drives (AFDs), or adjustable speed drives (ASDs) have been used for many years in the HVAC industry to control the speed of fans and pumps because of the energy savings that can be achieved during part-load operation.**
- B. VFDs are now being used by HVAC equipment manufacturers to control the speed of compressors in both water- and air-cooled chillers to achieve part-load energy savings as well.**
- C. VFDs can be used on scroll, helical rotary (or screw), and centrifugal compressors.**
- D. Application**
 1. For both scroll and screw compressors, refrigeration capacity is proportional to compressor speed. Therefore, VFDs can be the sole means of capacity control for these types of compressors. Other means of capacity control are

available for scroll and screw compressor, such as compressor cycling, digital on/off, and hot gas bypass. Slide valve control is available for capacity control of screw compressors. However, VFDs provide the greatest energy savings at part-load operation for both scroll and screw compressors.

2. For centrifugal compressors, refrigeration capacity can be varied not only by compressor speed, but also by guide vanes on the inlet of the impeller. The inlet guide vanes control the flow rate of refrigerant through the compressor, while the compressor speed determines the differential pressure across the compressor. Since both refrigerant flow and differential pressure affect a chiller's capacity, VFDs are commonly used in conjunction with inlet guide vanes on centrifugal compressors. Compressor cycling and hot gas bypass can also be used for capacity control of centrifugal compressors, but the use of VFDs coupled with inlet guide vanes provides the greatest energy savings at part-load operation.
3. Because only refrigerant lift (temperature difference between the condenser and evaporator conditions) is affected by the speed of a centrifugal compressor, variable-speed centrifugal chillers should be used in conjunction with a reduction in the temperature of entering condenser water in water-cooled chillers in order to maximize the energy-efficiency associated with their capacity control capabilities.
4. Using a fixed entering condenser water temperature, such as 85°F, can negate the savings that can be achieved by using VFDs on the compressors for water-cooled chillers.
5. For multiple-chiller plants, it is common to utilize one (or more) constant-speed chiller(s) and one variable-speed chiller. In this design, the constant-speed chiller(s) are staged while the capacity of the variable-speed chiller is controlled to meet the cooling load.

E. Other Considerations

1. It is important to note that the full-load efficiency of a variable-speed chiller is actually lower than the full-load efficiency of the same constant-speed chiller because the VFD introduces an additional electric efficiency loss. Care must be taken during the chiller plant design to ensure that the variable-speed chiller operates predominantly at part-load in order to maximize its energy efficiency.

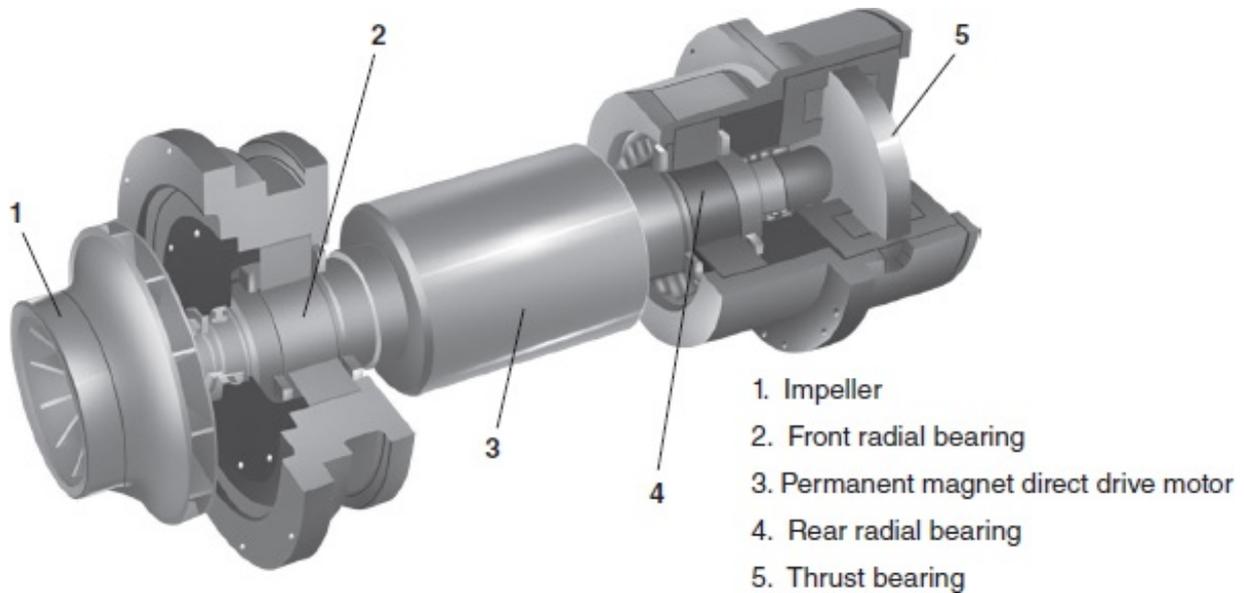
2. The full-load energy efficiency rating of a chiller (either energy efficiency ratio [EER] or coefficient of performance [COP]) should not be the sole criterion for comparing the energy-efficiency of variable-speed and constant-speed chillers. Integrated part load value (IPLV) or nonstandard part load value (NPLV) should be used instead because these performance characteristics also take into consideration the energy-efficiency of the chillers at part-load operation. IPLV and NPLV will provide a better relative measure of a chiller's annual energy use. For example, a chiller with an IPLV of 20 Btuh/W will use approximately 5 percent less energy on an annual basis than a chiller with an IPLV of 19 Btuh/W.
3. Chillers utilizing VFDs on the compressors are able to achieve lower sound levels at part-load conditions than constant-speed chillers.
4. VFDs are capable of handling voltage dips, surges, and other imbalances in the electrical distribution system.
5. As with all VFDs, harmonic distortion must be addressed by the VFD manufacturer to meet the IEEE 519 requirement for less than 5 percent total demand distortion.

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41.03. Magnetic Bearings for Centrifugal Compressors

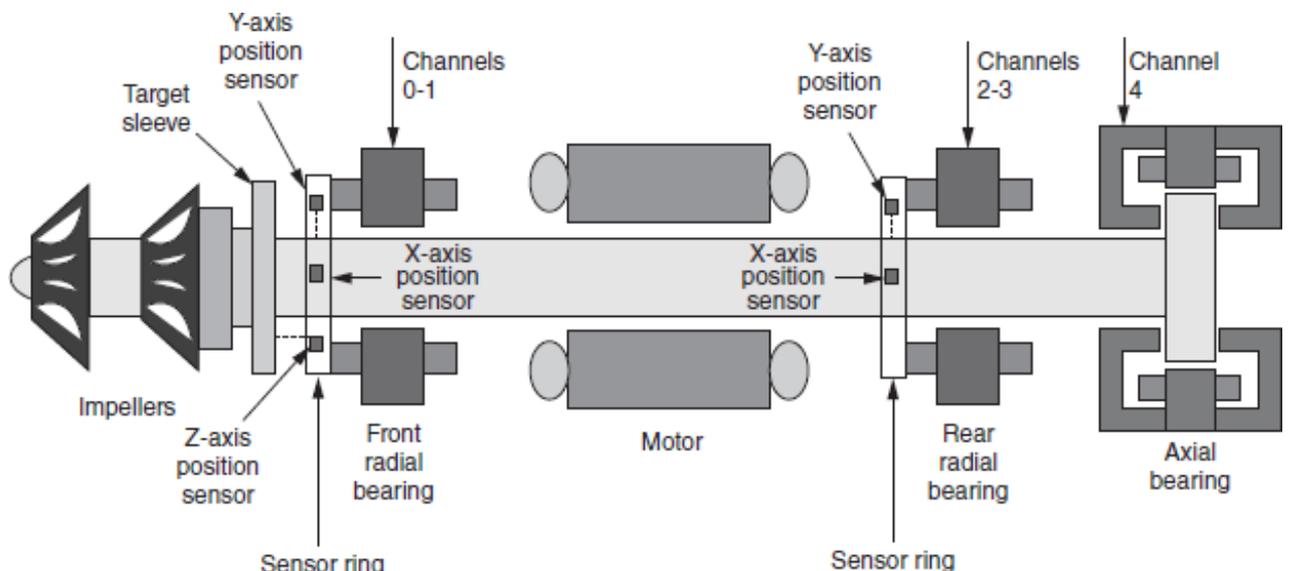
A. Description

1. Magnetic bearings levitate the centrifugal compressor shaft in a magnetic electric field instead of utilizing oil-lubricated bearings.
2. When coupled with a direct drive motor, the use of magnetic bearings results in a totally oil-free compressor.
3. Sensors are required at each magnetic bearing to provide real-time feedback to the bearing control system.
4. In the event of a power failure, the compressor motor acts as a generator and provides power to the bearing control system during coast down.
5. A system is required to gently de-levitate the compressor shaft.
6. Figures 41.10 through 41.12 illustrate the magnetic bearing technology.



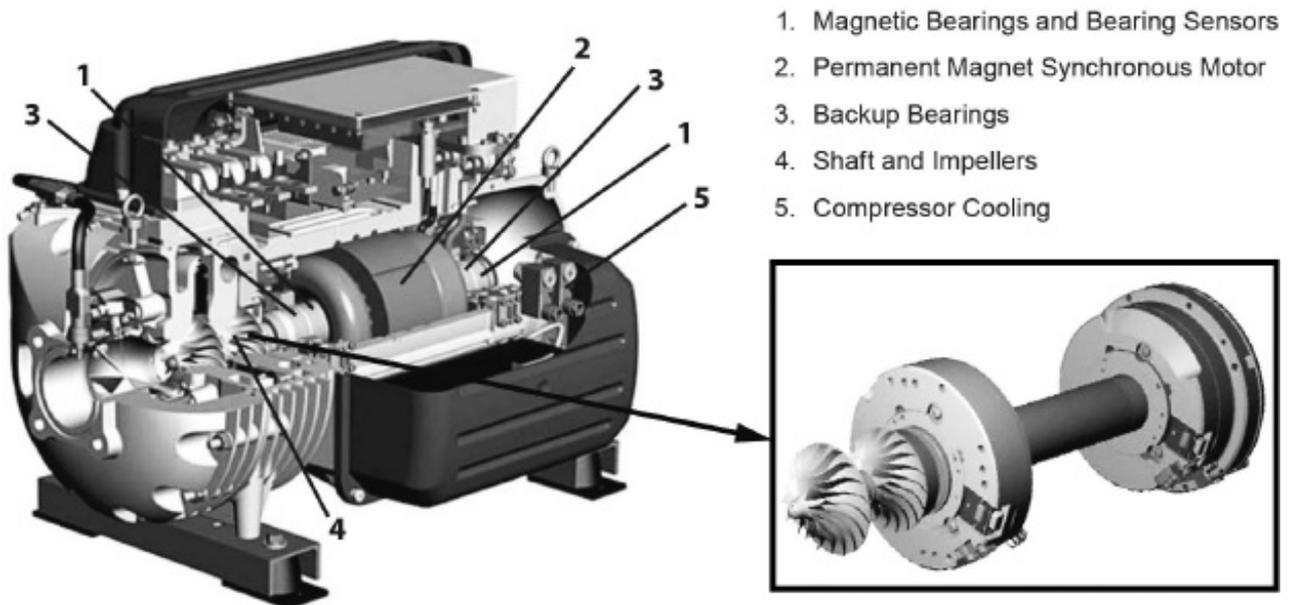
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Figure 41.10. CUT-AWAY VIEW OF COMPRESSOR SHAFT. (Daikin Applied Americas Inc.)



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Figure 41.11. SCHEMATIC DIAGRAM OF COMPRESSOR SHAFT. (Daikin Applied Americas Inc.)



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Figure 41.12. CUT-AWAY VIEW OF COMPRESSOR. (Daikin Applied Americas Inc.)

B. Benefits

1. Reduced frictional losses within the bearing system.
2. Improved reliability and reduced maintenance cost due to oil-free operation.
 - a. No need for oil-handling equipment, such as oil pumps, oil reservoirs, oil coolers, oil filters, water regulating valves, oil relief valves, oil system controls, starter, piping, heaters, etc.
 - b. No possibility of oil loss at light loads.
 - c. No need for oil system maintenance such as oil sampling, oil and filter changes, and oil leak repairs.
 - d. No need for oil storage and disposal.
3. Consistent efficiency over the life of the equipment since there is no oil to coat heat transfer surfaces.
4. Lower compressor vibration that could be transmitted to the structure.
5. Lower compressor sound level compared to traditional centrifugal chillers.

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41.04. Electronically-Commutated Motors (ECMs) for Fans and Pumps

A. Description

1. Electronically-commutated, or brushless DC permanent-magnet, motors use the same principle as AC motors—interaction of rotating magnetic fields in the rotor (rotating member in the motor) and stator (stationary members in the motor).
2. Electronically-commutated motors (ECMs) are more energy efficient than the traditional shaded pole and permanent-split capacitor (PSC) AC motors commonly used in the fractional horsepower (less than 1 hp) size range. Fractional horsepower ECMs are approximately 70 percent efficient; whereas, fractional horsepower PSC motors are approximately 50 percent efficient.
3. ECMs are not only more efficient at full-load, the efficiency difference is even greater at part-load. This gives ECMs a decided advantage over traditional AC motors in variable speed applications.
4. In addition to greater energy efficiency, ECMs have the advantages of quieter operation, greater output power, higher operating speeds, and longer service life.
5. The disadvantages of ECMs are that they have a higher first cost than traditional AC motors and also create disruptive harmonic currents in the electrical power distribution system which can overheat conductors and connectors and can also interfere with the operation of sensitive electronic equipment.

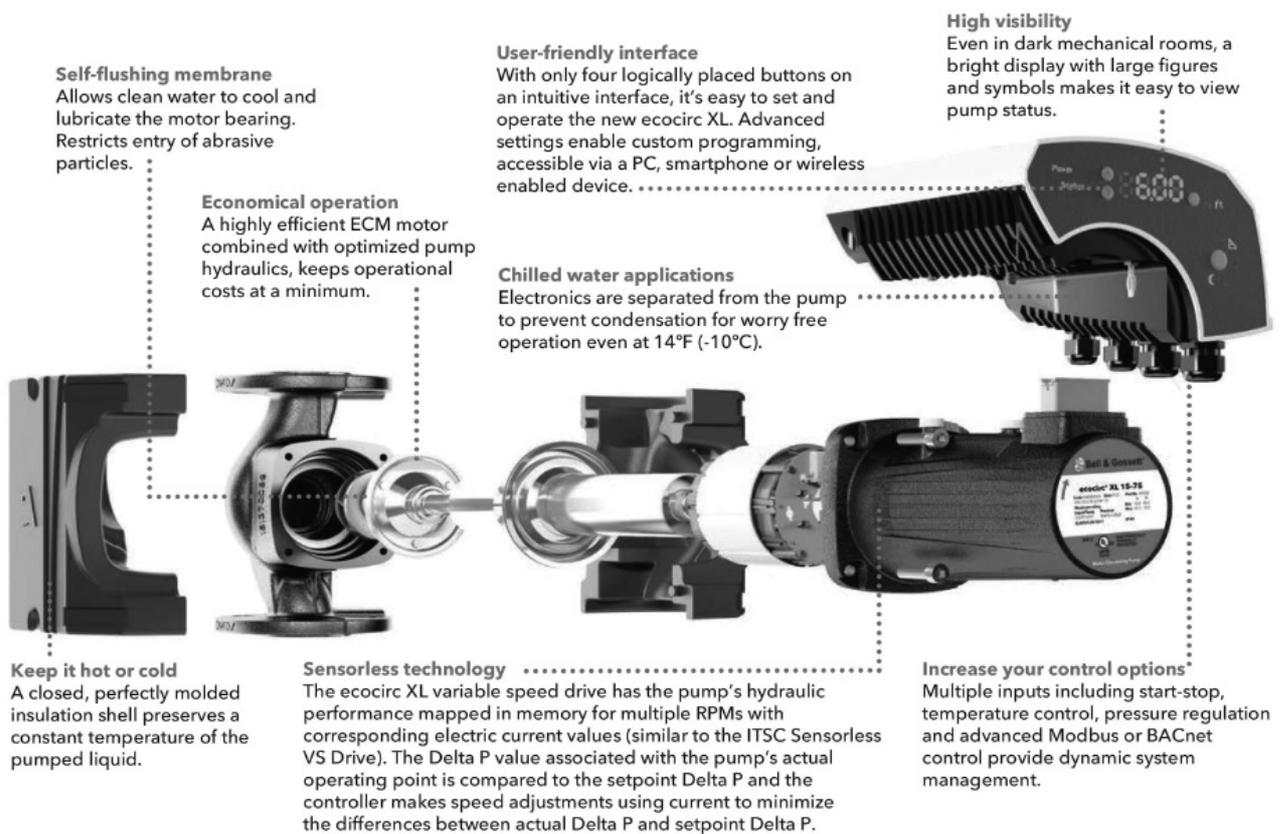
B. Applications

1. ECMs are now a commonly available option for fan-powered VAV terminal units and small fan-coil units (up to about 800 CFM). Thermostats which enable variable speed operation of the fan motors take advantage of the higher efficiencies of ECMs at part load than traditional AC motors.
2. ECMs are also available for fractional horsepower pumps for heating, cooling, and domestic hot water applications. One pump manufacturer incorporates a variable speed drive into the pump motor to provide constant speed, constant differential pressure, or proportional differential pressure operation. Pump control is accomplished without the use of external sensors, but rather by the pump control system which continuously monitors the electric current draw of the motor and adjusts the motor speed accordingly based on the pump's hydraulic performance which is mapped into memory. [Figures 41.13](#) and [41.14](#) illustrate this type of pump.



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Figure 41.13. INTEGRAL VARIABLE SPEED DRIVE FOR FRACTIONAL HORSEPOWER PUMP. (Xylem AWS)



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Figure 41.14. EXPLODED VIEW OF PUMP, MOTOR, AND DRIVE. (Xylem AWS)

41.05. New Technologies for Small Packaged Rooftop Units

A. New Energy-Efficient Options

1. Many of the options previously available only for large packaged, and custom rooftop units (20 tons and larger) are now available for small packaged rooftop units in the 3 to 15 ton range. These options include: variable speed supply and exhaust fans (through the use of electronically-commutated motors), single-zone and multiple-zone variable air volume operation, variable speed condenser fans (through the use of electronically-commutated motors), electronic expansion valve, outdoor airflow monitoring and control, variable speed drives for the compressors, and an energy recovery wheel. These options significantly increase the energy efficiency of these units, particularly at part-load operation.

B. Other New Options

1. Other options that are now available in this size range include a modulating hot gas reheat coil for humidity control, and 2-inch and 4-inch filter racks for a filtration efficiency as high as MERV 14.

C. Standard Options

1. Other options that are not new for this size range include integrated airside economizer; communication to a building automation system through BACnet, LonWorks, or a manufacturer-specific communications protocol; natural gas, electric, or hot water heating coil; single-point electrical connection; unit-powered ground fault circuit interrupter-type receptacle; nonfused safety switch; and a field-erected roof curb.

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Part 42: Plastic Piping Systems

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42.01. Cross-Linked Polyethylene (PEX or XLPE)

A. Description

1. High density polyethylene plastic pipe cross-linked during or after extrusion of the piping. Cross-linking improves the temperature limitations of the material.

B. Uses

1. Domestic hot and cold water systems.
2. Radiant heating systems.
 - a. PEX-AL-PEX—Aluminum tube laminated between interior and exterior layers of plastic.
3. Available in sizes from 1/4 in. to 4 in.
4. Red and blue piping used for domestic hot and cold water, respectively.

C. Advantages

1. Flexible.
2. Scale, chlorine, and corrosion resistant.
3. Fewer joints. PEX piping can be run continuously from source to outlet.
4. Less costly material than copper tubing.
5. Less costly installation than copper tubing.

6. Won't develop "pinhole" leaks.
7. Approved for use in domestic water piping systems in all 50 states of the United States as well as Canada.

D. Disadvantages

1. Costly crimping tools required for fittings.
2. Degradation from ultraviolet radiation.
3. Dezincification in yellow brass fittings having 30 percent zinc content. Red brass fittings are recommended which have 5 to 10 percent zinc content.

E. Temperature Limitations

1. Maximum operating temperature of 180°F.

F. Pressure Limitations

1. 100 psi maximum nonshock operating pressure at 180°F.

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42.02. Polypropylene (PP)

A. Description

1. Chemically inert thermoplastic polymer.

B. Uses

1. Domestic hot and cold water systems.
2. High purity water systems.
3. Clean chemical processes.
4. Pharmaceutical operations.
5. Food processing.
6. Available in sizes from 1/2 in. to 6 in.

C. Advantages

1. Corrosion and chemical resistant.
2. Impact resistant.
3. Joined by heat fusion rather than gluing.

D. Disadvantages

1. Degradation from ultraviolet radiation.

E. Temperature Limitations

1. Maximum operating temperature of 180°F.

F. Pressure Limitations

1. 4" Schedule 80 PP pipe with thermo-seal joints:
 - a. 160 psi maximum nonshock operating pressure at 73°F.
 - b. 104 psi maximum nonshock operating pressure at 140°F.
2. Smaller pipe sizes have higher pressure ratings and larger pipe sizes have lower pressure ratings.

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42.03. Polyvinyl Chloride (PVC)

A. Description

1. Thermoplastic polymer.

B. Uses

1. Sanitary (sewage) systems.
2. Intake and exhaust piping for high efficiency condensing water heaters.
3. Schedule 80 piping—chilled water systems.
4. Available in sizes from 1/4 in. to 12 in.

C. Advantages

1. Light weight.
2. Low cost.
3. Corrosion and chemical resistant.
4. Ease of joining.

D. Disadvantages

1. Brittle.

E. Temperature Limitations

1. Maximum operating temperature of 140°F.

F. Pressure Limitations

1. 12" Schedule 40 PVC pipe with solvent cemented joints:
 - a. 130 psi maximum nonshock operating pressure at 73°F.
2. Smaller pipe sizes have higher pressure ratings and larger pipe sizes have lower pressure ratings.

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42.04. Chlorinated Polyvinylchloride (CPVC)

A. Description

1. Thermoplastic produced by chlorination of polyvinyl chloride.

B. Uses

1. Domestic hot and cold water systems.
2. Sprinkler systems.
3. Available in sizes from 1/4 in. to 12 in.

C. Advantages

1. Higher temperature limitation than PVC.
2. Low cost.
3. Corrosion and chemical resistant.
4. Ease of joining.
5. More ductile than PVC.

D. Disadvantages

1. Degradation from ultraviolet radiation.
2. Brittle.

E. Temperature Limitations

1. Maximum operating temperature of 210°F.

F. Pressure Limitations

1. 6" Schedule 40 CPVC pipe with solvent cemented joints:
 - a. 180 psi maximum nonshock operating pressure at 73°F
 - b. 99 psi maximum nonshock operating pressure at 140°F.

2. Smaller pipe sizes have higher pressure ratings and larger pipe sizes have lower pressure ratings.

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42.05. High-Density Polyethylene (HDPE)

A. Description

1. Linear polymer prepared from ethylene by a catalytic process.

B. Uses

1. Geothermal systems.
2. Irrigation systems.
3. Sprinkler systems.
4. Industrial systems.
5. Available in sizes from 3/4 in. to 24 in. Available in coils through 6".

C. Advantages

1. Nontoxic.
2. Corrosion, abrasion, and chemical resistant.
3. Durable and light weight.
4. Carbon black is added to provide ultraviolet protection.
5. Joined by heat fusion rather than gluing.

D. Disadvantages

1. Non-UV stabilized pipe degrades from ultraviolet radiation.

E. Temperature Limitations

1. Maximum operating temperature of 122°F.

F. Pressure Limitations

1. 4" Type IV HDPE pipe with butt fused joints:
 - a. 232 psi maximum nonshock operating pressure at 68°F.
 - b. 93 psi maximum nonshock operating pressure at 122°F.
2. Larger pipe sizes have lower pressure ratings.

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Part 43: Noise and Vibration Control

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43. Part 43: Noise and Vibration Control

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43.01. Noise Control

A. Indoor Noise Control

1. Mechanical equipment rooms.
 - a. Locate mechanical equipment rooms away from noise-sensitive areas.
 - b. Design spaces such as corridors and storage rooms around mechanical equipment rooms that can be used as buffer zones for noise control.
 - c. Design walls of mechanical equipment rooms to be constructed of concrete masonry units.
 - d. Design mechanical chases terminating in mechanical equipment rooms to be closed at the mechanical equipment room.
 - e. Specify sleeves for all duct and pipe penetrations of mechanical equipment room walls, floors, ceilings, and mechanical chase enclosures. The gap between the pipe or duct and the sleeve should be packed with an appropriate material and caulked.
 - f. Specify rubber flexible pipe connectors for piping connections to pumps and chillers.
 - g. Specify noise suppressors for steam pressure reducing valves where recommended by the manufacturer.
2. Fans and air handling units.

- a. Design flexible duct connectors for all duct connections to fans and air handling units.
- b. Design duct silencers (sound attenuators) for supply and return air duct connections to air handling units.
- c. Consider the use of round or oval ductwork for the first 20 feet of ductwork. This will reduce low frequency breakout noise from the equipment.
- d. Keep the aspect ratio of the ductwork near the equipment as low as possible.
- e. Select fans at their point of maximum efficiency.
- f. Minimize the system effect of ductwork connected to fans and air handling units.
- g. For VAV systems, select fans for maximum efficiency at 70 to 80 percent of maximum airflow, which is the airflow at which the system will operate most of the time.
- h. Locate equipment away from noise-sensitive areas inside the building.
- i. Where rooftop units need to be located over noise-sensitive areas, design concrete pads under the units and/or design acoustical material in the areas directly beneath the condensing sections. Only the supply and return air ducts for each rooftop unit should penetrate the acoustical material and roof deck within the curb perimeter. Openings around the supply and return air duct penetrations should be sealed once the ducts are installed.

3. Ductwork.

- a. Do not exceed airflow velocities of: 950 fpm for ducts within occupied spaces, 1,200 fpm for ducts above suspended ceilings, 1,700 fpm for ducts in shafts, and 2,000 fpm for supply air ducts upstream of VAV terminal units.
- b. Maintain at least four to five duct diameters of straight duct between duct fittings, such as elbows and branch takeoffs.
- c. Specify turning vanes for all duct elbows.
- d. Design open-end ductwork for a maximum of 500 fpm airflow velocity

through the opening.

- e. Design open-end return air ductwork to have at least one elbow or tee between the opening and the air handling unit.
- f. Design transfer air ducts to be sound-lined and have a Z-configuration.

4. VAV terminal units.

- a. Locate fan-powered VAV terminal units over areas that are not noise-sensitive, such as corridors and storage rooms.
- b. For most applications, select VAV terminal units for a maximum noise criterion of NC 30 (incorporating sound attenuating effects from the room).
- c. Design 5 feet of sound-lined ductwork or specify duct silencers downstream of VAV terminal units.

5. Diffusers, registers, and grilles.

- a. For most applications, select diffusers, registers, and grilles for a maximum noise criterion of NC 30 (incorporating sound attenuating effects from the room).
- b. Do not exceed airflow velocities at the neck of supply and return air diffusers, registers, and grilles of: 425 fpm for supply air outlets, and 500 fpm for return and exhaust air inlets.
- c. Design insulated flexible ducts for final connections to diffusers, registers, and grilles installed above suspended ceilings. Maximum length of flexible ducts should be 8 feet. Keep flexible ducts straight with long radius bends. Avoid abrupt bend at connection to diffusers, registers, and grilles.
- d. Design branch takeoffs from duct mains that are at least 5 feet long for final connections to diffusers, registers, and grilles. Avoid direct connections of diffusers, registers, and grilles to duct mains.
- e. Locate balancing dampers at least 5 feet away from diffusers, registers, and grilles.
- f. Do not use dampers at the neck of diffusers and registers for significant throttling of airflow.

B. Outdoor Noise Control

1. Outdoor equipment.

- a. Locate equipment away from noise-sensitive areas outside of the building.
- b. Specify manufacturer-furnished sound attenuating devices, such as compressor enclosures and oversized condenser fans, when available.
- c. Design sound barriers around equipment, maintaining all required clearances between equipment and barrier.
- d. Ensure that noise at the property lines generated by mechanical equipment (usually expressed in terms of A-weighted sound pressure [dBA]) is below the daytime and nighttime limits of the local noise ordinance.

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43.02. Vibration Control

A. Mechanical Equipment

1. Specify vibration isolation for all reciprocating and rotating equipment connected to the structure.
 - a. Specify vibration isolation hangers for all equipment that is suspended from the building structure.
 - b. Specify vibration isolators and bases for all floor-mounted equipment. Refer to the 2011 *ASHRAE Handbook—HVAC Applications*, Chap. 48, Table 47, for complete information on recommended vibration isolation for floor-mounted equipment.
 - c. For roofs and floors constructed with open web joists or any unusually light construction, ensure that the isolator deflection is at least 15 times the deflection of the structure that is attributed to the mechanical equipment.
 - d. Avoid both internal and external vibration isolation of air handling units.
2. Specify vibration isolation pipe hangers for all piping in mechanical equipment rooms and for piping within 50 feet of vibration-isolated equipment.
3. Specify vibration isolation roof curbs for rooftop units located above noise-sensitive areas.

B. Piping Risers

1. Locate pipe risers away from noise sensitive areas so that pipe anchors and

guides rigidly attached to the building structure to accommodate pipe expansion do not need to be vibration isolated.

2. Completely spring-isolated piping riser systems must be carefully designed to avoid overstressing the piping due to movements in the riser and branch takeoffs.

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43.03. Sound Information

VELOCITY OF SOUND IN VARIOUS MEDIA

Medium	Velocity	
	Feet per Second	Miles per Hour
Rubber	310	211
Air	1,130	770
Water Vapor	1,328	905
Cork	1,640	1,118
Lead	4,026	2,745
Water	4,625	3,153
Wood	10,825	7,380
Brass	11,480	7,827
Copper	11,670	7,957
Brick	11,800	8,045
Concrete	12,100	8,250
Wood	12,500	8,523
Steel and Iron	16,000	10,909
Glass	16,400	11,181
Aluminum	19,000	12,955

VOICE LEVEL COMPARISON AT VARIOUS DISTANCES

Distance Feet	Normal Voice Level dB	Raised Voice Level dB	Very Loud Voice dB	Shouting Voice dB
1	70	76	82	88
3	60	66	72	78
6	54	60	66	72
12	48	54	60	66
24	42	48	54	60

DIRECTIONAL EFFECT ON SOUND

Direction of Sound Source with Respect to Listener	Decrease in Speech Energy
Face to Face	0 dB
30 Degree Rotation Away	1.5
60 Degree Rotation Away	3.0
90 Degree Rotation Away	4.5
120 Degree Rotation Away	6.0
150 Degree Rotation Away	7.5
180 Degree Rotation Away Source Turned Away from Listener	9.0

TYPICAL SOUND LEVELS

Pressure Level dB	Typical Sound	Subjective Impression
150	Jet plane take-off Military jet take-off at 100 ft.	Short exposure can cause hearing loss.
140		
130	Artillery fire at 10 ft. Machine gun	Deafening (threshold of pain)
120	Siren at 100 ft.	

Pressure Level dB	Typical Sound	Subjective Impression
110	Jet plane (passenger ramp) Thunder Sonic boom	Threshold of discomfort
100	Wood working shop Accelerating motorcycle Hard rock band 75-piece orchestra	Very loud
90	Truck unmuffled Train whistle Kitchen blender Pneumatic jackhammer Shouting at 5 ft.	
80	Printing press Subway (rubber wheels) Noisy office Computer printout room Average factory	Loud Intolerable for phone use
70	Average street noise Quiet typewriter Freight train at 100 ft. Average radio Speech at 3 ft.	Loud
60	Noisy home Average office Normal conversation at 3 ft.	Loud Unusual background
50	General office Quiet office Quiet radio, window AC unit Average home	Moderate

Pressure Level dB	Average home Typical Sound Quiet street	Subjective Impression
40	Private office Quiet home/residential area	Moderate
30	Quiet conversation Broadcast studio	Noticeably quiet
20	Empty auditorium Whisper Watch ticking Buzzing inset at 3 ft. Rural ambient	Very quiet
10	Rustling leaves Soundproof room Human breathing	Very faint Threshold of good hearing
0		Intolerably quiet Threshold of audibility (youthful hearing)

TYPICAL NOISE LEVELS

Equipment	dBA
Saturn rocket	200
Turbo jet engine	170
Jet plane/aircraft at take-off, inside jet engine test cell	150
Turbo propeller plane at take-off, military jet take-off at 100 ft.	140
Large pipe organ, artillery fire at 10 ft., machine gun	130
Jolt squeeze hammer	122
Small aircraft engine, siren at 100 ft., jet plane (passenger ramp), thunder, sonic boom, threshold of feeling (pain)	120

Equipment	dBA
Blaring radio, wood working shop, accelerating motorcycle, hard rock band, 75-piece orchestra, chain saw	110
Vacuum pump, large air compressor	108
Positive displacement blower, air hammer	107
Magnetic drill press, air chisel, high-pressure gas leak	106
Banging of steel plate, wood planer	104
Air compressor, automobile at highway speed, subway (steel wheels), propeller plane, outboard motor, loud street noise, power lawn mower, helicopter	100
Turbine condenser, welder, punch press, riveter, power saws, plastic chipper	98
Small air compressor, airplane cabin normal flight	94
Heavy duty grinder	93
Heavy diesel powered vehicle, spinning machines-looms, noisy street	92
Voice, shouting, truck unmuffled, train whistle, kitchen blender, pneumatic jackhammer, shouting at 5 ft., noisy factory, blender	90
Printing press, inside average rail road car, toilet flushing	86
Garbage disposal, printing press, subway (rubber wheels), noisy office, computer printout room, average factory, lathe, police whistle, telephone ring, clothes washer, dish	80

washer, IV-loud Equipment	dBA
Voice—conversational level, average street noise, quiet typewriter, freight train at 100 ft., average radio, speech at 3 ft., inside average automobile, clothes dryer, vacuum cleaner, TV-soft	70
Electronic equipment ventilation fan, noisy home, average office, normal conversation at 3 ft., hair dryer	60
Office air diffuser, general office, quiet office, quiet radio, window AC unit, average home, quiet street	50
Small electric clock, private office, quiet home/residential area, refrigerator, bird singing, wilderness ambient, agricultural land	40
Voice, soft whisper, quiet conversation, broadcast studio	30
Rustling leaves, empty auditorium, whisper, watch ticking, buzzing inset at 3 ft., rural ambient	20
Human breath, sound proof room, rustling leaves	10
Threshold of hearing	0

SUBJECTIVE EFFECT OF CHANGES IN SOUND CHARACTERISTICS

Change in Sound Pressure Level	Change in Apparent Loudness
1 dB	Insignificant
3 dB	Just perceptible
5 dB	Clearly noticeable
10 dB	Twice or half as loud
15 dB	Significant change
20 dB	Much louder or quieter

DECIBEL ADDITION

Difference between Two Levels dB	Add to Higher Level dB
0	3
1	2.5
2	2
3	2
4	1.5
5	1
6	1
7	1
8	0.5
9	0.5
10	0.5
More than 10	0

ACCEPTABLE HVAC NOISE LEVELS

Space Type	Recommended NC Level	Recommended RC Level	Equivalent Sound Level Meter Readings (A)
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**Scale) dB
Equivalent**

Space Type	NC 25-35 Recommended NC Level	RC 25-35 Recommended RC Level	Sound Level Meter Readings (A Scale) dB
Apartments	NC 25-35	RC 25-35	35-45
Assembly Halls	NC 30-35	RC 30-35	40-45
Churches	NC 30-35	RC 30-35	40-45
Concert and Recital Halls	NC 15-20	RC 15-20	25-30
Courtrooms	NC 30-40	RC 30-40	40-50
Factories	NC 40-65	RC 40-65	50-75
Hospitals and Clinics			
Private Rooms	NC 25-30	RC 25-30	35-40
Wards	NC 30-35	RC 30-35	40-45
Operating Rooms	NC 25-30	RC 25-30	35-40
Laboratories	NC 35-40	RC 35-40	45-50
Corridors	NC 30-35	RC 30-35	40-45
Public Areas	NC 35-40	RC 35-40	45-50
Hotels/Motels			
Individual Rooms/Suites	NC 25-35	RC 25-35	35-45
Meeting/Banquet Rooms	NC 25-35	RC 25-35	35-45
Halls/Corridors/Lobbies	NC 35-40	RC 35-40	45-50
Service/Support Areas	NC 40-45	RC 40-45	50-55
Legitimate Theaters	NC 20-25	RC 20-25	30-35
Libraries	NC 30-40	RC 30-40	40-50
Music Rooms	NC 20-25	RC 20-25	30-35
Movie/Motion Picture Theaters	NC 30-35	RC 30-35	40-45
Offices			
Executive	NC 25-30	RC 25-30	35-40

Space Type	NC Level	RC Level	Equivalent Sound Level Meter Readings (A Scale) dB
Conference Rooms	NC 25-30	RC 25-30	35-40
Private	NC 30-35	RC 30-35	40-45
Open-Plan Offices/Areas	NC 35-40	RC 35-40	45-50
Business Mach/Computers	NC 40-45	RC 40-45	50-55
Public Circulation	NC 40-45	RC 40-45	50-55
Private Residences	NC 25-35	RC 25-35	35-45
Recording Studios	NC 15-20	RC 15-20	25-30
Restaurants	NC 40-45	RC 40-45	50-55
Retail Stores	NC 40-45	RC 40-45	50-55
Schools			
Lecture and Classrooms	NC 25-30	RC 25-30	35-40
Open-Plan Classrooms	NC 35-40	RC 35-40	45-50
Sports Coliseums	NC 45-55	RC 45-55	55-65
TV/Broadcast Studios	NC 15-25	RC 15-25	25-35

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44.01. Engineering/Construction Contracts

A. Methods of Obtaining Contracts

1. *Competitive Bidding Contracts.* Contracts in which engineers/contractors are selected on the basis of their competitive bids.
2. *Negotiated Contracts.* Contracts in which engineers/contractors are selected on the basis of ability, reputation, past experience with the owner, or type of project, etc., and fees are then negotiated.

B. Contract Types

1. *Lump Sum Contract.* A contract in which the engineer/contractor agrees to carry out the stipulated project for a fixed sum of money.
2. *Unit Price Contract.* A contract based on estimated quantities of adequately specified items of work, and the costs for these items of work are expressed in dollars per unit of work. For example, the unit of work may be dollars per foot of caisson drilled, dollars per cubic yard of rock excavated, or dollars per cubic yard of soil removed.
 - a. This contract is generally only applicable to construction contracts.
 - b. Unit price contracts are usually used when quantities of work cannot be accurately defined by the construction documents (driving piles, foundation excavation, rock excavation, contaminated soil removal, etc.).

Unit prices may be included in part of a lump sum or other type of contract.

3. *Cost Plus Contracts.* A contract in which the owner reimburses the engineer/contractor for all costs incurred and compensates them for services rendered. Cost plus contracts are always negotiated. Compensation may be based on the following:
 - a. Fixed percentage of the cost of the work (cost plus fixed percentage contract). Compensation is based on an agreed percentage of the cost.
 - b. Sliding-scale percentage of the cost of the work (cost plus sliding-scale percentage contract). Compensation is based on an agreed sliding-scale percentage of the cost (federal income taxes are paid on an increasing sliding scale).
 - c. Fixed fee (cost plus fixed fee contract). Compensation is based on an agreed fixed sum of money.
 - d. Fixed fee with guaranteed maximum price (cost plus fixed fee with guaranteed maximum price contract). Compensation is based on an agreed fixed sum of money and the total cost will not exceed an agreed upon total project cost.
 - e. Fixed fee with bonus (cost plus fixed fee with bonus contract). Compensation is based on an agreed fixed sum of money and an agreed upon bonus is established for completing the project ahead of schedule, under budget, for superior performance, etc.
 - f. Fixed fee with guaranteed maximum price and bonus (cost plus fixed fee with guaranteed maximum price and bonus contract). Compensation is based on an agreed fixed sum of money, a guaranteed maximum price, and an agreed upon bonus is established for completing the project ahead of schedule, under budget, for superior performance, etc.
 - g. Fixed fee with agreement for sharing any cost savings (cost plus fixed fee with agreement for sharing any cost savings contract). Compensation is based on an agreed upon fixed sum of money and an agreed upon method of sharing any cost savings.
 - h. Other fixed fee contracts can be generated using variations on those listed earlier or by negotiating certain aspects particular to the project into a cost plus fixed fee contract with the owner.

4. *Incentive Contracts.* A contract in which the owner awards or penalizes the engineer/contractor for performance of work in accordance with an agreed upon target. The target is often project cost or project schedule.
5. *Liquidated Damages Contracts.* A contract in which the engineer/contractor is required to pay the owner an agreed upon sum of money in accordance with an agreed upon target. The target is often for each calendar day of delay in completion of the project.
 - a. Liquidated damages, when included in the contract, must be a reasonable measure of the damages suffered by the owner due to delay in the completion of the project to be enforceable in a court of law. The owner must also be able to demonstrate and prove the damages suffered due to delay in the completion of the project. Weather, strikes, contract changes, natural disasters, and other events beyond the control of the contractor can void the claim for liquidated damages.
6. *Percentage of Construction Fee Contracts.* A contract in which the engineer's fee is based on an agreed upon the percentage of the project's construction cost.
7. *Scope of Work.* The scope of work is part of the engineer's contract defining the engineer's responsibilities and work required to produce the contract documents required by the owner to get the project built. The engineer's scope of work can be compared to the Contract Documents defining a construction contract.

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44.02. Building Construction Business Players

- A. ***Owner.* The individual (or individuals) who initiates the building design process (may be a business, corporation, developer, hospital, local government, municipality, state government, or federal government).**
- B. ***Architect.* Design team member responsible for internal and external space planning, space sizes, relative location and interconnection of spaces, emergency egress, internal and external circulation, aesthetics, life safety, etc. Generally, the architect is the lead and the driving force behind the project.**

- C. ***Civil Engineers.*** The design team members responsible for site drainage, roadways, parking, site grading, site circulation, retaining walls, site utilities (sometimes done by the mechanical and electrical engineers), etc.
- D. ***Structural Engineers.*** The design team members responsible for building structure (design of beams, columns, foundations, floors, roof). Responsible for making the building stand.
- E. ***Interior Designers.*** The design team members responsible for building finishes (wall coverings, floor coverings, ceilings); often assist with, or are responsible for, space planning. Frequently, this is also done by the architect.
- F. ***Landscape Architect.*** The design team member responsible for interior as well as external plantings (grass, shrubs, trees, flowers), etc.
- G. ***Surveyors.*** Design team members responsible for establishing contours and site boundaries and locating existing benchmarks, trees, roads, water lines, sanitary and storm sewers, electric and telephone utilities, etc.
- H. ***Geologists/Soils Analysts.*** Design team members responsible for establishing soil characteristics for foundation analysis, potential ground water problems, rock formations, etc.
- I. ***Transportation Engineer.*** The design team member responsible for elevators, escalators, dumbwaiters, and other modes of vertical and/or horizontal transportation.
- J. ***Electrical Engineer.*** The design team member responsible for the design of electrical distribution systems, lighting, powering mechanical and other equipment, receptacles, communication systems (telephone, intercom, paging), fire alarm and detection systems, site lighting, site electrical (or civil engineer), emergency power systems, uninterruptible power systems, security systems, etc.
- K. **Mechanical Engineers**
 - 1. ***Plumbing Engineer.*** The design team member responsible for water supply and distribution systems; sanitary, vent, and storm water systems; natural gas systems; medical and laboratory gas and drainage systems;

underground storage tanks; plumbing fixtures; etc.

2. *Fire Protection Engineer.* The design team member responsible for sprinkler and other fire protection systems, standpipe and hose systems, fire pumps, site fire mains, fire extinguishers (sometimes fire extinguishers are designated by the architect), etc.
3. *HVAC Engineer.* The design team member responsible for the design of the heating, ventilating, and air conditioning systems; ductwork and piping systems; automatic temperature control systems; industrial ventilation systems; environmental control; indoor air quality; heat loss and heat gain within the building; human comfort; etc.

L. Contractors

1. *General Contractor.* Also referred to as prime contractor in single-contract construction projects. The general contractor is the construction team member responsible for construction of the building structure and foundations, building envelope, interior partitions, building finishes, roofing, site work, elevators, project schedule, project coordination, project management, etc. The general contractor may subcontract some or all of the work to other contractors. In single-contract projects, the general contractor is also responsible for mechanical and electrical work as well, but this work is most often done by subcontractors.
2. *Mechanical Contractor.* Also referred to as a subcontractor in single-contract construction projects. The mechanical contractor is the construction team member responsible for construction of the building HVAC, plumbing, and fire protection systems. The mechanical contractor may be broken into one, two, or three subcontracts for HVAC and plumbing and/or fire protection. The mechanical contractor may subcontract some or all of the work to other contractors (plumbing, sheet metal, fire protection, automatic temperature controls, etc.).
3. *Electrical Contractor.* Also referred to as a subcontractor in single-contract construction projects. The electrical contractor is the construction team member responsible for construction of the building electrical systems, fire alarm systems, communication systems, security systems, lighting systems, etc. The electrical contractor may subcontract some or all of the work to other contractors (communication, security fire alarm, etc.).

4. *Prime Contractor*. The contractor who signs a contract with the owner to perform the work.
5. *Multiple Prime Contractors*. When more than one contractor signs a contract with the owner to perform the work. Often this is accomplished with four prime contracts as follows, but may be done with any number of contracts:
 - a. General contract.
 - b. Mechanical (HVAC) contract.
 - c. Plumbing/fire protection contract.
 - d. Electrical contract.
6. *Subcontractor*. The contractor or contractors who sign a contract with the general or prime contractor to perform a particular portion of the prime contractor's work.
7. *Sub-Subcontractor*. The contractor or contractors who sign a contract with a subcontractor to perform a particular portion of the subcontractor's work.

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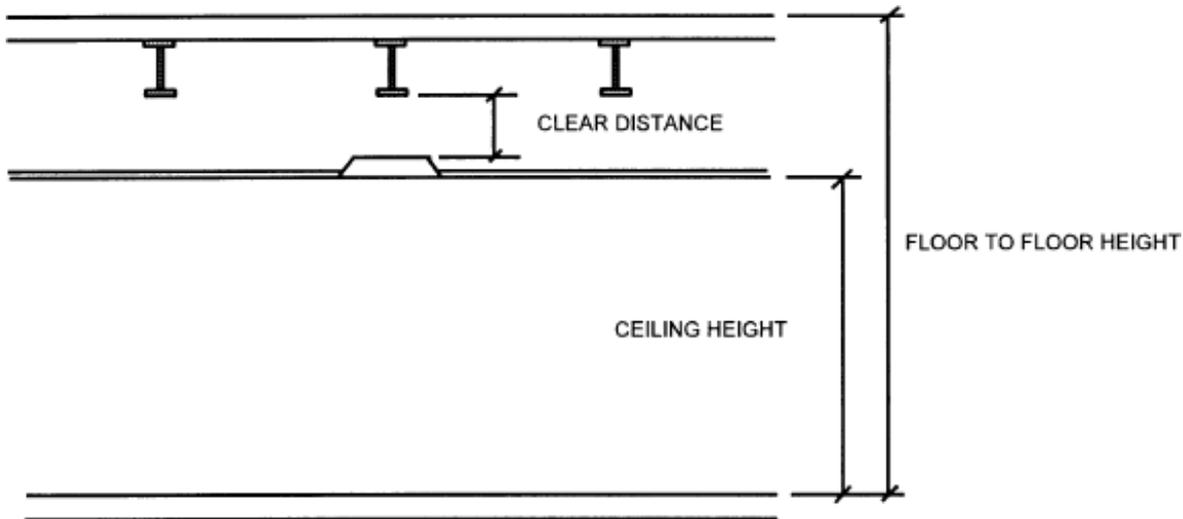
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45.01. Ceiling Plenum Space Requirements



CEILING PLENUM SPACE

Clear Distance—Light to Beam in Inches

Floor to Floor	Ceiling Height	Beam Depth								
		12"	14"	16"	18"	21"	24"	27"	30"	33"
Notes:	7'0"	*	*	*	*	*	*	*	*	*
	7'6"	*	*	*	*	*	*	*	*	*
1. Assumptions:	8'0"	*	*	*	*	*	*	*	*	*
	8'6"	*	*	*	*	*	*	*	*	*

2" fire proofing on beam, 6" fluorescent light depth, 5-1 floor slab thickness, 2" suspended ceiling thickness.

	9'0"	* Clear Distance—Light to Beam in Inches					* Beam Depth		*	*	*
Door to Floor	7'0" Ceiling Height	10.5	8.5	6.5	4.5	1.5	10.5	7.5	4.5	1.5	
	7'6"	4.5	2.5	*	*	*	*	*	*	*	
	8'0"	12"	14"	16"	18"	21"	24"	27"	30"	33"	
	8'6"	*	*	*	*	*	*	*	*	*	
	9'0"	*	*	*	*	*	*	*	*	*	
11'0"	8'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	
	8'6"	4.5	2.5	*	*	*	*	*	*	*	
	9'0"	*	*	*	*	*	*	*	*	*	
	9'6"	*	*	*	*	*	*	*	*	*	
	10'0"	*	*	*	*	*	*	*	*	*	
	10'6"	*	*	*	*	*	*	*	*	*	
12'0"	8'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	
	8'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	
	9'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	
	9'6"	4.5	2.5	0.5	*	*	*	*	*	*	
	10'0"	*	*	*	*	*	*	*	*	*	
	10'6"	*	*	*	*	*	*	*	*	*	
13'0"	8'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	
	8'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	
	9'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	
	9'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	
	10'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	
	10'6"	4.5	2.5	0.5	*	*	*	*	*	*	
14'0"	8'0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5	
	8'6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5	
	9'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	
	9'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	
	10'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	
	10'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	
	11'0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	
	11'6"	4.5	2.5	0.5	*	*	*	*	*	*	
Notes: 1. Assumptions: 2" fire proofing on beam, 6" fluorescent light depth, 5-1 floor slab thickness, 2" suspended ceiling thickness.	8'0"	58.5	56.5	54.5	52.5	49.5	46.5	43.5	40.5	37.5	
	8'6"	52.5	50.5	48.5	46.5	43.5	40.5	37.5	34.5	31.5	
	9'0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5	
	9'6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5	
	10'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	

Floor to Floor	Clear Distance—Light to Beam in Inches	Beam Depth								
		10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5
10'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	4.5
11'0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	*
11'6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	*
12'0"	10.5	8.5	6.5	4.5	2.5	0.5	*	*	*	*
20'0"	9'0"	106	104	102	100	97.5	94.5	91.5	88.5	85.5
	9'6"	100	98.5	96.5	94.5	91.5	88.5	85.5	82.5	79.5
	10'0"	94.5	92.5	90.5	88.5	85.5	82.5	79.5	76.5	73.5
	10'6"	88.5	86.5	84.5	82.5	79.5	76.5	73.5	70.5	67.5
	11'0"	82.5	80.5	78.5	76.5	73.5	70.5	67.5	64.5	61.5
	11'6"	76.5	74.5	72.5	70.5	67.5	64.5	61.5	58.5	55.5
	12'0"	70.5	68.5	66.5	64.5	61.5	58.5	55.5	52.5	49.5

Notes:

- 1. Assumptions: 2" fire proofing on beam, 6" fluorescent light depth, 5-1 floor slab thickness, 2" suspended ceiling thickness.**
- 2. For depth from beam to finished ceiling, add 6" to the preceding figure.**
- 3. For depth from underside of the slab to light, add depth of beam plus 6".**
- 4. * Indicates a beam protruding through the ceiling.**



45.02. Building Structural Systems

A. Standard Nominal Structural Steel Depths

- W-Shapes (Wide Flange Beams): 4, 5, 6, 8, 10, 12, 14, 16, 18, 21, 24, 27, 30, 33, 36, 40, 44.
- S-Shapes (I beams): 3, 4, 5, 6, 7, 8, 10, 12, 15, 18, 20, 24.
- C-Shapes (Channels): 3, 4, 5, 6, 7, 8, 9, 10, 12, 15.

B. Standard Nominal Joist Depths as Manufactured by Vulcraft

- K-Series: 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30.
- LH-Series and DLH-Series: 18, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 84.

C. Building mechanical equipment support points should not deflect

more than 0.33 in. for cooling towers and no more than 0.25 in. for all other mechanical equipment.

D. Maximum duct and pipe sizes that may pass through steel joists are given in the following table:

Joist Depth	Round Duct or Pipe Size	Square Duct Size	Rectangle Duct Size
8"	5"	4 × 4	3 × 8
10"	6"	5 × 5	3 × 8
12"	7"	6 × 6	4 × 9
14"	8"	6 × 6	5 × 9
16"	9"	7 × 7	6 × 10
18"	11"	8 × 8	7 × 11
20"	11"	9 × 9	7 × 12
22"	12"	9 × 9	8 × 12
24"	13"	10 × 10	8 × 13
26"	15"	12 × 12	9 × 18
28"	16"	13 × 13	9 × 18
30"	17"	14 × 14	10 × 18

Notes:

1. Table based on Vulcraft K Series joists. For LH or DLH Series joists, consult with Vulcraft.
2. The preceding values are maximum sizes. The designer must consider duct insulation or duct liner thickness.
3. Do not recommend running ductwork through joists or between joists because it generally becomes a problem in the field. If you must run ductwork through joists or between joists, notify the structural engineer and verify the locations of joist bridging.

E. Floor Span vs. Structural Member Depths is given in the following table:

Floor—Structural Member Depth (1)

Structural Member Span	Structural Steel Shapes				Structural Steel Joists			
	Beams		Girders		Joists (9)		Joists Girder	
	Min. (2,4)	Max. (3,4,8)	Min. (2,5,7)	Max. (3,5,8)	Min. (2,4,6)	Max. (3,6)	Min. (2,5)	Max. (3,6)
20 ft.	10"	14"	16"	24"	12"	14"	18"	24"
30 ft.	16"	18"	21"	33"	16"	24"	20"	30"
40 ft.	21"	24"	24"	36"	20"	24"	24"	36"
50 ft.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
60 ft.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Notes:

1. Floor spans generally do not exceed 40 ft.
2. Assumed Floor Dead Load (DL) = 50 psf; Live Load (LL) = 50 psf.
3. Assumed Floor Dead Load (DL) = 50 psf; Live Load (LL) = 150 psf.
4. Assumed Spacing = $\pm 5'0''$.
5. Assumed Spacing = $\pm 30'0''$.
6. Assumed Spacing = $\pm 2'0''$.
7. Assumed Steel Grade 50 ksi.
8. Assumed Steel Grade 36 ksi.
9. K Series Joists for 20' and 30' spans; LH Series for 40' spans.
10. Rule of Thumb: Beam and joist depths (in inches) are approximately 1/2 the length of the span (in feet).
11. Rule of Thumb: Girder and joist girder depths (in inches) are approximately 3/4 the length of the span (in feet).

F. **Roof Span vs. Structural Member Depths** is given in the following table:

Roof—Structural Member Depth

Structural Member Span	Structural Steel Shapes				Structural Steel Joists			
	Beams		Girders		Joists (7)		Joists Girders	
	Min. (1,3)	Max. (2,3)	Min. (1,4,5)	Max. (2,4,6)	Min. (1,3)	Max. (2,3)	Min. (1,4)	Max. (2,4)
20 ft.	8"	10"	10"	18"	12"	14"	18"	28"
30 ft.	14"	16"	16"	24"	16"	20"	20"	40"
40 ft.	18"	21"	21"	30"	20"	24"	24"	52"
50 ft.	N/A	N/A	27"	36"	28"	32"	32"	64"
60 ft.	N/A	N/A	30"	36"	32"	36"	44"	84"

Notes:

1. Assumed Roof Dead Load (DL) = 20 psf; Live Load (LL) = 20 psf.
2. Assumed Roof Dead Load (DL) = 35 psf; Live Load (LL) = 50 psf.
3. Assumed Spacing = ± 5'0".
4. Assumed Spacing = ± 30'0".
5. Assumed Steel Grade 50 ksi.
6. Assumed Steel Grade 36 ksi.
7. K Series Joists for 20' and 30' spans; LH Series for 40', 50', and 60' spans.



45.03. Architectural and Structural Information

A. **Equipment Weights.** Provide equipment weights, sizes, and locations to the architect and structural engineer. The architect does not normally need the weights of equipment, but this information is needed by the structural engineer. Obtain weights and sizes from the

manufacturers' catalogs or the manufacturers' representatives. Equipment weights should include the following information at minimum.

1. Item designation.
 2. Location.
 3. Size—length, width, height—include curb height if required.
 4. Weight. Operating weight if substantially different from the installed weight.
 5. Floor/roof openings. Wall openings if load bearing or shear walls are used.
 6. Special remarks.
- B. Ductwork Weight. Coordinate all ductwork with the structural engineer, especially when ductwork weight is 20 lbs./lf. or more. Provide ductwork weight and drawings showing the location of ductwork and sizes. See Part 17 for ductwork weight information.**
- C. Piping Weight. Coordinate all piping with the structural engineer, especially pipe sizes 6 in. and larger. Provide piping weight, location of anchors and forces, and drawings showing the location of piping and pipe sizes.**

Structural List

PROJECT STRUCTURAL LIST

PROJECT NAME: _____ **SUBMIT**
PRELIMI
FIR
SECO
THI
FIN

SHEET NO. _____ **OF** _____ **PROJECT**
NO. _____

ITEM NO.	ITEM DESIGNATION	LOCATION	SIZE			WEIGHT
			LENGTH	WIDTH	HEIGHT	

PROJECT NAME: _____

F

SHEET NO. _____ OF _____ PROJECT NO. _____

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45.05. Mechanical/Electrical Equipment Space Requirements

A. Commercial Buildings

1. 18–20% of gross floor area. Most of the mechanical equipment is located indoors (i.e., no rooftop AHUs).
2. 1/4–1/3 of total building volume. This includes the ceiling plenum as mechanical/electrical space.

B. Hospital and Laboratory Buildings

1. 15–50% of gross floor area. Most of the mechanical equipment is located indoors (i.e., no rooftop AHUs).
2. 1/3–1/2 of total building volume. This includes the ceiling plenum as mechanical/electrical space.

C. The original building design should allow from 10 to 15 percent additional shaft space for future expansion and modification of the facility. This additional shaft space will also reduce the initial installation cost.

D. Minimum recommended clearance around the boilers and chillers is 36 in. The minimum recommended clearance around all other mechanical equipment is 24 in. Maintain minimum clearances for coil pull, tube pull, and the cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the tubes and width of the piece of equipment. Maintain minimum clearance as required to open access and control doors on equipment for service, maintenance, and inspection.

- E. Minimum recommended clearance between the top of the lights and the deepest structural member is 24 in.**
- F. Mechanical and electrical rooms should be centrally located to minimize ductwork, pipe, and conduit runs (size and length). Centrally locating mechanical and electrical spaces will minimize construction, maintenance, and operating costs. Additional space is quite often required when mechanical and electrical equipment rooms cannot be centrally located or when space requirements are fragmented throughout the building. In addition, centrally located equipment rooms will simplify distribution systems and will in some cases decrease above ceiling space requirements.**
- G. Mechanical rooms with fans and air handling equipment should have at least 10-15 sq. ft. of floor area for each 1,000 CFM of equipment air flow.**
- H. Mechanical rooms with refrigeration equipment must have an exit door that opens directly to the outside or through a vestibule type exit equipped with self-closing, tight-fitting doors.**
- I. Mechanical rooms must be clear of electrical rooms, elevators, and stairs on at least two sides, preferably on three sides.**
- J. Electrical rooms must be clear of elevators and stairs on at least two sides, preferably on three sides.**
- K. In general, mechanical equipment rooms require from 12-20 ft. clearance from the floor to the underside of the structure.**
- L. Mechanical and electrical shafts must be clear of elevators and stairs on at least two sides. Rectangular shafts with aspect ratios of 2:1 to 4:1 are easier to work mechanical and electrical distribution systems in and out of the shafts than square shafts.**
- M. The main electrical switchgear room should be located as close as possible to the incoming electrical service. If an emergency generator is required, the emergency generator room should be located adjacent to the main switchgear room to minimize electrical costs and interconnection problems. The emergency generator room should be located on an outside wall, preferably a corner location to enable proper ventilation, combustion air, and venting of engine exhaust.**

- N. **A mechanical equipment room should be located on the first floor or basement floor to accommodate the incoming domestic water service main, the fire protection service mains, and the gas service. These service mains may include meter and regulator assemblies if these assemblies are not installed in meter vaults or outside the building. Consult your local utility company for service and meter/regulator assembly requirements.**
- O. **The locations and placement of mechanical and electrical rooms must take into account how large pieces of equipment (chillers, boilers, cooling towers, transformers, and others) can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.**

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45.06. Americans with Disabilities Act (ADA)

A. ADA Titles

1. Title I—Equal Employment Opportunity.
2. Title II—State and Local Governments.
3. Title III—Public Accommodations and Commercial Facilities.

B. Drinking Fountains

1. Where only one drinking fountain is provided on a floor, a drinking fountain with two bowls, one high bowl and one low bowl, is required.
2. Where more than one drinking fountain is provided on a floor, 50% shall be handicapped accessible and shall be on an accessible route.
3. Spouts shall be no higher than 36 in. above the finished floor or grade.
4. Spouts shall be located at the front of the unit and shall direct the water flow parallel or nearly parallel to the front of the unit.
5. Controls shall be mounted on the front or side of the unit.
6. Clearances:
 - a. Knee space below the unit should be 27 in. high, 30 in. wide, and 17–19 in. deep, with a minimum front clear floor space of 30 in. × 48 in.

- b. Units without clear space below: 30-in. × 48-in. clearance is suitable for parallel approach.

C. Water Closets

1. The height of the water closet shall be 17–19 in. to the top of the toilet seat.
2. Flush controls shall be hand-operated or automatic. Controls shall be mounted on the wide side of toilet areas, and no more than 44 in. above the floor.
3. At least one toilet shall be handicapped accessible.

D. Urinals

1. Urinals shall be stall-type or wall hung with an elongated rim at a maximum of 17 in. above the floor.
2. Flush controls shall be hand-operated or automatic. Controls shall be mounted no more than 44 in. above the floor.
3. If urinals are provided, at least one shall be handicapped accessible.

E. Lavatories

1. Lavatories shall be mounted with the rim or counter surface no higher than 34 in. above the finished floor with a clearance of at least 29 in. to the bottom of the apron.
2. Hot water and drain pipe under lavatories shall be insulated or otherwise configured to protect against contact.
3. Faucets shall be lever-operated, push-type, or electronically controlled. Self-closing valves are acceptable, provided they remain open a minimum of 10 seconds.

F. Bathtubs

1. Bathtub controls shall be located toward the front half of the bathtub.
2. Shower units shall be provided with a hose at least 60 in. long that can be used both as a fixed shower head and a handheld shower head.

G. Shower Stalls

1. The shower controls shall be opposite the seat in a 36 in. × 36 in. shower stall and adjacent to the seat in a 30 in. × 60 in. shower stall.

2. Shower units shall be provided with a hose at least 60 in. long that can be used both as a fixed shower head and a handheld shower head.

H. Forward Reach

1. Maximum high forward reach: 48 in.
2. Minimum low forward reach: 15 in.

I. Side Reach

1. Maximum high side reach: 54 in.
2. Minimum low side reach: 9 in.

J. Areas of Rescue Assistance

1. A portion of a stairway landing within a smokeproof enclosure.
2. A portion of an exterior exit balcony located immediately adjacent to an exit stairway.
3. A portion of a 1-hour fire-resistive corridor located immediately adjacent to an exit enclosure.
4. A portion of a stairway landing within an exit enclosure that is vented to the exterior and is separated from the interior of the building with not less than 1-hour fire-resistive doors.
5. A vestibule located immediately adjacent to an exit enclosure and constructed to the same fire-resistive standards as required for corridors.
6. When approved by the authorities having jurisdiction, an area or room that is separated from other portions of the building by a smoke barrier.
7. An elevator lobby when elevator shafts and adjacent lobbies are pressurized as required for smokeproof enclosures by local regulations and when complying with the requirements herein for size, communication, and signage.
8. Size:
 - a. Each area of rescue assistance shall have at least two accessible areas 30 × 48 minimum.
 - b. Area shall not encroach on the exit width.

- c. The total number of areas per floor shall be one for every 200 persons. If the occupancy per floor is less than 200, the authorities having jurisdiction may reduce the number of areas to one.
9. A method of two-way communication, with both visible and audible signals, is required between the primary fire entry and the areas of rescue assistance.
10. Each area must be identified.

K. Stairway Width, 48 in. Between Handrails Minimum

L. Protruding Objects

1. Objects protruding from the wall with their leading edges between 27 and 80 in. above the finished floor shall protrude no more than 4 in. into walks, halls, corridors, passageways, or aisles.
2. Objects mounted with their leading edges at or below 27 in. above the finished floor may protrude any amount.
3. Protruding objects shall not reduce the clear width of an accessible route or maneuvering space.
4. Walks, halls, corridors, passageways, aisles, or other circulation spaces shall have 80 in. minimum clear head room.

M. Controls and Operating Mechanisms

1. The highest operable part of controls, dispensers, receptacles, and other operable equipment shall be placed within at least one of the reach ranges.
2. Electrical and communication system receptacles on walls shall be mounted no less than 15 in. above the floor.
3. Controls and operating mechanisms shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate shall be no greater than 5 lbf.

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Part 46: Properties of Air

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46. Part 46: Properties of Air

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46.01. Thermodynamic Properties of Air/Water Vapor Mixtures

A. Psychrometric Definitions

1. Dry bulb temperature: The temperature of air read on a standard thermometer. Units: °F.DB. Symbol: T_{DB} or DB.
2. Wet bulb temperature: The wet bulb temperature is the temperature indicated by a thermometer whose bulb is covered by a wet wick and exposed to air moving at a velocity of 1,000 ft./min. Units: °F.WB. Symbol: T_{WB} or WB.
3. Humidity ratio: The weight of water vapor in each pound of dry air; also known as specific humidity. Units: lbs.H₂O/lbs.DA or Gr.H₂O/lbs.DA. Symbol: W.
4. Enthalpy: A thermodynamic property that serves as a measure of the heat content above some datum temperature (air 0°F.DB and water 32°F). Units: Btu/lbs.DA or Btu/lbs.H₂O. Symbol: h.
5. Specific volume: The cubic feet of air/water mixture per pound of dry air. Units: cu.ft./lbs.DA. Symbol: SpV.
6. Dewpoint temperature. The temperature at which moisture will start to condense from the air. Units: °F.DP. Symbol: T_{DP} or DP.
7. Relative humidity: The ratio of water vapor in the air/water mixture to the water vapor in saturated air/water mixture. Units: %RH. Symbol: RH.

8. Sensible heat: Heat that causes a rise in temperature. Units: Btu/h. Symbol: H_S .
9. Latent heat: Heat that causes a change in state (e.g., liquid water to gaseous water). Units: Btu/h. Symbol: H_L .
10. Total heat: Sum of sensible heat and latent heat. Units: Btu/h. Symbol: H_T .
11. Sensible heat ratio: The ratio of the sensible heat to the total heat. Units: None. Symbol: SHR.
12. Vapor pressure: Pressure exerted by water vapor in the air. Units: in. Hg. Symbol: P_W .
13. Standard barometric pressure: Pressure at sea level (29.921 in. Hg. = 14.7 psi).

B. Thermodynamic properties of air/water mixtures are given in the following table:

Temperature Range °F	Specific Heat Btu/lb. °F
-80-129	0.240
130-215	0.241
216-280	0.242
281-330	0.243
331-370	0.244
371-400	0.245
401-440	0.246
441-460	0.247
461-470	0.248
471-500	0.249

Refer to the online resource for thermodynamic and barometric properties of moist air, and physical properties of gases.
www.mheducation.com/HVACEquations

THERMODYNAMIC PROPERTIES OF MOIST AIR @14.696 psia

	Humidity Ratio	Specific Volume ft. ³ /lbs. DA	Enthalpy Btu/lb. DA
--	----------------	---	---------------------

Temp °F	Grains/ lb. DA	Pounds/ lb. DA	N _a	N _{av}	N _e	h _a	h _{av}	h _e
-80	0.0343	0.0000049	9.553	0.000	9.553	-19.221	0.005	-19.215
-79	0.0371	0.0000053	9.579	0.000	9.579	-18.980	0.005	-18.975
-78	0.0399	0.0000057	9.604	0.000	9.604	-18.740	0.006	-18.734
-77	0.0434	0.0000062	9.629	0.000	9.629	-18.500	0.007	-18.493
-76	0.0469	0.0000067	9.655	0.000	9.655	-18.259	0.007	-18.252
-75	0.0504	0.0000072	9.680	0.000	9.680	-18.019	0.007	-18.011
-74	0.0546	0.0000078	9.705	0.000	9.705	-17.778	0.008	-17.770
-73	0.0588	0.0000084	9.731	0.000	9.731	-17.538	0.009	-17.529
-72	0.0630	0.0000090	9.756	0.000	9.756	-17.298	0.010	-17.288
-71	0.0679	0.0000097	9.781	0.000	9.781	-17.057	0.010	-17.047
-70	0.0728	0.0000104	9.807	0.000	9.807	-16.806	0.011	-16.817
-69	0.0784	0.0000112	9.832	0.000	9.832	-16.577	0.012	-16.565
-68	0.0840	0.0000120	9.858	0.000	9.858	-16.336	0.013	-16.324
-67	0.0903	0.0000129	9.883	0.000	9.883	-16.096	0.013	-16.083
-66	0.0973	0.0000139	9.908	0.000	9.908	-15.856	0.015	-15.841
-65	0.1043	0.0000149	9.934	0.000	9.934	-15.616	0.015	-15.600
-64	0.1120	0.0000160	9.959	0.000	9.959	-15.375	0.017	-15.359
-63	0.12 04	0.0000172	9.984	0.000	9.984	-15.117	0.018	-15.135
-62	0.1288	0.0000184	10.010	0.000	10.010	-14.895	0.019	-14.876
-61	0.1386	0.0000198	10.035	0.000	10.035	-14.654	0.021	-14.634
-60	0.1484	0.0000212	10.060	0.000	10.060	-14.414	0.022	-14.392
-59	0.1590	0.0000227	10.085	0.000	10.085	-14.174	0.024	-14.150
-58	0.1701	0.0000243	10.111	0.000	10.111	-13.933	0.025	-13.908
-57	0.1820	0.0000260	10.136	0.000	10.136	-13.693	0.027	-13.666
-56	0.1953	0.0000279	10.161	0.000	10.161	-13.453	0.029	-13.424
-55	0.2086	0.0000298	10.187	0.000	10.187	-13.213	0.031	-13.182
-54	0.2233	0.0000319	10.212	0.001	10.213	-12.972	0.033	-12.939
-53	0.2387	0.0000341	10.237	0.001	10.238	-12.732	0.035	-12.697
-52	0.2555	0.0000365	10.263	0.001	10.263	-12.492	0.038	-12.454
-51	0.2730	0.0000390	10.288	0.001	10.289	-12.251	0.041	-12.211
-50	0.2912	0.0000416	10.313	0.001	10.314	-12.011	0.043	-11.968
-49	0.3115	0.0000445	10.339	0.001	10.340	-11.771	0.046	-11.725
-48	0.3325	0.0000475	10.364	0.001	10.365	-11.531	0.050	-11.481
-47	0.3549	0.0000507	10.389	0.001	10.390	-11.290	0.053	-11.237
-46	0.3787	0.0000541	10.415	0.001	10.416	-11.050	0.056	-10.994
-45	0.4039	0.0000577	10.440	0.001	10.441	-10.810	0.060	-10.750
-44	0.4305	0.0000615	10.465	0.001	10.466	-10.570	0.064	-10.505
-43	0.4592	0.0000656	10.491	0.001	10.492	-10.329	0.068	-10.261
-42	0.4893	0.0000699	10.516	0.001	10.517	-10.089	0.073	-10.016
-41	0.5208	0.0000744	10.541	0.001	10.543	-9.849	0.078	-9.771
-40	0.5551	0.0000793	10.567	0.001	10.568	-9.609	0.083	-9.526
-39	0.5908	0.0000844	10.592	0.001	10.593	-9.368	0.088	-9.280
-38	0.6286	0.0000898	10.617	0.002	10.619	-9.128	0.094	-9.034
-37	0.6692	0.0000956	10.643	0.002	10.644	-8.888	0.100	-8.788
-36	0.7119	0.0001017	10.668	0.002	10.670	-8.648	0.106	-8.541
-35	0.7567	0.0001081	10.693	0.002	10.695	-8.407	0.113	-8.294
-34	0.8050	0.0001150	10.719	0.002	10.721	-8.167	0.120	-8.047
-33	0.8554	0.0001222	10.744	0.002	10.746	-7.927	0.128	-7.799
-32	0.9086	0.0001298	10.769	0.002	10.772	-7.687	0.136	-7.551
-31	0.9653	0.0001379	10.795	0.002	10.797	-7.447	0.145	-7.302
-30	1.0255	0.0001465	10.820	0.003	10.822	-7.206	0.154	-7.053
-29	1.0885	0.0001555	10.845	0.003	10.848	-6.966	0.163	-6.803
-28	1.1550	0.0001650	10.871	0.003	10.873	-6.726	0.173	-6.553
-27	1.2257	0.0001751	10.896	0.003	10.899	-6.486	0.184	-6.302
-26	1.3006	0.0001858	10.921	0.003	10.924	-6.245	0.195	-6.051
-25	1.3790	0.0001970	10.947	0.003	10.950	-6.005	0.207	-5.798
-24	1.4616	0.0002088	10.972	0.004	10.976	-5.765	0.220	-5.545
-23	1.5498	0.0002214	10.997	0.004	11.001	-5.525	0.233	-5.292
-22	1.6422	0.0002346	11.022	0.004	11.027	-5.284	0.247	-5.038
-21	1.7395	0.0002485	11.048	0.004	11.052	-5.044	0.261	-4.783
-20	1.8424	0.0002632	11.073	0.005	11.078	-4.804	0.277	-4.527

-19	1.9502	0.0002786	11.098	0.005	11.103	-4.564	0.293	-4.271
-18	2.0650	0.0002950	11.124	0.005	11.129	-4.324	0.311	-4.013
-17	2.1847	0.0003121	11.149	0.006	11.155	-4.084	0.329	-3.754
-16	2.3121	0.0003303	11.174	0.006	11.180	-3.843	0.348	-3.495
-15	2.4451	0.0003493	11.200	0.006	11.206	-3.603	0.368	-3.235
-14	2.5858	0.0003694	11.225	0.007	11.232	-3.363	0.390	-2.973
-13	2.7335	0.0003905	11.250	0.007	11.257	-3.123	0.412	-2.710
-12	2.8896	0.0004128	11.276	0.007	11.283	-2.882	0.436	-2.447
-11	3.0534	0.0004362	11.301	0.008	11.309	-2.642	0.460	-2.182
-10	3.2256	0.0004608	11.326	0.008	11.335	-2.402	0.487	-1.915
-9	3.4069	0.0004867	11.351	0.009	11.360	-2.162	0.514	-1.647
-8	3.5973	0.0005139	11.377	0.009	11.386	-1.922	0.543	-1.378
-7	3.7975	0.0005425	11.402	0.010	11.412	-1.681	0.574	-1.108
-6	4.0082	0.0005726	11.427	0.010	11.438	-1.441	0.606	-0.835
-5	4.2287	0.0006041	11.453	0.011	11.464	-1.201	0.640	-0.561
-4	4.4611	0.0006373	11.478	0.012	11.490	-0.961	0.675	-0.286
-3	4.7054	0.0006722	11.503	0.012	11.516	-0.721	0.712	-0.008
-2	4.9616	0.0007088	11.529	0.013	11.542	-0.480	0.751	0.271
-1	5.2304	0.0007472	11.554	0.014	11.568	-0.240	0.792	0.552
0	5.5125	0.0007875	11.579	0.015	11.594	0.000	0.835	0.835
1	5.8086	0.0008298	11.604	0.015	11.620	0.240	0.880	1.121
2	6.1194	0.0008742	11.630	0.016	11.646	0.480	0.928	1.408
3	6.4449	0.0009207	11.655	0.017	11.672	0.721	0.978	1.699
4	6.7865	0.0009695	11.680	0.018	11.699	0.961	1.030	1.991
5	7.1449	0.0010207	11.706	0.019	11.725	1.201	1.085	2.286
6	7.5201	0.0010743	11.731	0.020	11.751	1.441	1.143	2.584
7	7.9142	0.0011306	11.756	0.021	11.778	1.681	1.203	2.884
8	8.3265	0.0011895	11.782	0.022	11.804	1.922	1.266	3.188
9	8.7584	0.0012512	11.807	0.024	11.831	2.162	1.332	3.494
10	9.2106	0.0013158	11.832	0.025	11.857	2.402	1.402	3.804
11	9.6845	0.0013835	11.857	0.026	11.884	2.642	1.474	4.117
12	10.1808	0.0014544	11.883	0.028	11.910	2.882	1.550	4.433
13	10.7002	0.0015286	11.908	0.029	11.937	3.123	1.630	4.753
14	11.2434	0.0016062	11.933	0.031	11.964	3.363	1.714	5.077
15	11.8118	0.0016874	11.959	0.032	11.991	3.603	1.801	5.404
16	12.4068	0.0017724	11.984	0.034	12.018	3.843	1.892	5.736
17	13.0291	0.0018613	12.009	0.036	12.045	4.084	1.988	6.072
18	13.6801	0.0019543	12.035	0.038	12.072	4.324	2.088	6.412
19	14.3605	0.0020515	12.060	0.040	12.099	4.564	2.193	6.757
20	15.0717	0.0021531	12.085	0.042	12.127	4.804	2.303	7.107
21	15.8144	0.0022592	12.110	0.044	12.154	5.044	2.417	7.462
22	16.5921	0.0023703	12.136	0.046	12.182	5.285	2.537	7.822
23	17.4041	0.0024863	12.161	0.048	12.209	5.525	2.662	8.187
24	18.2511	0.0026073	12.186	0.051	12.237	5.765	2.793	8.558
25	19.1373	0.0027339	12.212	0.054	12.265	6.005	2.930	8.935
26	20.0620	0.0028660	12.237	0.056	12.293	6.246	3.073	9.318
27	21.0273	0.0030039	12.262	0.059	12.321	6.486	3.222	9.708
28	22.0360	0.0031480	12.287	0.062	12.349	6.726	3.378	10.104
29	23.0888	0.0032984	12.313	0.065	12.378	6.966	3.541	10.507
30	24.1864	0.0034552	12.338	0.068	12.406	7.206	3.711	10.917
31	25.3330	0.0036190	12.363	0.072	12.435	7.447	3.888	11.335
32	26.5265	0.0037895	12.389	0.075	12.464	7.687	4.073	11.760
33	27.76290	0.0039470	12.414	0.079	12.492	7.927	4.243	12.170
34	28.7630	0.0041090	12.439	0.082	12.521	8.167	4.420	12.587
35	29.939	0.004277	12.464	0.085	12.550	8.408	4.603	13.010
36	31.164	0.004452	12.490	0.089	12.579	8.648	4.793	13.441
37	32.431	0.004633	12.515	0.093	12.608	8.888	4.990	13.878
38	33.740	0.004820	12.540	0.097	12.637	9.128	5.194	14.322
39	35.098	0.005014	12.566	0.101	12.667	9.369	5.405	14.773
40	36.512	0.005216	12.591	0.105	12.696	9.609	5.624	15.233
41	37.968	0.005424	12.616	0.110	12.726	9.849	5.851	15.700
42	39.480	0.005640	12.641	0.114	12.756	10.089	6.086	16.175
43	41.041	0.005863	12.667	0.119	12.786	10.330	6.330	16.660
44	42.658	0.006094	12.692	0.124	12.816	10.570	6.582	17.152

45	44.338	0.006334	12.717	0.129	12.846	10.810	6.843	17.653
46	46.067	0.006581	12.743	0.134	12.877	11.050	7.114	18.164
47	47.866	0.006838	12.768	0.140	12.908	11.291	7.394	18.685
48	49.721	0.007103	12.793	0.146	12.939	11.531	7.684	19.215
49	51.646	0.007378	12.818	0.152	12.970	11.771	7.984	19.756
50	53.627	0.007661	12.844	0.158	13.001	12.012	8.295	20.306
51	55.685	0.007955	12.869	0.164	13.033	12.252	8.616	20.868
52	57.813	0.008259	12.894	0.171	13.065	12.492	8.949	21.441
53	60.011	0.008573	12.920	0.178	13.097	12.732	9.293	22.025
54	62.279	0.008897	12.945	0.185	13.129	12.973	9.648	22.621
55	64.631	0.009233	12.970	0.192	13.162	13.213	10.016	23.229
56	67.060	0.009580	12.995	0.200	13.195	13.453	10.397	23.850
57	69.566	0.009938	13.021	0.207	13.228	13.694	10.790	24.484
58	72.163	0.010309	13.046	0.216	13.262	13.934	11.197	25.131
59	74.844	0.010692	13.071	0.224	13.295	14.174	11.618	25.792
60	77.609	0.011087	13.096	0.233	13.329	14.415	12.052	26.467
61	80.472	0.011496	13.122	0.242	13.364	14.655	12.502	27.157
62	83.433	0.011919	13.147	0.251	13.398	14.895	12.966	27.862
63	86.485	0.012355	13.172	0.261	13.433	15.135	13.446	28.582
64	89.635	0.012805	13.198	0.271	13.468	15.376	13.942	29.318
65	92.890	0.013270	13.223	0.281	13.504	15.616	14.454	30.071
66	96.250	0.013750	13.248	0.292	13.540	15.856	14.983	30.840
67	99.722	0.014246	13.273	0.303	13.577	16.097	15.530	31.626
68	103.306	0.014758	13.299	0.315	13.613	16.337	16.094	32.431
69	107.002	0.015286	13.324	0.326	13.650	16.577	16.677	33.254
70	110.824	0.015832	13.349	0.339	13.688	16.818	17.279	34.097
71	114.765	0.016395	13.375	0.351	13.726	17.058	17.901	34.959
72	118.832	0.016976	13.400	0.365	13.764	17.299	18.543	35.841
73	123.025	0.017575	13.425	0.378	13.803	17.539	19.204	36.743
74	127.358	0.018194	13.450	0.392	13.843	17.779	19.889	37.668
75	131.831	0.018833	13.476	0.407	13.882	18.020	20.595	38.615
76	136.437	0.019491	13.501	0.422	13.923	18.260	21.323	39.583
77	141.190	0.020170	13.526	0.437	13.963	18.500	22.075	40.576
78	146.097	0.020871	13.551	0.453	14.005	18.741	22.851	41.592
79	151.158	0.021594	13.577	0.470	14.046	18.981	23.652	42.633
80	156.380	0.022340	13.602	0.487	14.089	19.222	24.479	43.701
81	162.330	0.023109	13.627	0.505	14.132	19.462	25.332	44.794
82	167.314	0.023902	13.653	0.523	14.175	19.702	26.211	45.913
83	173.040	0.024720	13.678	0.542	14.220	19.943	27.120	47.062
84	178.941	0.025563	13.703	0.561	14.264	20.183	28.055	48.238
85	185.031	0.026433	13.728	0.581	14.310	20.424	29.021	49.445
86	191.303	0.027329	13.754	0.602	14.356	20.664	30.017	50.681
87	197.778	0.028254	13.779	0.624	14.403	20.905	31.045	51.949
88	204.456	0.029208	13.804	0.646	14.450	21.145	32.105	53.250
89	211.323	0.030189	13.829	0.669	14.498	21.385	33.197	54.582
90	218.421	0.031203	13.855	0.692	14.547	21.626	34.325	55.951
91	225.729	0.032247	13.880	0.717	14.597	21.866	35.489	57.355
92	233.261	0.033323	13.905	0.742	14.647	22.107	36.687	58.794
93	241.031	0.034433	13.930	0.768	14.699	22.347	37.924	60.271
94	249.039	0.035577	13.956	0.795	14.751	22.588	39.199	61.787
95	257.299	0.036757	13.981	0.823	14.804	22.828	40.515	63.343
96	265.804	0.037972	14.006	0.852	14.858	23.069	41.871	64.940
97	274.575	0.039225	14.032	0.881	14.913	23.309	43.269	66.578
98	283.612	0.040516	14.057	0.912	14.969	23.550	44.711	68.260
99	292.936	0.041848	14.082	0.944	15.026	23.790	46.198	69.988
100	302.533	0.043219	14.107	0.976	15.084	24.031	47.730	71.761
101	312.438	0.044634	14.133	1.010	15.143	24.271	49.312	73.583
102	322.630	0.046090	14.158	1.045	15.203	24.512	50.940	75.452
103	333.144	0.047592	14.183	1.081	15.264	24.752	52.621	77.373
104	343.980	0.049140	14.208	1.118	15.326	24.993	54.354	79.346
105	355.159	0.050737	14.234	1.156	15.390	25.233	56.142	81.375
106	366.681	0.052383	14.259	1.196	15.455	25.474	57.986	83.460
107	378.539	0.054077	14.284	1.236	15.521	25.714	59.884	85.599

108	390.782	0.055826	14.309	1.279	15.588	25.955	61.844	87.799
109	403.396	0.057628	14.335	1.322	15.657	26.195	63.866	90.061
110	416.402	0.059486	14.360	1.367	15.727	26.436	65.950	92.386
111	429.807	0.061401	14.385	1.414	15.799	26.677	68.099	94.776
112	443.646	0.063378	14.411	1.462	15.872	26.917	70.319	97.237
113	457.877	0.065411	14.436	1.511	15.947	27.158	72.603	99.760
114	472.584	0.067512	14.461	1.562	16.023	27.398	74.964	102.362
115	487.732	0.069676	14.486	1.615	16.101	27.639	77.396	105.035
116	503.356	0.071908	14.512	1.670	16.181	27.879	79.906	107.786
117	519.477	0.074211	14.537	1.726	16.263	28.120	82.497	110.617
118	536.102	0.076586	14.562	1.784	16.346	28.361	85.169	113.530
119	553.252	0.079036	14.587	1.844	16.432	28.601	87.927	116.528
120	570.920	0.081560	14.613	1.906	16.519	28.842	90.770	119.612
121	589.183	0.084169	14.638	1.971	16.609	29.083	93.709	122.792
122	608.020	0.086860	14.663	2.037	16.700	29.323	96.742	126.065
123	627.431	0.089633	14.688	2.106	16.794	29.564	99.868	129.432
124	647.500	0.092500	14.714	2.176	16.890	29.805	103.102	132.907
125	668.192	0.095456	14.739	2.250	16.989	30.045	106.437	136.482
126	689.528	0.098504	14.764	2.325	17.090	30.286	109.877	140.163
127	711.599	0.101657	14.789	2.404	17.193	30.527	113.438	143.965
128	734.370	0.104910	14.815	2.485	17.299	30.767	117.111	147.878
129	757.890	0.108270	14.840	2.569	17.409	31.008	120.908	151.916
130	782.166	0.111738	14.865	2.655	17.520	31.249	124.828	156.076
131	807.254	0.115322	14.891	2.745	17.635	31.489	128.880	160.370
132	833.161	0.119023	14.916	2.837	17.753	31.730	133.066	164.796
133	859.985	0.122855	14.941	2.934	17.875	31.971	137.403	169.374
134	887.628	0.126804	14.966	3.033	17.999	32.212	141.873	174.084
135	916.265	0.130895	14.992	3.136	18.127	32.452	146.504	178.957
136	945.868	0.135124	15.017	3.242	18.259	32.693	151.294	183.987
137	976.458	0.139494	15.042	3.352	18.394	32.934	156.245	189.179
138	1008.133	0.144019	15.067	3.467	18.534	33.175	161.374	194.548
139	1040.872	0.148696	15.093	3.585	18.678	33.415	166.677	200.092
140	1074.766	0.153538	15.118	3.708	18.825	33.656	172.168	205.824
141	1110.501	0.158643	15.143	3.835	18.978	33.897	177.857	211.754
142	1146.236	0.163748	15.168	3.967	19.135	34.138	183.754	217.892
143	1173.854	0.169122	15.194	4.103	19.297	34.379	189.855	244.233
144	1222.858	0.174694	15.219	4.245	19.464	34.620	196.183	230.802
145	1263.269	0.180467	15.244	4.392	19.637	34.860	202.740	237.600
146	1305.220	0.186460	15.269	4.545	19.815	35.101	209.550	244.651
147	1348.676	0.192668	15.295	4.704	19.999	35.342	216.607	251.949
148	1393.770	0.199110	15.320	4.869	20.189	35.583	223.932	259.514
149	1440.544	0.205792	15.345	5.040	20.385	35.824	231.533	267.356
150	1489.110	0.212730	15.370	5.218	20.585	36.064	239.426	275.490
151	1539.615	0.219945	15.396	5.404	20.799	36.305	247.638	283.943
152	1592.003	0.227429	15.421	5.596	21.017	36.546	256.158	292.705
153	1646.526	0.235218	15.446	5.797	21.243	36.787	265.028	301.816
154	1703.163	0.243309	15.471	6.005	21.477	37.028	274.245	311.273
155	1762.166	0.251738	15.497	6.223	21.720	37.269	283.849	321.118
156	1823.584	0.260512	15.522	6.450	21.972	37.510	293.849	331.359
157	1887.508	0.269644	15.547	6.686	22.233	37.751	304.261	342.012
158	1954.162	0.279166	15.572	6.933	22.505	37.992	315.120	353.112
159	2023.707	0.289101	15.598	7.190	22.788	38.233	326.452	364.685
160	2096.15	0.29945	15.623	7.459	23.082	38.474	338.263	376.737
161	2171.89	0.31027	15.648	7.740	23.388	38.715	350.610	389.325
162	2250.92	0.32156	15.673	8.034	23.707	38.956	363.501	402.457
163	2333.52	0.33336	15.699	8.341	24.040	39.197	376.979	416.175
164	2420.04	0.34572	15.724	8.664	24.388	39.438	391.095	430.533
165	2510.55	0.35865	15.749	9.001	24.750	39.679	405.865	445.544
166	2605.40	0.37220	15.774	9.355	25.129	39.920	421.352	461.271
167	2685.83	0.38639	15.800	9.726	25.526	40.161	437.578	477.739
168	2809.17	0.40131	15.825	10.117	25.942	40.402	454.630	495.032
169	2918.86	0.41698	15.850	10.527	26.377	40.643	472.554	513.197
170	3034.01	0.43343	15.875	10.959	26.834	40.884	491.372	532.256
171	3155.53	0.45079	15.901	11.414	27.315	41.125	511.231	552.356

172	3283.35	0.46905	15.926	11.894	27.820	41.366	532.138	573.504
173	3418.03	0.48829	15.951	12.400	28.352	41.607	554.160	595.767
174	3560.69	0.50867	15.976	12.937	28.913	41.848	577.489	619.337
175	3711.33	0.53019	16.002	13.504	29.505	42.089	602.139	644.229
176	3870.58	0.55294	16.027	14.103	30.130	42.331	628.197	670.528
177	4039.70	0.57710	16.052	14.741	30.793	42.572	655.876	698.448
178	4219.18	0.60274	16.078	15.418	31.496	42.813	685.260	728.073
179	4410.14	0.63002	16.103	16.138	32.242	43.054	716.524	759.579
180	4613.77	0.65911	16.128	16.909	33.037	43.295	749.871	793.166
181	4830.84	0.69012	16.153	17.730	33.883	43.536	785.426	828.962
182	5063.17	0.72331	16.178	18.609	34.787	43.778	823.487	867.265
183	5311.95	0.75885	16.204	19.551	35.755	44.019	864.259	908.278
184	5579.21	0.79703	16.229	20.564	36.793	44.260	908.061	952.321
185	5867.19	0.83817	16.254	21.656	37.910	44.501	955.261	999.763
186	6177.57	0.88251	16.280	22.834	39.113	44.742	1006.149	1050.892
187	6513.99	0.93057	16.305	24.111	40.416	44.984	1061.314	1106.298
188	6879.04	0.98272	16.330	25.498	41.828	45.225	1121.174	1166.399
189	7276.57	1.03951	16.355	27.010	43.365	45.466	1186.382	1231.848
190	7710.78	1.10154	16.381	28.661	45.042	45.707	1257.614	1303.321
191	8187.55	1.16965	16.406	30.476	46.882	45.949	1335.834	1381.783
192	8712.97	1.24471	16.431	32.477	48.908	46.190	1422.047	1468.238
193	9295.16	1.32788	16.456	34.695	51.151	46.431	1517.581	1564.013
194	9942.03	1.42029	16.481	37.161	53.642	46.673	1623.758	1670.430
195	10667.72	1.52396	16.507	39.928	56.435	46.914	1742.879	1789.793
196	11484.90	1.64070	16.532	43.046	59.578	47.155	1877.032	1924.188
197	12410.93	1.77299	16.557	46.580	63.137	47.397	2029.069	2076.466
198	13473.04	1.92472	16.583	50.636	67.218	47.638	2203.464	2251.102
199	14698.25	2.09975	16.608	55.316	71.923	47.879	2404.668	2452.547
200	16131.78	2.30454	16.663	60.793	77.426	48.121	2640.084	2688.205

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46.02. Barometric Properties of Air

BAROMETRIC PRESSURES AT VARIOUS ALTITUDES AT 70°F

Altitude Feet	Barometer (Absolute Pressure)				Relative Density
	in.Hg.	psi	ft.H ₂ O	in. W.G.	
60,000	2.14	1.05	2.43	29.1	0.07
50,000	3.44	1.69	3.90	46.8	0.11
40,000	5.56	2.73	6.31	75.7	0.18
30,000	8.90	4.37	10.10	121.1	0.30
20,000	13.76	6.76	15.61	187.2	0.46
15,000	16.88	8.29	19.15	229.7	0.56
10,000	20.57	10.11	23.34	280.0	0.69
9,000	21.34	10.49	24.22	290.5	0.71
8,000	22.12	10.87	25.10	301.0	0.74
7,000	23.09	11.34	26.20	314.2	0.77
6,000	23.98	11.78	27.21	326.4	0.80
5,000	24.89	12.23	28.24	338.8	0.83
4,000	25.84	12.70	29.32	351.7	0.86
3,500	26.33	12.94	29.88	358.3	0.88
3,000	26.81	13.17	30.42	364.8	0.90
2,500	27.31	13.42	30.99	371.7	0.91
2,000	27.82	13.67	31.57	378.6	0.93
1,500	28.33	13.92	32.15	385.6	0.95
1,000	28.85	14.17	32.74	392.6	0.96
500	29.38	14.43	33.33	399.9	0.98
Sea Level	29.92	14.70	33.95	407.2	1.00
-500	30.47	14.97	34.57	414.7	1.02
-1,000	31.02	15.24	35.20	422.2	1.04
-2,000	32.15	15.80	36.48	437.5	1.07
-3,000	33.31	16.36	37.80	453.3	1.11
-4,000	34.51	16.96	39.16	469.7	1.15
-5,000	35.74	17.56	40.55	486.4	1.19

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46.03. Properties of Air—Effects on Standard HVAC Air Equations

AIR EQUATION CONSTANTS FOR ALTITUDE

Altitude Feet	Sensible Heat	Latent Heat		Total Heat (4)
		Gr.H ₂ O (2)	lbs.H ₂ O (3)	
60,000	0.08	0.048	339	0.315
50,000	0.12	0.075	532	0.495
40,000	0.19	0.123	871	0.810
30,000	0.32	0.204	1452	1.350
20,000	0.49	0.306	2178	2.025
15,000	0.56	0.382	2710	2.520
10,000	0.69	0.470	3,340	3.105
9,000	0.77	0.483	3436	3.195
8,000	0.74	0.504	3582	3.330
7,000	0.77	0.525	3727	3.465
6,000	0.80	0.545	3872	3.600
5,000	0.83	0.566	4017	3.735
4,000	0.86	0.586	4162	3.870
3,500	0.88	0.600	4259	3.960
3,000	0.90	0.613	4356	4.050
2,500	0.91	0.620	4404	4.095
2,000	0.93	0.634	4501	4.185
1,500	0.95	0.647	4598	4.275
1,000	0.96	0.654	4646	4.320
500	0.98	0.668	4743	4.410
Sea Level	1.08	0.681	4840	4.500
-500	1.19	0.695	4937	4.590
-1,000	1.12	0.708	5034	4.680
-2,000	1.16	0.729	5179	4.815
-3,000	1.20	0.756	5372	4.995
-4,000	1.24	0.783	5566	5.175
-5,000	1.29	0.810	5760	5.335

Notes:

1. Equation Constants Units: Btu/h. CFM °F.

2. Equation Constants Units: Btu lbs. Latent Heat / DA/h. CFM.
3. Equation Constants Units: Btu lbs. Sensible Heat / DA/h. lbs. H₂O (2) / lbs. H₂O (3). Total Heat (4)
Altitude Feet
4. Equation Constants Units: lbs.DA/h. CFM.
5. Use table values in lieu of constants in equations in Part 3.

AIR EQUATION CONSTANTS FOR TEMPERATURE

Latent Heat

Temperature °F	Sensible Heat	Gr.H ₂ O (2)	lbs.H ₂ O (3)	Total Heat (4)
0	1.204	0.759	5397	5.018
50	1.102	0.695	4937	4.590
60	1.080	0.681	4840	4.500
100	1.015	0.640	4550	4.230
150	0.950	0.599	4259	3.960
200	0.896	0.565	4017	3.735
250	0.842	0.531	3775	3.510
300	0.799	0.504	3582	3.330
350	0.756	0.477	3388	3.150
400	0.724	0.456	3243	3.015
450	0.691	0.436	3098	2.880
500	0.659	0.415	2952	2.745
550	0.626	0.395	2807	2.610
600	0.610	0.385	2735	2.543
650	0.583	0.368	2614	2.430
700	0.567	0.358	2541	2.363
750	0.551	0.347	2468	2.295
800	0.529	0.334	2372	2.205
850	0.513	0.323	2299	2.138
900	0.497	0.313	2226	2.070
950	0.486	0.306	2178	2.025
1000	0.470	0.296	2105	1.958

Notes:

- 1. Equation Constants Units: Btu/h. CFM °F.**
- 2. Equation Constants Units: Btu lbs.DA/h. Gr.H₂O CFM.**
- 3. Equation Constants Units: Btu lbs.DA/h. lbs.H₂O CFM.**
- 4. Equation Constants Units: lbs.DA/h. CFM.**
- 5. Use table values in lieu of constants in equations in Part 3.**

AIR EQUATION FACTORS FOR DENSITY

Altitude Feet	Temperature °F						
	-40	0	40	70	100	150	200
60,000	0.90	0.08	0.08	0.07	0.07	0.06	0.06
50,000	0.14	0.13	0.12	0.11	0.11	0.10	0.09
40,000	0.23	0.21	0.20	0.19	0.18	0.16	0.15
30,000	0.37	0.34	0.32	0.30	0.28	0.26	0.24
20,000	0.58	0.53	0.49	0.46	0.44	0.40	0.37
15,000	0.71	0.65	0.60	0.56	0.54	0.49	0.45
10,000	0.87	0.79	0.73	0.69	0.65	0.60	0.55
9,000	0.90	0.82	0.76	0.71	0.68	0.62	0.57
8,000	0.93	0.85	0.79	0.74	0.70	0.65	0.60
7,000	0.97	0.89	0.82	0.77	0.73	0.67	0.62
6,000	1.01	0.91	0.85	0.80	0.75	0.69	0.64
5,000	1.05	0.95	0.88	0.83	0.78	0.72	0.66
4,000	1.09	0.99	0.92	0.86	0.81	0.75	0.69
3,500	1.11	1.01	0.94	0.87	0.83	0.77	0.70
3,000	1.13	1.03	0.95	0.89	0.85	0.78	0.71
2,500	1.15	1.05	0.97	0.91	0.87	0.80	0.73
2,000	1.17	1.07	0.99	0.93	0.88	0.81	0.74
1,500	1.20	1.09	1.01	0.95	0.90	0.83	0.76
1,000	1.22	1.11	1.02	0.96	0.92	0.84	0.77
500	1.24	1.13	1.04	0.98	0.94	0.86	0.79
Sea Level	1.26	1.15	1.06	1.00	0.95	0.87	0.80
-500	1.28	1.17	1.08	1.02	0.97	0.89	0.81
-1,000	1.31	1.19	1.10	1.04	0.98	0.90	0.83
-2,000	1.35	1.24	1.14	1.07	1.02	0.93	0.86
-3,000	1.40	1.28	1.18	1.11	1.06	0.97	0.89
-4,000	1.45	1.33	1.22	1.15	1.10	1.00	0.92
-5,000	1.51	1.37	1.27	1.19	1.13	1.04	0.96

Note:

1. Multiply constants in equations in Part 3 by values in the table.

AIR EQUATION FACTORS FOR DENSITY

Altitude Feet	Temperature °F						
	250	300	350	400	450	500	550
60,000	0.05	0.05	0.05	0.04	0.04	0.04	0.04
50,000	0.09	0.08	0.07	0.07	0.07	0.06	0.06
40,000	0.14	0.13	0.12	0.12	0.11	0.10	0.10
30,000	0.22	0.21	0.19	0.18	0.17	0.16	0.16
20,000	0.34	0.32	0.30	0.29	0.27	0.26	0.24
15,000	0.42	0.39	0.37	0.35	0.33	0.31	0.30
10,000	0.51	0.48	0.45	0.42	0.40	0.38	0.36
9,000	0.53	0.50	0.47	0.44	0.42	0.39	0.38
8,000	0.56	0.52	0.49	0.46	0.43	0.41	0.39
7,000	0.58	0.54	0.51	0.48	0.45	0.43	0.41
6,000	0.60	0.56	0.52	0.49	0.46	0.44	0.42
5,000	0.62	0.58	0.54	0.51	0.48	0.45	0.44
4,000	0.64	0.60	0.56	0.53	0.50	0.47	0.45
3,500	0.66	0.61	0.57	0.54	0.51	0.48	0.46
3,000	0.67	0.62	0.58	0.55	0.52	0.49	0.47
2,500	0.69	0.64	0.59	0.56	0.53	0.50	0.48
2,000	0.70	0.65	0.60	0.57	0.54	0.51	0.49
1,500	0.71	0.66	0.61	0.59	0.55	0.52	0.50
1,000	0.72	0.67	0.62	0.60	0.56	0.53	0.51
500	0.74	0.69	0.64	0.61	0.57	0.54	0.52
Sea Level	0.75	0.70	0.65	0.62	0.58	0.55	0.53
-500	0.76	0.71	0.66	0.63	0.59	0.56	0.54
-1,000	0.78	0.73	0.67	0.64	0.60	0.57	0.55
-2,000	0.81	0.75	0.70	0.67	0.62	0.59	0.57
-3,000	0.83	0.78	0.72	0.69	0.65	0.61	0.59
-4,000	0.87	0.81	0.75	0.72	0.67	0.63	0.61
-5,000	0.90	0.84	0.78	0.74	0.69	0.66	0.63

Note:

1. Multiply constants in equations in Part 3 by values in the table.

AIR EQUATION FACTORS FOR DENSITY

Temperature °F

	Altitude Feet	600	650	700	750	800	900	1000
60,000	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
50,000	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
40,000	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.07
30,000	0.15	0.14	0.14	0.13	0.12	0.12	0.11	0.11
20,000	0.23	0.22	0.21	0.20	0.19	0.18	0.17	0.17
15,000	0.28	0.27	0.26	0.25	0.24	0.22	0.20	0.20
10,000	0.34	0.33	0.32	0.31	0.29	0.27	0.25	0.25
9,000	0.35	0.34	0.33	0.32	0.30	0.28	0.26	0.26
8,000	0.37	0.36	0.34	0.33	0.31	0.29	0.27	0.27
7,000	0.39	0.37	0.35	0.33	0.32	0.30	0.28	0.28
6,000	0.40	0.38	0.37	0.35	0.33	0.31	0.29	0.29
5,000	0.41	0.40	0.38	0.37	0.35	0.32	0.30	0.30
4,000	0.43	0.41	0.39	0.38	0.36	0.33	0.31	0.31
3,500	0.44	0.42	0.40	0.39	0.37	0.34	0.32	0.32
3,000	0.45	0.43	0.41	0.39	0.37	0.35	0.32	0.32
2,500	0.46	0.44	0.42	0.40	0.38	0.36	0.33	0.33
2,000	0.46	0.45	0.43	0.41	0.39	0.36	0.33	0.33
1,500	0.47	0.46	0.44	0.42	0.40	0.37	0.34	0.34
1,000	0.48	0.46	0.44	0.42	0.40	0.37	0.35	0.35
500	0.49	0.47	0.45	0.43	0.41	0.38	0.36	0.36
Sea Level	0.50	0.48	0.46	0.44	0.42	0.39	0.36	0.36
-500	0.51	0.49	0.47	0.45	0.43	0.40	0.37	0.37
-1,000	0.52	0.50	0.48	0.46	0.44	0.41	0.38	0.38
-2,000	0.54	0.52	0.49	0.47	0.45	0.42	0.39	0.39
-3,000	0.56	0.53	0.51	0.49	0.47	0.43	0.40	0.40
-4,000	0.58	0.55	0.53	0.51	0.48	0.45	0.42	0.42
-5,000	0.60	0.57	0.55	0.55	0.50	0.47	0.43	0.43

Note:

1. Multiply constants in equations in Part 3 by values in the table.

Altitude	600	650	700	750	800	900	1000
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46.04. Physical Properties of Gases—Comparison with Air

PHYSICAL PROPERTIES OF GASES

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	Sp. Gr.
Gases						
Air	-	28.996	Gas	13.333	0.075	1.0
Carbon	C	12.01	Solid	-	-	-
Hydrogen	H ₂	2.016	Gas	187.723	0.005	0.0
Ammonia	NH ₃	17.031	Gas	21.914	0.046	0.6
Sulfur	S	32.06	Gas	7.407	0.135	1.8
Hydrogen Sulfide	H ₂ S	34.076	Gas	10.979	0.091	1.2
Nitrous Oxide	N ₂ O	44.013	Gas	8.772	0.114	1.5
Ozone	O ₃	48.0	Gas	8.032	0.125	1.6
Argon	Ar	39.948	Gas	9.662	0.104	1.3
Chlorine	Cl ₂	70.906	Gas	5.442	0.184	2.4
Helium	He	4.002	Gas	96.618	0.010	0.1
Neon	Ne	20.179	Gas	19.130	0.052	0.6
Products of Combustion—Complete						
Carbon Dioxide	CO ₂	44.01	Gas	8.548	0.117	1.5
Water Vapor	H ₂ O	18.016	Gas	21.017	0.048	0.6
Oxygen	O ₂	32.000	Gas	11.819	0.085	1.1

Nitrogen Substance	N ₂ Formula	Molecular Weight	Gas Phase	Specific Volume 13.443 cu.ft./lb.m	Density 0.074 lbs.m/cu.ft.	Sp Gr
Products of Combustion—Incomplete						
Carbon Monoxide	CO	28.01	Gas	13.699	0.073	0.9
Nitric Oxide	NO	30.006	Gas	12.821	0.078	1.0
Nitrogen Dioxide	NO ₂	46.006	Gas	-	-	-
Nitrous Trioxide	NO ₃	62.005	Gas	-	-	-
NO _x	NO _x	-	Gas	-	-	-
Sulfuric Oxide	SO	48.063	Gas	-	-	-
Sulfur Dioxide	SO ₂	64.06	Gas	5.770	0.173	2.3
Sulfur Trioxide	SO ₃	80.062	Gas	-	-	-
SO _x	SO _x	-	Gas	-	-	-



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Part 47: Properties of Water

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47. Part 47: Properties of Water

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47.01. Properties of Water—Effects on Standard HVAC Water Equations

WATER EQUATION FACTORS

System Type	System Temperature Range °F	Equation Factor
Low Temperature (Glycol) Chilled Water	0-40	See Note 2
Chilled Water	40-60	500
Condenser Water Heat Pump Loop	60-110	500
Low Temperature Heating Water	110-150	490
	151-200	485
	201-250	480
Medium Temperature Heating Water	251-300	475
	301-350	470
High Temperature Heating Water	351-400	470
	401-450	470

Notes:

- 1. Water equation corrections for temperature, density, and specific heat.**
- 2. For glycol system equation factors, see Part 20.**

A. Water Equation Factor Derivations

1. Standard water conditions:

- Temperature: 60°F.
- Pressure: 14.7 psia (sea level)
- Density: 62.4 lbs./ft.³

2. Water equation examples:

$$H = m \times c_w \times \Delta T$$

Water @ 250°F

$$c_w = 1.02 \text{ Btu/Lb H}_2\text{O } ^\circ\text{F} \times 62.4 \text{ Lbs.H}_2\text{O/ft.}^3 \times 1.0 \text{ ft.}^3 / 7.48052 \text{ gal.} \times 60 \text{ min./h} \times 0.94 \text{ (SG)}$$

$$= 480 \text{ Btu min./h } ^\circ\text{F gal.}$$

$$H_{250F} = 480 \text{ Btu min./h } ^\circ\text{F Gal.} \times \text{GPM (gal./min.)} \times \Delta T (^\circ\text{F})$$

$$H_{250F} = 480 \times \text{GPM} \times \Delta T (^\circ\text{F})$$

Water @ 450°F

$$c_w = 1.13 \text{ Btu/Lb H}_2\text{O } ^\circ\text{F} \times 62.4 \text{ Lbs.H}_2\text{O/ft.}^3 \times 1.0 \text{ ft.}^3 / 7.48052 \text{ gal.} \times 60 \text{ min./h} \times 0.83 \text{ (SG)}$$

$$= 470 \text{ Btu min./h } ^\circ\text{F gal.}$$

$$H_{450F} = 470 \text{ Btu min./h } ^\circ\text{F gal.} \times \text{GPM (gal./min.)} \times \Delta T (^\circ\text{F})$$

$$H_{450F} = 470 \times \text{GPM} \times \Delta T (^\circ\text{F})$$

Refer to the online resource for Section 47.02 Thermodynamic Properties of Water.

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47.02. Thermodynamic Properties of Water

BOILING POINTS OF WATER

Psia	Boiling Point °F	Psia	Boiling Point °F	Psia	Boiling Point °F
0.5	79.6	44	273.1	150	358.5
1	101.7	46	275.8	175	371.8
2	126.0	48	278.5	200	381.9
3	141.4	50	281.0	225	391.9
4	152.9	52	283.5	250	401.0
5	162.2	54	285.9	275	409.5
6	170.0	56	288.3	300	417.4
7	176.8	58	290.5	325	424.8
8	182.8	60	292.7	350	431.8
9	188.3	62	294.9	375	438.4
10	193.2	64	297.0	400	444.7
11	197.7	66	299.0	425	450.7
12	201.9	68	301.0	450	456.4
13	205.9	70	303.0	475	461.9
14	209.6	72	304.9	500	467.1
14.69	212.0	74	306.7	525	472.2
15	213.0	76	308.5	550	477.1
16	216.3	78	310.3	575	481.8

17 Psia	Boiling Point °F	80 Psia	Boiling Point °F	600 Psia	Boiling Point °F
18	219.4	82	312.1	625	486.3
19	222.4	84	313.8	650	490.7
20	225.2	86	315.5	675	495.0
22	228.0	88	317.1	700	499.2
24	233.0	90	318.7	725	503.2
26	237.8	92	320.3	750	507.2
28	242.3	94	321.9	775	511.0
30	246.4	96	323.4	800	514.7
32	250.3	98	324.9	825	518.4
34	254.1	100	326.4	850	521.9
36	257.6	105	327.9	875	525.4
38	261.0	110	331.4	900	528.8
40	264.2	115	334.8	950	532.1
42	267.3	120	338.1	1000	538.6
	270.2		341.3		544.8

THERMODYNAMIC PROPERTIES OF WATER

Temp °F	Press Psia	Specific Volume ft. ³ /lb.			Enthalpy Btu/lb.		
		v _l	v _{lg}	v _g	h _l	h _{lg}	h _g
-80	0.000116	0.01732	1953234	1953234	-	1219.19	1025.0
-79	0.000125	0.01732	1814052	1814052	193.50	1219.24	1026.0
-78	0.000135	0.01732	1685445	1685445	-	1219.28	1026.0
-77	0.000145	0.01732	1566663	1566663	193.11	1219.33	1027.0
-76	0.000157	0.01732	1456752	1456752	-	1219.38	1027.0
					192.71		
					-		
					192.31		
					-		
					191.92		
-75	0.000169	0.01733	1355059	1355059	-	1219.42	1027.0
-74	0.000182	0.01733	1260977	1260977	191.52	1219.47	1028.0
-73	0.000196	0.01733	1173848	1173848	-	1219.51	1028.0
-72	0.000211	0.01733	1093149	1093149	191.12	1219.55	1029.0
-71	0.000227	0.01733	1018381	1018381	-	1219.59	1029.0

Temp °F	Press Psia	Specific Volume ft. /lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
					190.72		
					-		
					190.32		
					-		
					189.92		
-70	0.000245	0.01733	949067	949067	-	1219.63	1030.0
-69	0.000263	0.01733	884803	884803	189.52	1219.67	1030.0
-68	0.000283	0.01733	825187	825187	-	1219.71	1031.0
-67	0.000304	0.01734	769864	769864	189.11	1219.74	1031.4
-66	0.000326	0.01734	718508	718508	-	1219.78	1031.8
					188.71		
					-		
					188.30		
					-		
					187.90		
-65	0.000350	0.01734	670800	670800	-	1219.82	1032.0
-64	0.000376	0.01734	626503	626503	187.49	1219.85	1032.0
-63	0.000404	0.01734	585316	585316	-	1219.88	1033.0
-62	0.000433	0.01734	548041	548041	187.08	1219.91	1033.0
-61	0.000464	0.01734	511446	511446	-	1219.95	1034.0
					186.67		
					-		
					186.26		
					-		
					185.85		
-60	0.000498	0.01734	478317	478317	-	1219.98	1034.0
-59	0.000533	0.01735	447495	447495	185.44	1220.01	1034.0
-58	0.000571	0.01735	418803	418803	-	1220.03	1035.4
-57	0.000612	0.01735	392068	392068	185.03	1220.06	1035.8
-56	0.000655	0.01735	367172	367172	-	1220.09	1036.0
					184.61		
					-		
					184.20		
					-		
					183.78		
-55	0.000701	0.01735	343970	343970	-	1220.11	1036.0
-54	0.000750	0.01735	322336	322336	183.37	1220.14	1037.0
-53	0.000800	0.01735	302157	302157	-	1220.17	1037.0

Temp °F	Press Psia	Specific Volume ft. ³ /lb.	302157 283335	302157 283335	Enthalpy Btu/lb. h	1220.16 1220.18	1037.0 1038.0
-53	0.000802	0.01735	302157	302157	-	1220.16	1037.0
-52	0.000857	0.01735	283335	283335	182.95	1220.18	1038.0
-51	0.000916	0.01736	265773	265773	-	1220.21	1038.0
-50	0.000979	0.01736	249381	249381	182.53	1220.23	1038.0
-49	0.001045	0.01736	234067	234067	-	1220.25	1039.0
-48	0.001116	0.01736	219766	219766	181.27	1220.26	1039.0
-47	0.001191	0.01736	206398	206398	-	1220.28	1040.0
-46	0.001271	0.01736	193909	193909	180.85	1220.30	1040.0
-45	0.001355	0.01736	182231	182231	-	1220.31	1041.0
-44	0.001445	0.01736	171304	171304	180.42	1220.33	1041.0
-43	0.001541	0.01737	161084	161084	-	1220.34	1042.0
-42	0.001642	0.01737	151518	151518	179.14	1220.36	1042.0
-41	0.001749	0.01737	142566	142566	-	1220.37	1042.0
-40	0.001863	0.01737	134176	134176	178.72	1220.38	1043.0
-39	0.001984	0.01737	126322	126322	-	1220.39	1043.0
-38	0.002111	0.01737	118959	118959	178.29	1220.40	1044.0
-37	0.002247	0.01737	112058	112058	-	1220.40	1044.0
-36	0.002390	0.01738	105592	105592	177.86	1220.41	1045.0
-35					-	1220.41	1045.0
-34					177.43	1220.41	1045.0
-33					-	1220.41	1045.0
-32					176.13	1220.41	1045.0
-31					-	1220.41	1045.0
-30					175.70	1220.41	1045.0
-29					-	1220.41	1045.0
-28					175.26	1220.41	1045.0

Temp °F	Press Psia	Specific Volume ft. ³ /lb.	h Btu/lb.	s ft. ² /lb.	h	h	h
-35	0.002542	0.01738	99532	99532	-	1220.42	1045.9
-34	0.002702	0.01738	93828	93828	174.83	1220.42	1046.0
-33	0.002872	0.01738	88489	88489	-	1220.43	1046.4
-32	0.003052	0.01738	83474	83474	174.39	1220.43	1046.9
-31	0.003242	0.01738	78763	78763	-	1220.43	1047.0
					173.95		
					-		
					173.51		
					-		
					173.07		
-30	0.003443	0.01738	74341	74341	-	1220.43	1047.0
-29	0.003655	0.01738	70187	70187	172.63	1220.43	1048.0
-28	0.003879	0.01739	66282	66282	-	1220.43	1048.0
-27	0.004116	0.01739	62613	62613	172.19	1220.43	1049.0
-26	0.004366	0.01739	59161	59161	-	1220.43	1049.0
					171.74		
					-		
					171.30		
					-		
					170.86		
-25	0.004630	0.01739	55915	55915	-	1220.42	1050.0
-24	0.004909	0.01739	52861	52861	170.41	1220.42	1050.4
-23	0.005203	0.01739	49986	49986	-	1220.41	1050.9
-22	0.005514	0.01739	47281	47281	169.96	1220.41	1051.0
-21	0.005841	0.01740	44733	44733	-	1220.40	1051.0
					169.51		
					-		
					169.07		
					-		
					168.62		
-20	0.006186	0.01740	42333	42333	-	1220.39	1052.0
-19	0.006550	0.01740	40073	40073	168.16	1220.38	1052.0
-18	0.006933	0.01740	37943	37943	-	1220.37	1053.0
-17	0.007337	0.01740	35934	35934	167.71	1220.36	1053.0
-16	0.007763	0.01740	34041	34041	-	1220.34	1053.0
					167.26		
					-		
					166.81		

Temp °F	Press psia	Specific Volume ft. /lb.			Enthalpy Btu/lb.		
		v _g	v _f	v _h	h _g	h _f	h _h
-15	0.008211	0.01740	32256	32256	166.35	1220.33	1054.4
-14	0.008683	0.01741	30572	30572	165.90	1220.31	1054.8
-13	0.009179	0.01741	28983	28983	-	1220.30	1055.1
-12	0.009702	0.01741	27483	27483	165.44	1220.28	1055.5
-11	0.010252	0.01741	26067	26067	-	1220.26	1056.0
					164.98		
					-		
					164.52		
					-		
					164.06		
-10	0.010830	0.01741	24730	24730	-	1220.24	1056.0
-9	0.011438	0.01741	23467	23467	163.60	1220.22	1057.0
-8	0.012077	0.01741	22274	22274	-	1220.20	1057.5
-7	0.012749	0.01742	21147	21147	163.14	1220.18	1057.9
-6	0.013456	0.01742	20081	20081	-	1220.16	1058.4
					162.68		
					-		
					162.21		
					-		
					162.75		
-5	0.014197	0.01742	19074	19074	-	1220.13	1058.8
-4	0.014977	0.01742	18121	18121	161.28	1220.11	1059.2
-3	0.015795	0.01742	17220	17220	-	1220.08	1059.7
-2	0.016654	0.01742	16367	16367	160.82	1220.05	1060.1
-1	0.017556	0.01742	15561	15561	-	1220.02	1060.6
					160.35		
					-		
					159.88		
					-		
					159.41		
0	0.018502	0.01743	14797	14797	-	1220.00	1061.0
1	0.019495	0.01743	14073	14073	158.94	1219.96	1061.5
2	0.020537	0.01743	13388	13388	-	1219.93	1061.9
3	0.021629	0.01743	12740	12740	158.47	1219.90	1062.3
4	0.022774	0.01743	12125	12125	-	1219.87	1062.8
					157.99		

Temp °F	Press Psia	Specific Volume ft. /lb.			Enthalpy Btu/lb.		
		v	v	v	h	h	h
					157.52		
					157.05		
5	0.023975	0.01743	11543	11543	-	1219.83	1063.0
6	0.025233	0.01743	10991	10991	156.57	1219.80	1063.0
7	0.026552	0.01744	10468	10468	-	1219.76	1064.0
8	0.027933	0.01744	9971	9971	156.09	1219.72	1064.0
9	0.029379	0.01744	9500	9500	-	1219.68	1065.0
					155.62		
					-		
					155.14		
					-		
					154.66		
10	0.030894	0.01744	9054	9054	-	1219.64	1065.0
11	0.032480	0.01744	8630	8630	154.18	1219.60	1065.0
12	0.034140	0.01744	8228	8228	-	1219.56	1066.0
13	0.035878	0.01745	7846	7846	153.70	1219.52	1066.0
14	0.037696	0.01745	7483	7483	-	1219.47	1067.0
					153.21		
					-		
					152.73		
					-		
					152.24		
15	0.039597	0.01745	7139	7139	-	1219.43	1067.0
16	0.041586	0.01745	6811	6811	151.76	1219.38	1068.0
17	0.043666	0.01745	6501	6501	-	1219.33	1068.0
18	0.045841	0.01745	6205	6205	151.27	1219.28	1068.0
19	0.048113	0.01745	5924	5924	-	1219.23	1069.0
					150.78		
					-		
					150.30		
					-		
					149.81		
20	0.050489	0.01746	5657	5657	-	1219.18	1069.0
21	0.052970	0.01746	5404	5404	149.32	1219.13	1070.0
22	0.055563	0.01746	5162	5162	-	1219.08	1070.0

Temp °F	Press Psia	Specific Volume v	Specific Volume v	Specific Volume v	Enthalpy h	Enthalpy h	Enthalpy h
23	0.058271	0.01746	4932	4932	148.82	1219.02	1071.0
24	0.061099	0.01746	4714	4714	-	1218.97	1071.0
					148.33		
					-		
					147.84		
					-		
					147.34		
25	0.064051	0.01746	4506	4506	-	1218.91	1072.0
26	0.067133	0.01747	4308	4308	146.85	1218.85	1072.0
27	0.070349	0.01747	4119	4119	-	1218.80	1072.0
28	0.073706	0.01747	3940	3940	146.35	1218.74	1073.0
29	0.077207	0.01747	3769	3769	-	1218.68	1073.0
					145.85		
					-		
					145.35		
					-		
					144.85		
30	0.080860	0.01747	3606	3606	-	1218.61	1074.0
31	0.084669	0.01747	3450	3450	144.35	1218.55	1074.0
32	0.08865	0.01602	3302.07	3302.09	-	1075.15	1075.0
33	0.09229	0.01602	3178.15	3178.16	143.85	1074.59	1075.0
34	0.09607	0.01602	3059.47	3059.49	-0.02	1074.02	1076.0
					0.99		
					2.00		
35	0.09998	0.01602	2945.66	2945.68	3.00	1073.45	1076.0
36	0.10403	0.01602	2836.60	2836.61	4.01	1072.88	1076.0
37	0.10822	0.01602	2732.13	2732.15	5.02	1072.32	1077.0
38	0.11257	0.01602	2631.88	2631.89	6.02	1071.75	1077.0
39	0.11707	0.01602	2535.86	2535.88	7.03	1071.18	1078.0
40	0.12172	0.01602	2443.67	2443.69	8.03	1070.62	1078.0
41	0.12654	0.01602	2355.22	2355.24	9.04	1070.05	1079.0
42	0.13153	0.01602	2270.42	2270.43	10.04	1069.48	1079.0
43	0.13669	0.01602	2189.02	2189.04	11.04	1068.92	1079.0
44	0.14203	0.01602	2110.92	2110.94	12.05	1068.35	1080.0
45	0.14755	0.01602	2035.91	2035.92	13.05	1067.79	1080.0
46	0.15326	0.01602	1963.85	1963.87	14.05	1067.22	1081.0
47	0.15917	0.01602	1894.71	1894.73	15.06	1066.66	1081.0
48	0.16527	0.01602	1828.28	1828.28	16.06	1066.08	1082.0

			Specific Volume	ft. /lb.		Enthalpy	Btu/lb.
48	0.16527	0.01602	1828.28	1828.30	16.06	1066.09	1082.1
49	0.17158	0.01602	1764.44	1764.46	17.06	1065.53	1082.1
Temp	Press						
°F	Psia						
50	0.17811	0.01602	1703.18	1703.20	18.06	1064.96	1083.0
51	0.18484	0.01602	1644.25	1644.26	19.06	1064.40	1083.4
52	0.19181	0.01603	1587.64	1587.65	20.07	1063.83	1083.9
53	0.19900	0.01603	1533.22	1533.24	21.07	1063.27	1084.3
54	0.20643	0.01603	1480.89	1480.91	22.07	1062.71	1084.7
55	0.21410	0.01603	1430.61	1430.62	23.07	1062.14	1085.1
56	0.22202	0.01603	1382.19	1382.21	24.07	1061.58	1085.6
57	0.23020	0.01603	1335.65	1335.67	25.07	1061.01	1086.0
58	0.23864	0.01603	1290.85	1290.87	26.07	1060.45	1086.5
59	0.24735	0.01603	1247.76	1247.78	27.07	1059.89	1086.9
60	0.25635	0.01604	1206.30	1206.32	28.07	1059.32	1087.3
61	0.26562	0.01604	1166.38	1166.40	29.07	1058.76	1087.8
62	0.27519	0.01604	1127.93	1127.95	30.07	1058.19	1088.2
63	0.28506	0.01604	1090.94	1090.96	31.07	1057.63	1088.7
64	0.29524	0.01604	1055.32	1055.33	32.07	1057.07	1089.1
65	0.30574	0.01604	1020.98	1021.00	33.07	1056.50	1089.5
66	0.31656	0.01604	987.95	987.97	34.07	1055.94	1090.0
67	0.32772	0.01605	956.11	956.12	35.07	1055.37	1090.4
68	0.33921	0.01605	925.44	925.45	36.07	1054.81	1090.8
69	0.35107	0.01605	895.86	895.87	37.07	1054.24	1091.2
70	0.36328	0.01605	867.34	867.36	38.07	1053.68	1091.6
71	0.37586	0.01605	839.87	839.88	39.07	1053.11	1092.0
72	0.38882	0.01606	813.37	813.39	40.07	1052.55	1092.4
73	0.40217	0.01606	787.85	787.87	41.07	1051.98	1093.0
74	0.41592	0.01606	763.19	763.21	42.06	1051.42	1093.4
75	0.43008	0.01606	739.42	739.44	43.06	1050.85	1093.9
76	0.44465	0.01606	716.51	716.53	44.06	1050.29	1094.3
77	0.45966	0.01607	694.38	694.40	45.06	1049.72	1094.7
78	0.47510	0.01607	673.05	673.06	46.06	1049.16	1095.1
79	0.49100	0.01607	652.44	652.46	47.06	1048.59	1095.6
80	0.50736	0.01607	632.54	632.56	48.06	1048.03	1096.0
81	0.52419	0.01608	613.35	613.37	49.06	1047.46	1096.4
82	0.54150	0.01608	594.82	594.84	50.05	1046.89	1096.8
83	0.55931	0.01608	576.90	576.92	51.05	1046.33	1097.2
84	0.57763	0.01608	559.63	559.65	52.05	1045.76	1097.6

		Specific Volume ft. ³ /lb.			Enthalpy Btu/lb.		
85	0.59647	0.01609	542.93	542.94	53.05	1045.19	1098.5
Temp	Press	v	v	v	h	h	h
87	0.61994	0.01609	526.80	526.81	54.05	1044.63	1098.0
87	0.63975	0.01609	511.21	511.22	55.05	1044.06	1099.5
88	0.65622	0.01609	496.14	496.15	56.05	1043.49	1099.0
89	0.67726	0.01610	481.60	481.61	57.04	1042.92	1099.0
90	0.69889	0.01610	467.52	467.53	58.04	1042.36	1100.4
91	0.72111	0.01610	453.91	453.93	59.04	1041.79	1100.8
92	0.74394	0.01611	440.76	440.78	60.04	1041.22	1101.2
93	0.76740	0.01611	428.04	428.06	61.04	1040.65	1101.6
94	0.79150	0.01611	415.74	415.76	62.04	1040.08	1102.0
95	0.81625	0.01612	403.84	403.86	63.03	1039.51	1102.4
96	0.84166	0.01612	392.33	392.34	64.03	1038.95	1102.9
97	0.86776	0.01612	381.20	381.21	65.03	1038.38	1103.4
98	0.89456	0.01612	370.42	370.44	66.03	1037.81	1103.8
99	0.92207	0.01613	359.99	360.01	67.03	1037.24	1104.2
100	0.95031	0.01613	349.91	349.92	68.03	1036.67	1104.6
101	0.97930	0.01613	340.14	340.15	69.03	1036.10	1105.0
102	1.00904	0.01614	330.69	330.71	70.02	1035.53	1105.4
103	1.03956	0.01614	321.53	321.55	71.02	1034.95	1105.8
104	1.07088	0.01614	312.67	312.69	72.02	1034.38	1106.2
105	1.10301	0.01615	304.08	304.10	73.02	1033.81	1106.6
106	1.13597	0.01615	295.76	295.77	74.02	1033.24	1107.0
107	1.16977	0.01616	287.71	287.73	75.01	1032.67	1107.4
108	1.20444	0.01616	279.91	279.92	76.01	1032.10	1107.8
109	1.23999	0.01616	272.34	272.36	77.01	1031.52	1108.2
110	1.27644	0.01617	265.02	265.03	78.01	1030.95	1108.6
111	1.31381	0.01617	257.91	257.93	79.01	1030.38	1109.0
112	1.35212	0.01617	251.02	251.04	80.01	1029.80	1109.4
113	1.39138	0.01618	244.36	244.38	81.01	1029.23	1110.0
114	1.43162	0.01618	237.89	237.90	82.00	1028.66	1110.4
115	1.47286	0.01619	231.62	231.63	83.00	1028.08	1111.0
116	1.51512	0.01619	225.53	225.55	84.00	1027.51	1111.4
117	1.55842	0.01619	219.63	219.65	85.00	1026.93	1111.8
118	1.60277	0.01620	213.91	213.93	86.00	1026.36	1112.2
119	1.64820	0.01620	208.36	208.37	87.00	1025.78	1112.6
120	1.69474	0.01620	202.98	202.99	88.00	1025.20	1113.0

Temp F	Press Psia	Specific Volume ft ³ /lb	Specific Volume ft ³ /lb	Specific Volume ft ³ /lb	Enthalpy Btu/lb	Enthalpy Btu/lb	Enthalpy Btu/lb
121	1.74240	0.01621	197.76	197.76	89.00	1019.62	1113.0
122	1.79117	0.01621	192.69	192.69	90.00	1024.05	1114.0
123	1.84117	0.01622	187.78	187.78	90.99	1024.47	1114.4
124	1.89233	0.01622	182.98	182.99	91.99	1022.90	1114.8
125	1.94470	0.01623	178.34	178.36	92.99	1022.32	1115.2
126	1.99831	0.01623	173.85	173.86	93.99	1021.74	1115.7
127	2.05318	0.01623	169.47	169.49	94.99	1021.16	1116.2
128	2.10934	0.01624	165.23	165.25	95.99	1020.58	1116.7
129	2.16680	0.01624	161.11	161.12	96.99	1020.00	1116.9
130	2.22560	0.01625	157.11	157.12	97.99	1019.42	1117.4
131	2.28576	0.01625	153.22	153.23	98.99	1018.84	1117.8
132	2.34730	0.01626	149.44	149.46	99.99	1018.26	1118.2
133	2.41025	0.01626	145.77	145.78	100.99	1017.68	1118.0
134	2.47463	0.01627	142.21	142.23	101.99	1017.10	1119.0
135	2.54048	0.01627	138.74	138.76	102.99	1016.52	1119.5
136	2.60782	0.01627	135.37	135.39	103.98	1015.93	1119.9
137	2.67667	0.01628	132.10	132.12	104.98	1015.35	1120.2
138	2.74707	0.01628	128.92	128.94	105.98	1014.77	1120.7
139	2.81903	0.01629	125.83	125.85	106.98	1014.18	1121.1
140	2.89260	0.01629	122.82	122.84	107.98	1013.60	1121.5
141	2.96780	0.01630	119.90	119.92	108.98	1013.01	1122.0
142	3.04465	0.01630	117.05	117.07	109.98	1012.43	1122.4
143	3.12320	0.01631	114.29	114.31	110.98	1011.84	1122.8
144	3.20345	0.01631	111.60	111.62	111.98	1011.26	1123.2
145	3.28546	0.01632	108.99	109.00	112.98	1010.67	1123.0
146	3.36924	0.01632	106.44	106.45	113.98	1010.09	1124.0
147	3.45483	0.01633	103.96	103.98	114.98	1009.50	1124.4
148	3.54226	0.01633	101.55	101.57	115.98	1008.91	1124.8
149	3.63156	0.01634	99.21	99.22	116.98	1008.32	1125.2
150	3.72277	0.01634	96.93	96.94	117.98	1007.73	1125.7
151	3.81591	0.01635	94.70	94.72	118.99	1007.14	1126.2
152	3.91101	0.01635	92.54	92.56	119.99	1006.55	1126.6
153	4.00812	0.01636	90.44	90.46	120.99	1005.96	1126.9
154	4.10727	0.01636	88.39	88.41	121.99	1005.37	1127.2
155	4.20848	0.01637	86.40	86.41	122.99	1004.78	1127.7
156	4.31180	0.01637	84.45	84.47	123.99	1004.19	1128.2

Temp °F	Press Psia	Specific Volume ft. ³ /lb.	Specific Volume ft. ³ /lb.	Enthalpy Btu/lb.	Enthalpy Btu/lb.	Enthalpy Btu/lb.	
157	4.41725	0.01638	82.56	82.58	124.99	1003.60	1128.9
158	4.52488	0.01638	80.72	80.73	125.99	1003.00	1128.9
159	4.63472	0.01639	78.92	78.94	126.99	1002.41	1129.4
160	4.7468	0.01639	77.175	77.192	127.99	1001.82	1129.8
161	4.8612	0.01640	75.471	75.488	128.99	1001.22	1130.2
162	4.9778	0.01640	73.812	73.829	130.00	1000.63	1130.6
163	5.0969	0.01641	72.196	72.213	131.00	1000.03	1131.0
164	5.2183	0.01642	70.619	70.636	132.00	999.43	1131.4
165	5.3422	0.01642	69.084	69.101	133.00	998.84	1131.8
166	5.4685	0.01643	67.587	67.604	134.00	998.24	1132.2
167	5.5974	0.01643	66.130	66.146	135.00	997.64	1132.6
168	5.7287	0.01644	64.707	64.723	136.01	997.04	1133.0
169	5.8627	0.01644	63.320	63.336	137.01	996.44	1133.4
170	5.9993	0.01645	61.969	61.989	138.01	995.84	1133.8
171	6.1386	0.01646	60.649	60.666	139.01	995.24	1134.2
172	6.2806	0.01646	59.363	59.380	140.01	994.64	1134.6
173	6.4253	0.01647	58.112	58.128	141.02	994.04	1135.0
174	6.5729	0.01647	56.887	56.904	142.02	993.44	1135.4
175	6.7232	0.01648	55.694	55.711	143.02	992.83	1135.8
176	6.8765	0.01648	54.532	54.549	144.03	992.23	1136.2
177	7.0327	0.01649	53.397	53.414	145.03	991.63	1136.6
178	7.1918	0.01650	52.290	52.307	146.03	991.02	1137.0
179	7.3539	0.01650	51.210	51.226	147.03	990.42	1137.4
180	7.5191	0.01651	50.155	50.171	148.04	989.81	1137.8
181	7.6874	0.01651	49.126	49.143	149.04	989.20	1138.2
182	7.8589	0.01652	48.122	48.138	150.04	988.60	1138.6
183	8.0335	0.01653	47.142	47.158	151.05	987.99	1139.0
184	8.2114	0.01653	46.185	46.202	152.05	987.38	1139.4
185	8.3926	0.01654	45.251	45.267	153.05	986.77	1139.8
186	8.5770	0.01654	44.339	44.356	154.06	986.16	1140.2
187	8.7649	0.01655	43.448	43.465	155.06	985.55	1140.6
188	8.9562	0.01656	42.579	42.595	156.07	984.94	1141.0
189	9.1510	0.01656	41.730	41.746	157.07	984.32	1141.4
190	9.3493	0.01657	40.901	40.918	158.07	983.71	1141.8
191	9.5512	0.01658	40.092	40.108	159.08	983.10	1142.2
192	9.7567	0.01658	39.301	39.317	160.08	982.48	1142.6
193	9.9659	0.01659	38.528	38.544	161.08	981.87	1143.0

		Specific Volume ft. /lb.			Enthalpy Btu/lb.		
193	9.9659	0.01659	38.528	38.544	161.09	981.87	1142.9
194	10.1788	0.01659	37.774	37.790	162.09	981.25	1143.9
Temp	Press						
195	10.3955	0.01660	37.035	37.052	163.10	980.63	1143.9
196	10.6160	0.01661	36.314	36.331	164.10	980.02	1144.9
197	10.8404	0.01661	35.611	35.628	165.11	979.40	1144.9
198	11.0687	0.01662	34.923	34.940	166.11	978.78	1144.9
199	11.3010	0.01663	34.251	34.268	167.12	978.16	1145.9
200	11.5374	0.01663	33.594	33.610	168.13	977.54	1145.9
201	11.7779	0.01664	32.951	32.968	169.13	976.92	1146.9
202	12.0225	0.01665	32.324	32.340	170.14	976.29	1146.9
203	12.2713	0.01665	31.710	31.726	171.14	975.67	1146.9
204	12.5244	0.01666	31.110	31.127	172.15	975.05	1147.9
205	12.7819	0.01667	30.523	30.540	173.16	974.42	1147.9
206	13.0436	0.01667	29.949	29.965	174.16	973.80	1147.9
207	13.3099	0.01668	29.388	29.404	175.17	973.17	1148.9
208	13.5806	0.01669	28.839	28.856	176.18	972.54	1148.9
209	13.8558	0.01669	28.303	28.319	177.18	971.92	1149.9
210	14.1357	0.01670	27.778	27.795	178.19	971.29	1149.9
212	14.7096	0.01671	26.763	26.780	180.20	970.03	1150.9
214	15.3025	0.01673	25.790	25.807	182.22	968.76	1150.9
216	15.9152	0.01674	24.861	24.878	184.24	967.50	1151.9
218	16.5479	0.01676	23.970	23.987	186.25	966.23	1152.9
220	17.2013	0.01677	23.118	23.134	188.27	964.95	1153.9
222	17.8759	0.01679	22.299	22.316	190.29	963.67	1153.9
224	18.5721	0.01680	21.516	21.533	192.31	962.39	1154.9
226	19.2905	0.01682	20.765	20.782	194.33	961.11	1155.9
228	20.0316	0.01683	20.045	20.062	196.35	959.82	1156.9
230	20.7961	0.01684	19.355	19.372	198.37	958.52	1156.9
232	21.5843	0.01686	18.692	18.709	200.39	957.22	1157.9
234	22.3970	0.01688	18.056	18.073	202.41	955.92	1158.9
236	23.2345	0.01689	17.466	17.463	204.44	954.62	1159.9
238	24.0977	0.01691	16.860	16.877	206.46	953.31	1159.9
240	24.9869	0.01692	16.298	16.314	208.49	952.00	1160.9
242	25.9028	0.01694	15.757	15.774	210.51	950.68	1161.9
244	26.8461	0.01695	15.238	15.255	212.54	948.35	1161.9
246	27.8172	0.01697	14.739	14.756	214.57	948.03	1162.9
248	28.8169	0.01698	14.259	14.276	216.60	946.70	1163.9

		Specific Volume ft. /lb.			Enthalpy Btu/lb.		
Temp	Press	v	v	v	h	h	h
°F	Psia						
250	29.8457	0.01700	13.798	13.815	218.63	945.36	1163.9
252	30.9643	0.01702	13.355	13.372	220.66	944.02	1164.0
254	31.9994	0.01703	12.928	12.945	222.69	942.68	1165.0
256	33.1135	0.01705	12.526	12.147	224.73	939.99	1166.0
258	34.2653	0.01707	12.123	12.140	226.76	939.97	1166.0
260	35.4496	0.01708	11.742	11.759	228.79	938.61	1167.4
262	36.6669	0.01710	11.376	11.393	230.83	937.25	1168.0
264	37.9180	0.01712	11.024	11.041	232.87	935.88	1168.0
266	39.2035	0.01714	10.684	10.701	234.90	934.50	1169.4
268	40.5241	0.01715	10.357	10.374	236.94	933.12	1170.0
270	41.8806	0.01717	10.042	10.059	238.98	931.74	1170.0
272	43.2736	0.01719	9.737	9.755	241.03	930.35	1171.0
274	44.7040	0.01721	9.445	9.462	243.07	928.95	1172.0
276	46.1723	0.01722	9.162	9.179	245.11	927.55	1172.0
278	47.6794	0.01724	8.890	8.907	247.16	926.15	1173.0
280	49.2260	0.01726	8.627	8.644	249.20	924.74	1173.0
282	50.8128	0.01728	8.373	8.390	251.25	923.32	1174.0
284	52.4406	0.01730	8.128	8.146	253.30	921.90	1175.0
286	54.1103	0.01731	7.892	7.910	255.35	920.47	1175.0
288	55.8225	0.01733	7.664	7.681	257.40	919.03	1176.4
290	57.5780	0.01735	7.444	7.461	259.45	917.59	1177.0
292	59.3777	0.01737	7.231	7.248	261.51	916.15	1177.0
294	61.2224	0.01739	7.026	7.043	263.56	914.69	1178.0
296	63.1128	0.01741	6.827	6.844	265.62	913.24	1178.0
298	65.0498	0.01743	6.635	6.652	267.68	911.77	1179.4
300	67.03	0.01745	6.450	6.467	269.74	910.3	1180.0
302	69.01	0.01747	6.275	6.292	271.79	909.0	1180.0
304	71.09	0.01749	6.102	6.119	273.86	907.5	1181.0
306	73.22	0.01751	5.933	5.951	275.93	906.0	1181.0
308	75.40	0.01753	5.771	5.789	278.00	904.5	1182.0
310	77.64	0.01755	5.614	5.632	280.06	903.0	1183.0
312	79.92	0.01757	5.462	5.480	282.13	901.5	1183.0
314	82.26	0.01759	5.315	5.333	284.21	899.9	1184.0
316	84.65	0.01761	5.172	5.190	286.28	898.4	1184.0
318	87.10	0.01763	5.034	5.052	288.36	896.9	1185.0
320	89.60	0.01765	4.901	4.919	290.43	895.3	1185.0

Temp F	Press psia	Specific Volume ft ³ /lb	Specific Volume ft ³ /lb	Specific Volume ft ³ /lb	Enthalpy Btu/lb	Enthalpy Btu/lb	Enthalpy Btu/lb
322	92.16	0.01767	4.772	4.790	292.51	893.8	1186.0
324	94.78	0.01770	4.647	4.665	294.59	892.2	1186.0
326	97.46	0.01772	4.525	4.543	296.67	890.7	1187.0
328	100.20	0.01774	4.408	4.426	298.76	889.1	1187.0
330	103.00	0.01776	4.294	4.312	300.84	887.5	1188.0
332	105.86	0.01778	4.183	4.201	302.93	885.9	1188.0
334	108.78	0.01780	4.076	4.094	305.02	884.3	1189.0
336	111.76	0.01783	3.973	3.991	307.11	882.7	1189.0
338	114.82	0.01785	3.872	3.890	309.21	881.1	1190.0
340	117.93	0.01787	3.774	3.792	311.30	879.5	1190.0
342	121.11	0.01789	3.680	3.698	313.39	877.9	1191.0
344	124.36	0.01792	3.588	3.606	315.49	876.3	1191.0
346	127.68	0.01794	3.499	3.517	317.59	874.6	1192.0
348	131.07	0.01796	3.412	3.430	319.70	873.0	1192.0
350	134.53	0.01799	3.328	3.346	321.80	871.3	1193.0
352	138.06	0.01801	3.247	3.265	323.91	869.6	1193.0
354	141.66	0.01804	3.167	3.185	326.02	868.0	1194.0
356	145.34	0.01806	3.091	3.109	328.13	866.3	1194.0
358	149.09	0.01808	3.286	3.304	330.24	864.6	1194.0
360	152.92	0.01811	2.943	2.961	332.35	862.9	1195.0
362	156.82	0.01813	2.873	2.891	334.47	861.2	1195.0
364	160.80	0.01816	2.804	2.822	336.59	859.5	1196.0
366	164.87	0.01818	2.738	2.756	338.71	857.7	1196.0
368	169.01	0.01821	2.673	2.691	340.83	856.0	1196.0
370	173.23	0.01823	5.283	2.628	342.96	854.2	1197.0
372	177.53	0.01826	2.549	2.567	345.08	852.5	1197.0
374	181.92	0.01828	2.325	2.508	347.21	850.7	1197.0
376	186.39	0.01831	2.432	2.450	349.35	848.9	1198.0
378	190.95	0.01834	2.376	2.394	351.48	847.2	1198.0
380	195.60	0.01836	2.321	2.339	353.62	845.4	1199.0
382	200.33	0.01839	2.268	2.286	355.76	843.6	1199.0
384	205.15	0.01842	2.216	2.234	357.90	841.7	1199.0
386	210.06	0.01844	2.165	2.183	360.04	839.9	1199.0
388	215.06	0.01847	2.116	2.134	362.19	838.1	1200.0
390	220.2	0.01850	2.069	2.087	364.34	836.2	1200.0
392	225.3	0.01853	2.021	2.040	366.49	834.4	1200.0

Temp °F	Press Psia	Specific Volume ft. ³ /lb.	Specific Volume ft. ³ /lb.	Specific Volume ft. ³ /lb.	Enthalpy Btu/lb.	Enthalpy Btu/lb.	Enthalpy Btu/lb.
394	230.6	0.01855	1.976	1.995	368.64	832.5	1201.0
396	236.0	0.01858	1.932	1.951	370.80	830.6	1204.4
398	241.5	0.01861	1.889	1.908	372.96	828.7	1207.8
400	247.1	0.01864	1.847	1.866	375.12	826.8	1201.0
405	261.4	0.01871	1.747	1.766	380.53	822.0	1202.0
410	276.5	0.01878	1.654	1.673	385.97	817.2	1203.0
415	292.1	0.01886	1.566	1.585	391.42	812.2	1203.0
420	308.5	0.01894	1.483	1.502	396.89	807.2	1204.0
425	325.6	0.01901	1.406	1.425	402.38	802.1	1204.4
430	343.3	0.01909	1.333	1.352	407.89	796.9	1204.7
435	361.9	0.01918	1.265	1.284	413.42	791.7	1205.0
440	381.2	0.01926	1.200	1.219	418.98	786.3	1205.0
445	401.2	0.01935	1.139	1.158	424.55	780.9	1205.4
450	422.1	0.01943	1.082	1.101	430.20	775.4	1205.0
455	443.8	0.01952	1.027	1.047	435.80	769.8	1205.0
460	466.3	0.01961	0.976	0.996	441.40	764.1	1205.0
465	489.8	0.01971	0.928	0.948	447.10	758.3	1205.4
470	514.1	0.01980	0.883	0.903	452.80	752.4	1205.0
475	539.3	0.01990	0.840	0.8594	458.5	746.4	1204.0
480	565.5	0.02000	0.799	0.8187	464.3	740.3	1204.0
485	592.6	0.02011	0.760	0.7801	470.1	734.1	1204.0
490	620.7	0.02021	0.723	0.7436	475.9	727.8	1203.0
495	649.8	0.02032	0.689	0.7090	481.8	721.3	1203.0
500	680.0	0.02043	0.656	0.6761	487.7	714.8	1202.0
525	847.1	0.02104	0.514	0.5350	517.8	680.0	1197.0
550	1044.0	0.02175	0.406	0.4249	549.1	641.6	1190.0
575	1274.0	0.02259	0.315	0.3378	581.9	598.6	1180.0
600	1541.0	0.02363	0.244	0.2677	616.7	549.7	1166.0



PROPERTIES OF WATER

Temp °F	Specific Heat Btu/lb. °F	Density lbs./ft. ³	Specific Gravity
32-100	1.00	62.40	1.000
101-150	1.00	61.15	0.980
151-200	1.01	59.90	0.960
201-250	1.02	58.66	0.940
251-300	1.03	57.41	0.920
301-350	1.05	55.85	0.895
351-400	1.08	53.98	0.865
401-450	1.13	51.79	0.830

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 47: Properties of Water, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 48: Cleanroom Criteria

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48. Part 48: Cleanroom Criteria

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48.01. Airborne Contaminants

A. Particle Classifications

1. Fine	<2.5 microns
2. Course	2.5 microns
3. Respirable	<10.0 microns
4. Nonrespirable	10.0 microns

B. Relative Sizes

1. Micron = 1 millionth of a meter (0.000001 meter) = 39 millionths of an in. (0.000039 in.)	
2. Visible to the naked eye:	25 microns
3. Human hair:	100 microns
4. Dust:	25 microns
5. Optical microscope:	0.25 microns
6. Scanning electron microscope:	0.002 microns
7. Macro particle range	25 microns and larger
8. Micro particle range	1.0-25 microns
9. Molecular macro range	0.085-1.0 microns
10. Molecular range	0.002-0.085 microns
11. Ionic range	0.002 microns and smaller

C. Airborne particle sizes are given in the following table:

AIRBORNE PARTICLE SIZE TABLE

Particle	Particle Size Microns	Particle	Particle Size Microns
Plant			
Pollen	10-100	Tea dust	8-300
Spanish moss	150-750	Grain dusts	5-1,000+
pollen	3-12	Sawdust	30-600
Mold			
Spores	3-40	Corn starch	0.09-0.75
Starches	3-100	Pudding mix	3-160
Milled flour	1-100	Cayenne pepper	15-1,000
Milled corn	1-100	Snuff	3-30
Mustard	6-10	Textile fibers	8-1,000+
Ginger	25-40	Corn cob chaff	30-100
Coffee	5-400	Carbon black	0.2-10
Coffee roast soot	0.6-3.5	Channel black	0.2-100
Animal			
Bacteria	0.2-5.0	Human hair	50-100

Particle	Particle Size Microns	Particle	Particle Size Microns
Bacteria	0.5-60	Human hair	60-600
Virus	0.005-0.1	Hair	5-200
Dust mites	100-300	Red blood cells	5-10
Spider web	2.5	Liquid droplets:	-
Disintegrated feces	0.8-1.5	sneezed	0.5-5
Feces	10-45	Bone dust	3-350
Combustion			
Combustion	0.01-0.1	Smoke particles:	-
Tobacco smoke	0.01-4.5	natural materials	0.01-0.1
Burning wood	0.2-3	synthetic materials	1-50
Rosin smoke	0.01-1	Smoldering	-
Coal flue gas	0.08-0.2	cooking oil	0.3-0.9
Oil smoke	0.03-1	Flaming cooking oil	0.3-0.9
		Auto emissions	1-150
Fly ash	0.9-1000		
Mineral			
Asbestos	0.7-90	Carbon dust	0.25-5
Cement dust	3-100	Carbon dust-	0.02-2
Coal dust	1-100	graphite	10-1,000
		Fertilizer	
Sea salt	0.035-0.5	Ground	10-1,000
Textiles	6-20	limestone	0.1-0.7
Clay	0.1-50	Lead	0.1-0.7
		Bromine	
Calcium, zinc	0.7-20	Glass wool	1,000
Iron	4-20	Fiberglass	8
Lead dust	2	Insulation	1-1,000
Talc	0.5-50	Metallurgical	0.1-1,000
NH ₃ Cl fumes	0.1-3	dust	0.1-1,000
		Metallurgical fumes	
Other			

Atmospheric dust	0.001-40 Particle Size Microns	Yeast cells Sugars	2-75 Particle Size Microns
Lung damaging dust	0.6-7	Gelatin	0.0008-0.005
Mist	70-350		5-90
Oxygen	0.00050	Beach sand	100-10,000
Carbon dioxide	0.00065	Copier toner	0.5-15
Atomic radii	0.0001-0.001	Fabric protector	2.5-5
Air freshener	0.2-2	Face powder	0.1-30
Hairspray	3-7	Lint	10-90
Spray paint	8-10	Humidifier	0.9-3
Antiperspirant	6-10	Artificial textile fibers	- 10-30
Dusting aid	6-15	Insecticide dusts	0.5-10
Paint pigments	0.1-5		

D. Cleanroom Definitions

1. A *clean zone* is a defined space in which the concentration of airborne particles is controlled to meet a specified airborne particulate cleanliness class.
2. A *cleanroom* is a room in which the concentration of airborne particles is controlled and which contains one or more clean zones.
 - a. An as-built cleanroom is a cleanroom complete and ready for operation, certifiable, with all services connected and functional, but without equipment or operating personnel in the facility.
 - b. An at-rest cleanroom is a cleanroom that is complete, with all services functioning and with equipment installed and operable or operating, as specified, but without operating personnel in the facility.
 - c. An operational cleanroom is a cleanroom in normal operation, with all services functioning and with equipment and personnel, if applicable, present and performing their normal work functions in the facility.

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48.02. Cleanroom Class Designations: FED-STD-209E

CLEANROOM CLASS DESIGNATIONS

Class Limits

Cleanroom Class Name		0.1 μm		0.2 μm		0.3 μm		0.5 μm
		Volume Units	Volume Units	Volume Units	Volume Units	Volume Units	Volume Units	
SI	English	M ³	Ft. ³	M ³	Ft. ³	M ³	Ft. ³	M ³
M1		350	9.91	75.7	2.14	30.9	0.875	10.0
M1.5	1	1,240	35.0	265	7.50	106	3.00	35.3
M2		3,500	99.1	757	21.4	309	8.75	100
M2.5	10	12,400	350	2,650	75.0	1,060	30.0	353
M3		35,000	991	7,570	214	3,090	87.5	1,000
M3.5	100	-	-	26,500	750	10,600	300	3,530
M4		-	-	75,700	2,140	30,900	875	10,000
M4.5	1,000	-	-	-	-	-	-	35,300
M5		-	-	-	-	-	-	100,000
M5.5	10,000	-	-	-	-	-	-	353,000
M6		-	-	-	-	-	-	1,000,000
M6.5	100,000	-	-	-	-	-	-	3,530,000
M7		-	-	-	-	-	-	10,000,000

Notes:

- 1. Federal Standard 209E is obsolete and superseded by the International ISO 14644.**
- 2. Federal Standard 209E information provided for comparison purposes**



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48.03. Cleanroom Class Designations: ISO Standard 14644-1

CLEANROOM CLASS DESIGNATIONS

Maximum Number of Particles in the Air (Particles in Each Cubic Meter Equal to or Greater than the Specified Particle)

**Cubic Meter Equal to or Greater than the Specified Particle Size)
Maximum Number of Particles in the Air (Particles in Each
Cubic Meter Equal to or Greater than the Specified Particle
Particle Size)**

ISO Class	>0.1 μm	>0.2 μm	>0.3 μm	>0.5 μm	>1.0 μm	>5.0 μm
ISO Class 1	0	0	0	0	0	0
ISO Class 2	100	24	10	4	0	0
ISO Class 3	1,000	237	102	35	8	0
ISO Class 4	10,000	2,370	1,020	352	83	0
ISO Class 5	100,000	23,700	10,200	3,520	832	29
ISO Class 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO Class 7				352,000	83,200	2,930
ISO Class 8				3,520,000	832,000	29,300
ISO Class 9				35,200,000	8,320,000	293,000

Notes:

1. Cleanrooms are maintained virtually free of contaminants, such as

dust or bacteria, are used in laboratory work, and in the production of precision parts for electronic or aerospace equipment.

Maximum Number of Particles in the Air (Particles in Each Cubic Meter Equal to or Greater than the Specified Particle Size)

2. In the cleanroom standard ISO 14644-1 *Classification of Air*

Cleanliness, the classes are based on the formula:

$$C_n = 10^N (0.1/D)^{2.08}$$

where $>0.1 \mu\text{m}$ $>0.2 \mu\text{m}$ $>0.3 \mu\text{m}$ $>0.5 \mu\text{m}$ $>1.0 \mu\text{m}$ $>5.0 \mu\text{m}$

C_n = the maximum permitted number of particles per cubic meter equal to or greater than the specified particle size, rounded to a whole number

N = the ISO Class number, which must be a multiple of 1 and be 9 or less

D = the particle size in micrometers

3. ISO Cleanroom Standards

ISO 14644-1 Classification of Air Cleanliness

ISO 14644-2 Cleanroom Testing for Compliance

ISO 14644-3 Methods for Evaluating and Measuring Cleanroom and Associated Controlled Environment

ISO 14644-4 Cleanroom Design and Construction

ISO 14644-5 Cleanroom Operations

ISO 14644-6 Terms, Definitions, and Units

ISO 14644-7 Enhanced Clean Devices

ISO 14644-8 Molecular Contamination

ISO 14698-1 Bio-contamination: Control General Principles

ISO 14698-2 Bio-contamination: Evaluation and Interpretation of Data

ISO 14698-3 Bio-contamination: Methodology for Measuring Efficiency of Cleaning Inert Surfaces

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48.04. Cleanroom Design Criteria

CLEANROOM DESIGN CRITERIA

Cleanroom Design Criteria	Federal Standard 209e Classifications English/Metric					
	1	10	100	1,000	10,000	100,000
	M1.5	M2.5	M3.5	M4.5	M5.5	M6.0
ISO Class	360	360	210-540	120	30-120	12-60

Circulation Room AC/Design Criteria	Federal Standard 209e Classifications					
	300- 540	300- 540	210-340	120- 300	30-120	12-30
	1	10	100	1,000	10,000	100,000
Room Air Velocity ft./min.	60-120	60-120	35-90 (1)	20-45	5-25	2-16
% Filter Coverage	100	100	50-100 (1)	25-60	10-40	5-20
Room Characteristics	Laminar	Laminar	Laminar/non- laminar	Non- laminar	Non- laminar	Non- laminar
Unidirectional Flow	Yes	Yes	Yes/No	No	No	No
Parallelism Degrees (2)	10-35	10-35	10-35 N/A	N/A	N/A	N/A

Notes:

- 1. Velocity and filter coverage could be reduced possibly as low as 35 fpm and 50 percent coverage if parallelism requirements are relaxed by the client.**
- 2. Parallelism requirements are often driven by a client's standard facility criteria.**
- 3. Makeup air: 1-6 CFM/sq.ft.**
- 4. Pressurization requirement: 1/4-1/2 CFM/sq.ft.**
- 5. Temperature**
 - a. Range: 68-74°F**
 - b. Tolerance: ±0.1-±2.0°F**
 - c. Change rate: 0.75-2.0°F/h**
 - d. Example: 72°F, ±2.0°F**
- 6. Relative humidity**
 - a. Range: 30-50 percent RH**
 - b. Tolerance: ±1.0-± 5.0 percent RH**
 - c. Change rate: 1.0-5.0 percent RH/h**

c. Change rate: 1.0-5.0 percent RH/h

Federal Standard 209e Classifications English/Metric

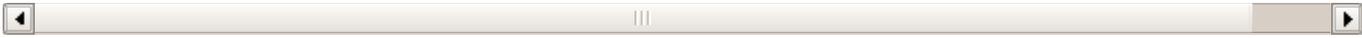
Cleanroom

d. Example: 45 percent RH, ±5.0 percent RH

Design 1 10 100 1,000 10,000 100,000

7. Criteria for fire protection/smoke purge/exhaust: M1.5 M2.5 M3.5 M4.5 M5.5 M6.

8. The air change rate is based on a 10'0" ceiling height.



Refer to the online resource for Sections 48.05 Areas and Circumferences of Circles, 48.06 Fraction/Decimal Equivalents, 48.07 Physical Properties of Fuels and Oils, and 48.08 U.S. Postal Service Abbreviations. www.mheducation.com/HVACequations

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48.05. Areas and Circumferences of Circles

AREAS AND CIRCUMFERENCES OF CIRCLES

Diameter in Inches	Area		Circumference	
	Square Inches	Square Feet	Inches	Feet
0.5	0.20	0.0014	1.57	0.1309
0.75	0.44	0.0031	2.36	0.1963
1	0.79	0.0055	3.14	0.2618
1.25	1.23	0.0085	3.93	0.3272
1.5	1.77	0.0123	4.17	0.3927
2	3.14	0.0218	6.28	0.5236
2.5	4.91	0.0341	7.85	0.6545
3	7.07	0.0491	9.42	0.7854
3.5	9.62	0.0668	11.00	0.9163
4	12.57	0.0873	12.57	1.0472
4.5	15.90	0.1104	14.14	1.1781
5.0	19.63	0.1364	15.71	1.3090
5.5	23.76	0.1650	17.28	1.4399
6	28.27	0.1963	18.85	1.5708
6.5	33.18	0.2304	20.42	1.7017
7	38.48	0.2673	21.99	1.8326

Diameter in Inches	Area Square Inches	Area Square Feet	Circumference Inches	Circumference Feet
7.5	44.18	0.3068	23.56	1.9635
8	50.27	0.3491	25.13	2.0944
8.5	56.75	0.3941	26.70	2.2259
9	63.62	0.4418	28.27	2.3562
9.5	70.88	0.4922	29.85	2.4871
10	78.54	0.5454	31.42	2.6180
10.5	86.59	0.6013	32.99	2.7489
11	95.03	0.6600	34.56	2.8798
11.5	103.87	0.7213	36.13	3.0107
12	113.10	0.7854	37.70	3.1416
13	132.73	0.9218	40.84	3.4034
14	153.94	1.0690	43.98	3.6652
15	176.71	1.2272	47.12	3.9270
16	201.06	1.3963	50.27	4.1888
17	226.98	1.5763	53.41	4.4506
18	254.47	1.7671	56.55	4.7124
19	283.53	1.9689	59.69	4.9742
20	314.16	2.1817	62.83	5.2360
21	346.36	2.4053	65.97	5.4978
22	380.13	2.6398	69.12	5.7596
23	415.48	2.8852	72.26	6.0214
24	452.39	3.1416	75.40	6.2832
25	490.87	3.4088	78.54	6.5450
26	530.93	3.6870	81.68	6.8068
27	572.56	3.9761	84.82	7.0686
28	615.75	4.2761	87.96	7.3304
29	660.52	4.5869	91.11	7.5922
30	706.86	4.9087	94.25	7.8540
31	754.77	5.2414	97.39	8.1158
32	804.25	5.5851	100.53	8.3776
33	855.30	5.9396	103.67	8.6394
34	907.92	6.3050	106.81	8.9012
35	962.11	6.6813	109.96	9.1630
36	1017.88	7.0686	113.10	9.4248
37	1075.21	7.4667	116.24	9.6866

Diameter in Inches	Area Square Inches	Area Square Feet	Circumference Inches	Circumference Feet
38	1134.11	7.8758	119.38	9.9484
39	1195.59	8.2958	122.52	10.2102
40	1256.64	8.7266	125.66	10.4720
41	1320.25	9.1684	128.81	10.7338
42	1385.44	9.6211	131.95	10.9956
43	1452.20	10.0847	135.09	11.2574
44	1520.53	10.5592	138.23	11.5192
45	1590.43	11.0447	141.37	11.7810
46	1661.90	11.5410	144.51	12.0428
47	1734.94	12.0482	147.65	12.3046
48	1809.55	12.5663	150.80	12.5663
49	1885.74	13.0954	153.94	12.8282
50	1963.50	13.6354	157.08	13.0900
52	2123.72	14.7480	163.36	13.6136
54	2290.22	15.9043	169.65	14.1372
56	2463.01	17.1042	175.93	14.6608
58	2642.08	18.3478	182.21	15.1844
60	2827.43	19.6350	188.50	15.7080
62	3019.07	20.9658	194.78	16.2316
64	3216.99	22.3402	201.06	16.7552
66	3421.19	23.7583	207.35	17.2788
68	3631.68	25.2200	213.63	17.8024
70	3848.45	26.7254	219.91	18.3260
72	4071.50	28.2743	226.19	18.8496
74	4300.84	29.8669	232.48	19.3732
76	4536.46	31.5032	238.76	19.8968
78	4778.36	33.1831	245.04	20.4204
80	5026.55	34.9066	251.33	20.9440
82	5281.02	36.6737	257.61	21.4675
84	5541.77	38.4845	263.89	21.9911
86	5808.80	40.3389	270.18	22.5147
88	6082.12	42.2370	276.46	23.0383
90	6361.73	44.1786	282.74	23.5619

48.06. Fraction/Decimal Equivalents

FRACTION/DECIMAL EQUIVALENTS

64 ^{THS}	32 ^{NDS}	16 ^{THS}	8 ^{THS}	4 ^{THS}	Half	Whole	Decimal
1/64	-	-	-	-	-	-	0.0156
2/64	1/32	-	-	-	-	-	0.0313
3/64	-	-	-	-	-	-	0.0469
4/64	2/32	1/16	-	-	-	-	0.0625
5/64	-	-	-	-	-	-	0.0781
6/64	3/32	-	-	-	-	-	0.0938
7/64	-	-	-	-	-	-	0.1094
8/64	4/32	2/16	1/8	-	-	-	0.1250
9/64	-	-	-	-	-	-	0.1406
10/64	5/32	-	-	-	-	-	0.1563
11/64	-	-	-	-	-	-	0.1719
12/64	6/32	3/16	-	-	-	-	0.1875
13/64	-	-	-	-	-	-	0.2031
14/64	7/32	-	-	-	-	-	0.2188
15/64	-	-	-	-	-	-	0.2344
16/64	8/32	4/16	2/8	1/4	-	-	0.2500
17/64	-	-	-	-	-	-	0.2656
18/64	9/32	-	-	-	-	-	0.2813
19/64	-	-	-	-	-	-	0.2969
20/64	10/32	5/16	-	-	-	-	0.3125
21/64	-	-	-	-	-	-	0.3281
22/64	11/32	-	-	-	-	-	0.3438
23/64	-	-	-	-	-	-	0.3594
24/64	12/32	6/16	3/8	-	-	-	0.3750
25/64	-	-	-	-	-	-	0.3906
26/64	13/32	-	-	-	-	-	0.4063
27/64	-	-	-	-	-	-	0.4219
28/64	14/32	7/16	-	-	-	-	0.4375
29/64	-	-	-	-	-	-	0.4531
30/64	15/32	-	-	-	-	-	0.4688

$\frac{31}{64}$ 64 $\frac{32}{64}$	$\frac{-}{32}$ 32 $\frac{16}{32}$	$\frac{-}{16}$ 16 $\frac{8}{16}$	$\frac{-}{8}$ 8 $\frac{4}{8}$	$\frac{-}{4}$ 4 $\frac{2}{4}$	$\frac{-}{\text{Half}}$ Half $\frac{1}{2}$	$\frac{-}{\text{Whole}}$ Whole -	0.4844 Decimal 0.5000
33/64	-	-	-	-	-	-	0.5156
34/64	17/32	-	-	-	-	-	0.5312
35/64	-	-	-	-	-	-	0.5469
36/64	18/32	9/16	-	-	-	-	0.5625
37/64	-	-	-	-	-	-	0.5781
38/64	19/32	-	-	-	-	-	0.5938
39/64	-	-	-	-	-	-	0.6094
40/64	20/32	10/16	5/8	-	-	-	0.6250
41/64	-	-	-	-	-	-	0.6406
42/64	21/32	-	-	-	-	-	0.6563
43/64	-	-	-	-	-	-	0.6719
44/64	22/32	11/16	-	-	-	-	0.6875
45/64	-	-	-	-	-	-	0.7031
46/64	23/32	-	-	-	-	-	0.7188
47/64	-	-	-	-	-	-	0.7343
48/64	24/32	12/16	6/8	3/4	-	-	0.7500
49/64	-	-	-	-	-	-	0.7656
50/64	25/32	-	-	-	-	-	0.7813
51/64	-	-	-	-	-	-	0.7969
52/64	26/32	13/16	-	-	-	-	0.8125
53/64	-	-	-	-	-	-	0.8281
54/64	27/32	-	-	-	-	-	0.8438
55/64	-	-	-	-	-	-	0.8594
56/64	28/32	14/16	7/8	-	-	-	0.8750
57/64	-	-	-	-	-	-	0.8906
58/64	29/32	-	-	-	-	-	0.9063
59/64	-	-	-	-	-	-	0.9219
60/64	30/32	15/16	-	-	-	-	0.9375
61/64	-	-	-	-	-	-	0.9531
62/64	31/32	-	-	-	-	-	0.9688
63/64	-	-	-	-	-	-	0.9844
64/64	32/32	16/16	8/8	4/4	2/2	1	1.0000

48.07. Physical Properties of Fuels and Oils

PHYSICAL PROPERTIES OF FUELS AND OILS

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lbs.m/cu.ft.	Sp. G
Fuels						
Gasoline	-	113.0	Liq.	0.0223	44.9	0.
Kerosene	-	154.0	Liq.	0.0200	49.9	0.
Diesel Fuel (1-D)	-	170.0	Liq.	0.0183	54.6	0.
Diesel Fuel (2-D)	-	184.0	Liq.	0.0174	57.4	0.
Diesel Fuel (4-D)	-	198.0	Liq.	0.0167	59.9	0.
Fuel Oil No. 1	-	-	Liq.	0.0183	54.6	0.
Fuel Oil No. 2	-	-	Liq.	0.0174	57.4	0.
Fuel Oil No. 4	-	198.0	Liq.	0.0167	59.8	0.
Fuel Oil No. 5 Lt	-	-	Liq.	0.0167	59.9	0.
Fuel Oil No. 5 Hv	-	-	Liq.	0.0167	59.9	0.
Fuel Oil No. 6	-	-	Liq.	0.0167	59.9	0.
Paraffin or Alkane Series						
Methane (Nat. Gas)	CH ₄	16.041	Gas	24.0963	0.0415	0.
Ethane	C ₂ H ₆	30.067	Gas	12.9032	0.0775	1.

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lb.m/cu.ft.	Sp. Gr.
Propane	C ₃ H ₈	44.092	Gas	8.7710	0.114	1.52
N-Butane	C ₄ H ₁₀	58.118	Gas	0.0276	36.14	4.0
Isobutane	C ₄ H ₁₀	58.118	Gas	0.0288	34.77	4.0
N-Pentane	C ₅ H ₁₂	72.144	Liq.	0.0256	39.08	0.62
Isopentane	C ₅ H ₁₂	72.144	Liq.	0.0258	38.77	0.62
Neopentane	C ₅ H ₁₂	72.144	Gas	0.0261	38.27	5.0
N-Hexane	C ₆ H ₁₄	86.178	Liq.	0.0243	41.14	0.66
Neohexane	C ₆ H ₁₄	86.178	Liq.	0.0247	40.51	0.66
N-Heptane	C ₇ H ₁₆	100.206	Liq.	0.0239	41.70	0.68
Triptane	C ₇ H ₁₆	100.206	Liq.	0.0232	43.07	0.68
N-Octane	C ₈ H ₁₈	114.223	Liq.	0.0227	44.14	0.70
Iso-Octane	C ₈ H ₁₈	114.223	Liq.	0.0228	43.82	0.70
Olefin or Alkene Series						
Ethylene	C ₂ H ₄	28.054	Gas	13.6426	0.0733	0.91
Propylene	C ₃ H ₆	42.081	Gas	7.5187	0.113	1.26
Butylene	C ₄ H ₈	56.108	Gas	0.0269	37.12	4.0
Isobutene	C ₄ H ₈	56.108	Gas	0.0272	36.83	4.0
N-Pentene	C ₅ H ₁₀	70.135	Liq.	0.0250	40.02	0.69
Aromatic Series						
Benzene	C ₆ H ₆	78.114	Liq.	0.0172	58.18	0.88
Toluene	C ₇ H ₈	92.141	Liq.	0.0181	55.31	0.87
Xylene	C ₈ H ₁₀	106.169	Liq.	0.0186	53.75	0.86
Other Hydrocarbons						
Acetylene	C ₂ H ₂	26.038	Gas	14.8148	0.0675	0.91
Naphthalene	C ₁₀ H ₈	128.175	Solid	-	71.48	-
Methyl Alcohol	CH ₃ OH	32.041	Liq.	0.0204	49.10	0.79
Ethyl Alcohol	C ₂ H ₅ OH	46.067	Liq.	0.0204	49.01	0.79

Motor Oils						
Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lb.m	Density lb.m/cu.ft.	Sp. Gr.
5W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
10W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
20W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
30W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
40W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
50W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
Gear Oils						
75W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
80W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
85W	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
90	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
120	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
140	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9
150	-	-	Liq.	0.0176	54.9-58.7	0.85-0.9



PHYSICAL PROPERTIES OF FUELS AND OILS

Flammability

Boiling Pt

Ignition

Limits (%)

Substance	Boiling Pt. °F	Ignition Temp. °F	Flash Point	Limits (in Flammability Air) % by
Substance	Boiling Pt. °F	Ignition Temp. °F	Flash Point	Limits (in Volume Air) % by
Fuels				
Gasoline	100–400	536	-45	1.4–7.6
Kerosene	304–574	410	100–162	0.7–5.0
Diesel Fuel (1-D)	-	-	100	-
Diesel Fuel (2-D)	-	-	125	-
Diesel Fuel (4-D)	-	-	130	-
Fuel Oils No. 1	304–574	410	100–162	0.7–5.0
Fuel Oils No. 2	-	494	126–204	-
Fuel Oils No. 4	-	505	142–240	-
Fuel Oils No. 5 Lt	-	-	156–336	-
Fuel Oils No. 5 Hv	-	-	160–250	-
Fuel Oils No. 6	-	-	150	-
Paraffin or Alkane Series				
Methane (Nat. Gas)	-258.7	900–1170	Gas	5.0–15.0
Ethane	-127.5	959	Gas	3.0–12.5
Propane	-43.8	842	Gas	2.1–10.1
N-Butane	31.1	761	-76	1.86–8.41
Isobutane	10.9	864	-117	1.80–8.44
N-Pentane	97.0	500	<-40	1.40–7.80

Substance	Boiling Pt.	Ignition Temp. °F	Flash Point	Flammability Limits (in Air) % by Volume
Isopentane	82.2	788	<-60	1.32-9.16
Neopentane	49.1 °F	842	Gas	1.25-7.0
N-Hexane	155.7	437	-7	1.25-7.0
Neohexane	121.5	797	-54	1.19-7.58
N-Heptane	209.1	419	25	1.00-6.00
Triptane	177.6	849	-	1.08-6.69
N-Octane	258.3	428	56	0.95-3.20
Iso-Octane	243.9	837	10	0.79-5.94
Olefin or Alkene Series				
Ethylene	-154.7	914	Gas	2.75-28.6
Propylene	-53.9	856	Gas	2.00-11.1
Butylene	21.2	829	Gas	1.98-9.65
N-Butene	-	-	-	-
Isobutene	19.6	869	Gas	1.8-9.0
N-Pentene	86.0	569	-	1.65-7.70
Aromatic Series				
Benzene	176.2	1040	12	1.35-6.65
Toluene	321.1	992	40	1.27-6.75
Xylene	281.1	867	63	1.00-6.00
Other Hydrocarbons				
Acetylene	-119.2	581	Gas	2.50-100
Naphthalene	424.4	959	174	0.90-5.90
Methyl Alcohol	151	725	-	6.7-36.0
Ethyl Alcohol	172	689	-	3.3-19.0
Motor Oils				
5W	-	-	420	-
10W	-	-	425	-

10W Substance	Boiling Pt. °F	Ignition Temp. °F	Flash Point	Flammability Limits (in Air) % by Volume
20W	-	-	465	-
30W	-	-	450	-
40W	-	-	475	-
50W	-	-	485	-
Gear Oils				
75W	-	-	375	-
80W	-	-	425	-
85W	-	-	435	-
90	-	-	425	-
120	-	-	425	-
140	-	-	580	-
150	-	-	580	-

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48.08. U.S. Postal Service Abbreviations

U.S. POSTAL SERVICE ABBREVIATIONS

United States Postal Service Standard Abbreviations

State	Abbrev.	State	Abbrev.
Alabama	AL	Montana	MT
Alaska	AK	Nebraska	NE
Arizona	AZ	Nevada	NV
Arkansas	AR	New Hampshire	NH
California	CA	New Jersey	NJ
Colorado	CO	New Mexico	NM
Connecticut	CT	New York	NY
Delaware	DE	North Carolina	NC
District of Columbia	DC	North Dakota	ND

United States Postal Service Standard Abbreviations			
State	Abbrev.	State	Abbrev.
Florida	FL	Ohio	OH
Georgia	GA	Oklahoma	OK
Hawaii	HI	Oregon	OR
Idaho	ID	Pennsylvania	PA
Illinois	IL	Puerto Rico	PR
Indiana	IN	Rhode Island	RI
Iowa	IA	South Carolina	SC
Kansas	KS	South Dakota	SD
Kentucky	KY	Tennessee	TN
Louisiana	LA	Texas	TX
Maine	ME	Utah	UT
Maryland	MD	Vermont	VT
Massachusetts	MA	Virginia	VA
Michigan	MI	Washington	WA
Minnesota	MN	West Virginia	WV
Mississippi	MS	Wisconsin	WI
Missouri	MO	Wyoming	WY

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Part 49: Wind Chill and Heat Index

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49. Part 49: Wind Chill and Heat Index

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49.01. Wind Chill Index

WIND CHILL INDEX

°F Dry Bulb	Wind Velocity (mph)										
	0 Calm	5	10	15	20	25	30	35	40	45	50
35	35	33	21	16	12	7	5	3	1	1	0
30	30	27	16	11	3	0	-2	-4	-5	-6	-7
25	25	21	9	1	-4	-7	-11	-13	-15	-17	-17
20	20	16	2	-6	-9	-15	-18	-20	-22	-24	-24
15	15	12	-2	-11	-17	-22	-26	-27	-29	-31	-31
10	10	7	-9	-18	-24	-29	-33	-35	-37	-38	-39
5	5	0	-15	-25	-32	-37	-41	-43	-45	-46	-47
0	0	-6	-22	-33	-40	-45	-49	-52	-53	-54	-56
-5	-5	-11	-27	-40	-46	-52	-56	-60	-62	-63	-63
-10	-10	-15	-31	-45	-52	-58	-63	-67	-69	-70	-70
-15	-15	-20	-38	-51	-60	-67	-70	-72	-76	-78	-79
-20	-20	-25	-45	-60	-68	-75	-78	-83	-87	-87	-88
Notes:	-25	-31	-52	-65	-76	-83	-87	-90	-94	-94	-96

Dry Bulb Temperature (°F)	Wind Velocity (mph)										
	0	5	10	15	20	25	30	35	40	45	50
-30	-30	-35	-58	-70	-81	-89	-94	-98	-	-	-
-35	-35	-41	-64	-78	-88	-96	-	-	-	-	-
-40	-40	-47	-70	-85	-96	-	-	-	-	-	-
-45	-45	-54	-77	-90	-	-	-	-	-	-	-

Notes:

- The table provides equivalent wind chill temperatures at various outside dry bulb temperatures and corresponding wind velocities.
- Wind speeds greater than 40 mph have little additional chilling effect.
- $WCF \cong T_{DB} - (1.5 \times W_S)$
WCF = Wind Chill Factor
T_{DB} = Dry Bulb Air Temperature
W_S = Wind Speed

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49.02. Heat Index

HEAT INDEX

%RH	Apparent Temperature, °F											
	Temperature, °F											
	70	75	80	85	90	95	100	105	110	115	120	125
0	64	69	73	78	83	87	91	95	99	103	107	111
5	64	69	74	79	84	88	83	97	102	107	111	115
10	65	70	75	80	85	90	95	100	105	111	116	123
15	65	71	76	81	85	91	97	102	106	115	123	131
20	66	72	77	82	87	93	99	105	112	120	130	141
25	66	73	77	83	89	94	101	108	117	127	138	150

	60	72	77	83	88	94	101	109	117	127	139	
						Apparent Temperature, °F						
30	67	73	78	84	90	96	104	113	123	135	148	
						Temperature, °F						
%RH	67	73	79	85	91	98	107	118	130	143		
35	70	75	80	85	90	95	100	105	110	115	120	125
40	68	74	79	86	93	101	110	123	137	151		
45	68	74	80	87	95	104	115	129	143			
50	69	75	81	88	96	107	120	135	150			
55	69	75	81	89	96	110	126	142				
60	70	76	82	90	100	114	132	149				
65	70	76	83	91	102	119	138					
70	70	77	85	93	106	124	144					
75	70	77	86	95	109	130						
80	71	77	86	97	113	136						
85	71	78	87	99	117							
90	71	79	88	102	122							
95	71	79	89	105								
100	72	80	91	106								

Notes:

- 1. The table provides equivalent heat index temperatures at various ten corresponding relative humidities.**
- 2. The heat index is a measure of how the average person perceives ten humidity and how it affects the body's ability to cool itself.**
- 3. Sunstroke and heat exhaustion are likely when the heat index is 105 (**



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Part 50: General Notes

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50. Part 50: General Notes

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50.01. General

- A. Provide all materials and equipment and perform all labor required to install complete and operable mechanical systems as indicated on the drawings, as specified, and as required by code.**
- B. Contract document drawings for mechanical work (HVAC, plumbing, and fire protection) are diagrammatic and are intended to convey scope and general arrangement only.**
- C. Install all mechanical equipment and appurtenances in accordance with manufacturers' recommendations, contract documents, and applicable codes and regulations.**
- D. Provide vibration isolation for all mechanical equipment to prevent transmission of vibration to building structure.**
- E. Provide vibration isolators for all piping supports connected to, and within 50 ft. of, isolated equipment (except at base elbow supports and anchor points) throughout mechanical equipment rooms. Do the same for supports of steam mains within 50 ft. of boiler or pressure-reducing valves.**
- F. Provide vibration isolators for all piping supports of steam mains within 50 ft. of boilers and pressure-reducing valves.**
- G. The location of existing underground utilities is shown in an approximate way only. The contractor shall determine the exact location**

of all existing utilities before commencing work. The contractor shall pay for and repair all damages caused by failure to exactly locate and preserve any and all underground utilities unless otherwise indicated.

H. Coordinate construction of all mechanical work with architectural, structural, civil, electrical work, etc., shown on other contract document drawings.

I. Maintain a minimum 6'8" clearance to the underside of pipes, ducts, conduits, suspended equipment, etc., throughout access routes in mechanical rooms.

J. All tests shall be completed before any mechanical equipment or piping insulation is applied.

K. Locate all temperature, pressure, and flow measuring devices in accessible locations with the straight section of pipe or duct up- and downstream as recommended by the manufacturer for good accuracy.

L. Testing, adjusting, and balancing agency shall be a member of the Associated Air Balance Council (AABC) or the National Environmental Balancing Bureau (NEBB). Testing, adjusting, and balancing shall be performed in accordance with the AABC standards.

M. Where two or more items of the same type of equipment are required, the product of one manufacturer shall be used.

N. Reinforcement, detailing, and placement of concrete shall conform to *ASTM 315* and *ACI 318*. Concrete shall conform to *ASTM C94*. Concrete work shall conform to *ACI 318*, part entitled "Construction Requirements." Compressive strength in 28 days shall be 3,000 psi. Total air content of exterior concrete shall be between 5 and 7 percent by volume. Slump shall be between 3 and 4 in. Concrete shall be cured for 7 days after placement.

O. Coordinate all equipment connections with manufacturers' certified drawings. Coordinate and provide all duct and piping transitions required for final equipment connections to furnished equipment. Field verify and coordinate all duct and piping dimensions before fabrication.

P. All control wire and conduit shall comply with the National Electric Code and Division 16 of the specification.

Q. Concrete housekeeping pads to suit mechanical equipment shall be sized and located by the mechanical contractor. Minimum concrete pad thickness shall be 6 in. Pad shall extend beyond the equipment a minimum of 6 in. on each side. Concrete housekeeping pads shall be provided by the general contractor. It shall be the responsibility of the mechanical contractor to coordinate the size and location of concrete housekeeping pads with the general contractor.

R. All mechanical room doors shall be a minimum of 4'0" wide.

S. Where beams are indicated to be penetrated with ductwork or piping, coordinate ductwork and piping layout with beam opening size and opening locations. Coordination shall be done prior to the fabrication of ductwork, cutting of piping, or fabrication of beams.

T. When mechanical work (HVAC, plumbing, sheet metal, fire protection, etc.) is subcontracted, it shall be the mechanical contractor's responsibility to coordinate subcontractors and the associated contracts. When discrepancies arise pertaining to which contractor provides a particular item of the mechanical contract or which contractor provides final connections for a particular item of the mechanical contract, it shall be brought to the attention of the mechanical contractor, whose decision shall be final.

U. The locations of all items shown on the drawings or called for in the specifications that are not definitely fixed by dimensions are approximate only. The exact locations necessary to secure the best conditions and results must be determined by the project site conditions and shall have the approval of the engineer before being installed. Do not scale drawings.

V. All miscellaneous steel required to ensure proper installation and as shown in details for piping, ductwork, and equipment (unless otherwise noted) shall be furnished and installed by the mechanical contractor.

W. Provide access panels for installation in walls and ceilings, where required, to service dampers, valves, smoke detectors, and other concealed mechanical equipment. Access panels shall be turned over to the general contractor for installation.

X. All equipment, piping, ductwork, etc., shall be supported as detailed, specified, and required to provide a vibration-free installation.

Y. All ductwork, piping, and equipment supported from structural steel shall be coordinated with the general contractor. All attachments to steel bar joists, trusses, or joist girders shall be at panel points. Provide beam clamps meeting MSS standards. Welding to structural members shall not be permitted. The use of C-clamps shall not be permitted.

Z. Mechanical equipment, ductwork, and piping shall not be supported from a metal deck.

AA. All roof-mounted equipment curbs for equipment provided by the mechanical contractor shall be furnished by the mechanical contractor and installed by the general contractor.

BB. Locations and sizes of all floor, wall, and roof openings shall be coordinated with all other trades involved.

CC. All openings in fire walls due to ductwork, piping, conduit, etc., shall be fire stopped with a product similar to 3M or an approved equal.

DD. All air conditioning condensate drain lines from each air handling unit and rooftop unit shall be piped full size of the unit drain outlet, with "P" trap, and piped to the nearest drain. See the details shown in the drawings or the contract specifications for the depth of the air conditioning condensate trap.

EE. Refer to typical details for ductwork, piping, and equipment installation.

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50.02. Piping

A. Provide all materials and equipment and perform all labor required to install complete and operable piping systems as indicated on the drawings, as specified, and as required by code.

B. Elevations shown on the drawings are to the bottom of all pressure piping and to the invert of all gravity piping unless otherwise noted.

C. Maintain a minimum of 36" of ground cover over all underground HVAC piping (edit the depth of the ground cover to suit frost line depth and project requirements).

- D. Unless otherwise noted, all chilled water and heating water piping shall be 3/4 in. size (edit system type or pipe size to suit project requirements).**
- E. Provide an air vent at the high point of each drop in the heating-water, chilled-water, and other closed-water piping systems (edit system types to suit the project requirements). All piping shall grade to low points. Provide hose end drain valves at the bottom of all risers and low points.**
- F. Unless otherwise noted, all piping is overhead, tight to the underside of the structure or slab, with space for insulation if required.**
- G. Install piping so all valves, strainers, unions, traps, flanges, and other appurtenances requiring access are accessible.**
- H. All valves shall be installed so that the valve remains in service when equipment or piping on the equipment side of the valve is removed.**
- I. All balancing valves and butterfly valves shall be provided with position indicators and maximum adjustable stops (memory stops).**
- J. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level; chain shall extend to 7'0" above floor level.**
- K. All valves (except control valves) and strainers shall be the full size of the pipe before reducing in size to make connections to equipment and controls.**
- L. Unions and/or flanges shall be installed at each piece of equipment, in bypasses, and in long piping runs (100 ft. or more) to permit disassembly for alteration and repairs.**
- M. Pitch steam piping downward in the direction of flow 1/4 in. per 10 ft. (1 in. in 40 ft.) minimum. Pitch all steam return lines downward in the direction of condensate flow 1/2 in. per 10 ft. (1 in. in 20 ft.) minimum. Where the length of branch lines is less than 8 ft., pitch branch lines toward mains 1/2 in. per ft. minimum.**

- N. Pitch up all steam and condensate runouts to risers and equipment 1/2 in./ft. Where this pitch cannot be obtained, runouts over 8 ft. in length shall be one size larger than noted.**
- O. Tap all branch lines from the top of steam mains (45 degrees preferred; 90 degrees acceptable).**
- P. Provide an end of main drip at each rise in the steam main. Provide condensate drips at the bottom of all steam risers, downfed runouts to equipment, radiators, etc., at the end of mains and low points, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.**
- Q. On straight steam piping runs with no natural drainage points, install drip legs at intervals not exceeding 200 ft. where the pipe is pitched downward in the direction of steam flow and a maximum of 100 ft. where the pipe is pitched up so that condensate flow is opposite of steam flow.**
- R. Steam traps shall be minimum 3/4" size.**
- S. Install all piping without forcing or springing.**
- T. All piping shall clear doors and windows.**
- U. All valves shall be adjusted for smooth and easy operation.**
- V. All piping work shall be coordinated with all trades involved. Offsets in piping around obstructions shall be provided at no additional cost to the owner.**
- W. Provide flexible connections in all piping systems connected to pumps, chillers, cooling towers, and other equipment which require vibration isolation except water coils. Flexible connections shall be provided as close to the equipment as possible or as indicated on the drawings.**
- X. Slope refrigerant piping one percent in the direction of oil return. Liquid lines may be installed level.**
- Y. Install horizontal refrigerant hot gas discharge piping with 1/2" per 10 ft. downward slope away from the compressor.**
- Z. Install horizontal refrigerant suction lines with 1/2" per 10 ft.**

downward slope to the compressor, with no long traps or dead ends that may cause oil to separate from the suction gas and return to the compressor in damaging slugs.

AA. Provide line size liquid indicators in the main liquid line leaving the condenser or receiver. Install moisture-liquid indicators in liquid lines between filter dryers and thermostatic expansion valves, and in liquid line to receiver.

BB. Provide a line size strainer upstream of each automatic valve. Provide a shutoff valve on each side of the strainer.

CC. Provide permanent filter dryers in low-temperature systems and systems using hermetic compressors.

DD. Provide replaceable cartridge filter dryers with a three-valve bypass assembly for solenoid valves, adjacent to receivers.

EE. Provide refrigerant charging valve connections in the liquid line between the receiver shutoff valve and the expansion valve.

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50.03. Plumbing

A. Provide all materials and equipment and perform all labor required to install complete and operable plumbing systems as indicated on the drawings, as specified, and as required by code.

B. Run all soil waste and vent piping with 2 percent minimum grade unless otherwise noted (edit the slope to suit project requirements). Horizontal vent piping shall be graded to drip back to the soil or waste pipe by gravity.

C. Elevations shown on the drawings are to the bottom of all pressure piping and to the invert of all gravity piping.

D. Adjust sewer inverts to keep the tops of pipes in line where the pipe's size changes.

E. Maintain a minimum of 3'6" of ground cover over all underground water mains and a minimum of 3'0" of ground cover over all underground sewers and drains (edit the depth of the ground cover to suit frost line depth and project requirements).

- F. Provide shutoff valves in all domestic water piping system branches in which branch piping serves two or more fixtures.**
- G. Unless otherwise noted, all domestic cold and hot water piping shall be 1/2" size (edit the system type or pipe size to suit project requirements).**
- H. Unless otherwise noted, all piping is overhead, tight to the underside of the slab, with space for insulation if required.**
- I. Install piping so all valves, strainers, unions, traps, flanges, and other appurtenances requiring access are accessible.**
- J. Where domestic cold and hot water piping drops into a pipe chase, the size shown for the pipe drops shall be used to the last fixture.**
- K. Install all piping without forcing or springing.**
- L. All piping shall clear doors and windows.**
- M. All piping shall grade to low points. Provide hose end drain valves at the bottom of all risers and low points.**
- N. Unions and/or flanges shall be installed at each piece of equipment, in bypasses, and in long piping runs (100 ft. or more) to permit disassembly for alteration and repairs.**
- O. All valves shall be adjusted for smooth and easy operation.**
- P. All valves (except control valves) and strainers shall be the full size of the pipe before reducing the size to make connections to the equipment and controls.**
- Q. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7'0" above floor level; chain shall extend to 7'0" above floor level.**
- R. Provide all plumbing fixtures and equipment with accessible stops.**
- S. Unless otherwise noted, drains shall be installed at the low point of roofs, areaways, floors, etc.**

T. Provide cleanouts in sanitary and storm drainage systems at ends of runs, at changes in direction, near the base of stacks, every 50 ft. in horizontal runs, and elsewhere as indicated (edit horizontal cleanout spacing to suit code and project requirements).

U. All cleanouts shall be the full size of the pipe for pipe sizes 6 in. and smaller, and shall be 6 in. for pipe sizes larger than 6 in.

V. All balancing valves and butterfly valves shall be provided with position indicators and maximum adjustable stops (memory stops).

W. All valves shall be installed so the valve remains in service when the equipment or piping on the equipment side of the valve is removed.

X. All piping work shall be coordinated with all trades involved. Offsets in piping around obstructions shall be provided at no additional cost to the owner.

Y. Provide flexible connections in all piping systems connected to pumps and other equipment that require vibration isolation. Flexible connections shall be provided as close to the equipment as possible or as indicated on the drawings.

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50.04. HVAC/Sheet Metal

A. Provide all materials and equipment and perform all labor required to install complete and operable HVAC systems as indicated on the drawings, as specified, and as required by code.

B. Certain items such as rises and drops in ductwork, access doors, volume dampers, etc., are indicated on the contract document drawings for clarity for a specific location requirement and shall not be interpreted as the extent of the requirements for these items.

C. In corridors where ceiling speakers and air diffusers are indicated between the same light fixtures, install both devices at the quarter points between the same fixture.

D. Unless otherwise shown, locate all room thermostats and humidistats 4'-0" (centerline) above the finished floor. Notify the engineer of any rooms where the preceding location cannot be maintained or where there is a question on location.

- E. All ductwork shall clear doors and windows.**
- F. All ductwork dimensions, as shown on the drawings, are internal clear dimensions. Duct size shall be increased to compensate for duct lining thickness.**
- G. Provide all 90-degree square elbows with double radius turning vanes unless otherwise indicated. Elbows in dishwasher, kitchen, and laundry exhausts shall be of unvaned smooth radius construction with a centerline radius equal to 1-1/2 times the width of the duct. Provide access doors upstream of all elbows with turning vanes.**
- H. Coordinate diffuser, register, and grille locations with architectural reflected ceiling plans, lighting, and other ceiling items and make minor duct modifications to suit.**
- I. Field-erected and factory-assembled air handling unit coils shall be arranged for removal from the upstream side without dismantling supports. Provide galvanized structural steel supports for all coils (except the lowest coil) in banks over two coils high to permit the independent removal of any coil.**
- J. All air handling units shall operate without moisture carryover.**
- K. Locate all mechanical equipment (single duct, dual duct, variable volume, constant volume and fan-powered boxes, fan coil units, cabinet heaters, unit heaters, unit ventilators, coils, steam humidifiers, etc.) for unobstructed access to unit access panels, controls, and valving.**
- L. Finned tube radiation enclosures shall be wall-to-wall unless otherwise indicated.**
- M. Provide flexible connections in all ductwork systems (supply, return, and exhaust) connected to air handling units, fans, and other equipment that require vibration isolation. Flexible connections shall be provided at the point of connection to the equipment unless otherwise indicated.**
- N. Unless otherwise noted, all ductwork is overhead, tight to the underside of the structure, with space for insulation if required.**

O. Runs of flexible duct shall not exceed 5 ft. (edit the maximum length of the flexible duct to suit the project; 5 ft. maximum recommended length, 8 ft. maximum length).

P. All ductwork shall be coordinated with all trades involved. Offsets in ducts, including divided ducts and transitions around obstructions, shall be provided at no additional cost to the owner.

Q. Provide access doors in ductwork to provide access for all smoke detectors, fire dampers, smoke dampers, volume dampers, humidifiers, coils, and other items located in the ductwork that require service and/or inspection.

R. Provide access doors in ductwork for the operation, adjustment, and maintenance of all fans, valves, and mechanical equipment.

S. All ducts shall be grounded across flexible connections with flexible copper grounding straps. Grounding straps shall be bolted or soldered to both the equipment and the duct.

T. Smoke detectors shall be furnished and wired by the electrical contractor. The mechanical contractor shall be responsible for mounting the smoke detector in ductwork as shown on the drawings and in accordance with the manufacturer's printed instructions.

U. Terminate gas vents for unit heaters, water heaters, high-pressure parts washers, high-pressure cleaners, and other gas appliances a minimum of 30" above the roof with rain cap (edit any appliances and the height above the roof to meet the code and suit project requirements).

V. See specifications for ductwork gauges, bracing, hangers, and other requirements.

W. Exterior louvers are indicated for information only. Detailed descriptions are provided in the architectural specifications.

X. Exterior louvers are indicated for information only. Louver sizes, locations, and details shall be coordinated with the general contractor.

Y. Exterior louvers are indicated for information only. Louver sizes, locations, mounting, and details shall be coordinated with other trades involved.

50.05. Fire Protection

- A. Provide all materials and equipment and perform all labor required to install complete and operate fire protection systems as indicated on the drawings, as specified, and in compliance with the standards of the National Fire Protection Association, Industrial Risk Insurers, Factory Mutual, and all state and local regulations.**
- B. The entire building sprinkler system shall be hydraulically designed unless otherwise noted on the drawings. Head spacing in general and water quantity shall be based on Light Hazard Occupancy (edit occupancy classification to suit project requirements; see NFPA 13— Light Hazard Occupancy, Ordinary Hazard Group I Occupancy, Ordinary Hazard Group II Occupancy, Extra Hazard Group I Occupancy, Extra Hazard Group II Occupancy).**
- C. The entire building sprinkler system shall be pipe schedule designed unless otherwise noted on the drawings. Head spacing in general and water quantity shall be based on Light Hazard Occupancy (edit the occupancy classification to suit project requirements; see NFPA 13— Light Hazard Occupancy, Ordinary Hazard Group I Occupancy, Ordinary Hazard Group II Occupancy, Extra Hazard Group I Occupancy, Extra Hazard Group II Occupancy).**
- D. Provide an automatic wet pipe sprinkler system throughout the entire building, complete in all respects and ready for operation including all test and drain lines, pressure gauges, hangers and supports, signs, and other standard appurtenances. Wiring shall be provided under the electrical division.**
- E. Provide an automatic dry pipe sprinkler system throughout the entire building, complete in all respects and ready for operation, including all test and drain lines, pressure gauges, dry pipe valves, air compressors, hangers and supports, signs, and other standard appurtenances. Wiring shall be provided under the electrical division.**
- F. See the architectural drawings for the exact location of fire extinguisher cabinets, fire hose cabinets, and Siamese connections.**

G. All shutoff valves in the sprinkler, standpipe, and combined systems shall be approved, indicating type.

H. Coordinate sprinkler head locations with the architectural reflected ceiling plans, lighting, and other ceiling items, and make minor modifications for suitability purposes.

I. Sprinklers installed in the ceilings of finished areas shall be symmetrical in relation to ceiling system components and centered in the ceiling tile.

Citation

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. **EXPORT** Part 50: General Notes, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 51: Designer's Checklist

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51.01. Boilers, Chillers, Cooling Towers, Heat Exchangers, and Other Central Plant Equipment

- A. Have owner redundancy requirements been met? Has future equipment space been clearly indicated on the drawings? Has move-in route and replacement access been determined?**
- B. Have multiple pieces of central plant equipment been provided to prevent system shutdown in the event of equipment failure? Has low load been evaluated and is equipment selected capable of operating at this low-load condition?**
- C. Has proper service access been provided? Has tube pull or cleaning space been provided?**
- D. Have final loads been calculated and the final equipment selection been made? Has equipment been specified and capacity scheduled?**
- E. Has chemical treatment of hydronic and steam systems been properly addressed? Have flushing and passivation of the hydronic and steam systems been adequately covered in particular waste treatment handling of spent flushing water and chemicals?**
- F. Does central plant equipment need to be on emergency power?**
- G. When multiple pieces of equipment are headered together, have adequate provisions for expansion and contraction been provided, especially regarding boiler systems? Recommendation: Multiple boiler**

connections to header, from boiler nozzles to header main, should be U-shaped (first traveling away from the header, then traveling parallel to the header, and finally traveling back toward the header) to accommodate expansion and contraction of piping to prevent excess stress on the boiler nozzles.

H. When specifying boiler control and oxygen trim systems, chillers with remote starters and remote control panels, cooling tower basin heaters, and other electrical or control systems associated with central plant equipment, has field wiring required for these systems been coordinated with the electrical and instrumentation and control (I&C) engineers? This includes panel installation, interconnecting power and control wiring, instrument air, and the mounting of devices.

I. Have starter, disconnect switch, variable frequency drive, and/or motor control center spaces been coordinated and/or located?

J. When specifying dual fuel boilers, does the owner want a dual fuel pilot (natural gas and fuel oil) or is a tee connection preferred for connection to a portable propane bottle?

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51.02. Air Handling Equipment—Makeup, Recirculation, and General Air Handling Equipment

A. Have owner redundancy requirements been met? Has future equipment space been clearly indicated on the drawings? Has move-in route and replacement access been determined?

B. Have multiple pieces of air handling equipment been provided to prevent system shutdown in the event of equipment failure?

C. Has adequate coil pull space and service space been provided?

Recommendation: The service access space should be a minimum of the unit width plus 2 ft. on at least one side and a minimum of 2 ft. on the other side.

D. Have unit components and capacities been properly specified, detailed, and scheduled—coils, filters, fans, motors, humidifiers, outside air and return air dampers, smoke detectors, smoke dampers, access section, service vestibules, access doors, interior lighting (incandescent, fluorescent), etc.? Have coil and filter air pressure drops been

scheduled? Have coil water pressure drops been scheduled?

E. Have outside air and return air been mixed prior to entering any air handling unit filters or coils?

F. Has proper length downstream of humidifiers been provided to absorb humidification vapor trail? The first air handling unit section downstream of the humidifier should be stainless steel, including coil frames, especially with deionized (DI), reverse osmosis (RO), or ultra pure water (UPW).

G. Have cooling coils been locked out during the air handling unit preheat and humidification operation?

H. Has piping in service vestibules been checked for adequate space? Recommendation: A minimum of 6'0" wide and a minimum of 9'0" high clearance should be maintained to allow for pipe installation for the full length of the unit.

I. Are access doors of adequate size to remove fans, motors, filters, dampers, actuators, inlet guide vanes or other variable flow device, and other devices requiring service and/or replacement?

J. Do all air handling unit preheat coils with a design mixed air temperature below 40°F have preheat pumps? To reduce the risk of freezing, preheat pumps are recommended for all preheat coils with a design mixed air temperature below 40°F.

K. Have coil selections been made so that low water flows, in direct response to low loads, do not fall into laminar flow region?

L. Have air conditioning condensate drains been piped to an appropriate drainage system? Have drains been provided for storm water and sanitary?

M. Have receptacles been provided for roof-mounted equipment in accordance with the NEC?

N. Have the starter, disconnect switch, adjustable frequency drive, and/or motor control center spaces been coordinated and/or located?

O. Does air handling equipment need to be on emergency power?

51.03. Piping Systems—General

- A. Expansion tank: Has size, location, adequate space, support, makeup water pressure, and makeup water location been coordinated with the plumbing engineer?**
- B. Are there provisions for piping expansion and contraction, anchors, guides, loops vs. joints? Have anchor locations and forces been coordinated with the structural engineer? Locate anchors at steel beams and avoid joists if possible. Is piping coordinated with building expansion joints?**
- C. Do the drawings clearly indicate where ASME code piping and valves are required at the boilers in accordance with ASME code requirements for high temperature (over 250°F) and high-pressure boilers (over 15 psig)?**
- D. Does the boiler layout and design have enough expansion and flexibility in the boiler connection piping to prevent overstressing the boiler nozzle? It is best to use a U-shaped layout to the header.**
- E. Have flexible connections been clearly shown on the drawings and have they been properly detailed? Have the appropriate flexible connections been specified for the application?**
- F. Is there structural support for large water risers?**
- G. Are there drains and air vents on water systems and adequate space for service?**
- H. Are balancing valves required on parallel piping loops?**
- I. Is adequate space available for the pitching of pipes?**
- J. Is there space for coil and tube removal or cleaning (e.g., AHUs, chillers, boilers, etc.) and is it clearly shown on the drawings where it is required?**
- K. Is coil piped for counterflow or parallel flow as indicated by detail (parallel flow for preheat coils only; all others counter flow)?**
- L. Condensate drains from room terminals with chilled, dual**

temperature water and packaged cooling units: Do local authorities require condensate drains to be piped to sanitary or to storm? Can condensate drains be discharged onto roof? Onto grade?

M. Are relief valve settings noted on drawings or schedules?

N. Is there adequate straight pipe up- and downstream of flow meter orifices?

O. Have all required equipment valves not covered by standard details been indicated? Avoid duplications.

P. Do not run horizontal piping in solid masonry walls or in narrow stud partitions.

Q. Has all piping been eliminated from electrical switchgear, transformer, motor control center, and emergency generator rooms? If not, have drain troughs or enclosures been provided?

R. Are shutoff valves provided at the base of all risers?

S. Are all systems compatible with flow requirements established by control diagrams?

T. Is cathodic protection required for buried piping?

U. Has required heat tracing been included, coordinated, and insulated?

V. Will large mains or risers transmit noise to occupied spaces? Are isolators required in supply and return at the pump?

W. Is the present and future duty for pumps, boilers, chillers, cooling towers, heat exchangers, terminal units, coils, AHUs, etc., specified? Scheduled?

X. Are air conditioning and steam condensate (when wasted) piped to storm water or sanitary? Is steam condensate cooled?

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51.04. Steam and Condensate Piping

A. See the "Piping Systems—General" section earlier for additional requirements.

- B. Are the ends of main drips shown, detailed, and specified?**
- C. Will condensate drain? Are pipes oversized for opposing flow?**
- D. Will humidifier arms add excessive sensible heat to the air stream (likely on small flat ducts and some AHUs)? Insulate where needed. Provide motor-operated shutoff valves if steam is live during the mechanical cooling season.**
- E. Are riser drips shown, detailed, and specified?**
- F. Flash tanks for medium- and high-pressure condensate. Vent flash tanks either to low pressure steam or outdoors.**
- G. Are relief valves piped to outside? Have they been sized?**
- H. Has steam consumption for humidification been considered in establishing the water makeup quantity for the boiler?**
- I. Has adequate space been allowed for pressure reducing stations? Have standard details been edited?**
- J. Are water sampling connections provided?**
- K. Are steam injectors piped to the floor drains?**
- L. Avoid cross-connections between gravity condensate returns and pumped condensate return lines.**
- M. Is there adequate height between the condensate receiver and/or feedwater heater and the pump to prevent flashing at the pump, particularly with condensate above 200°F?**
- N. Has bypass around the boiler feedwater heater been provided for maintenance?**
- O. Are there drip runouts to equipment such as sterilizers and glassware washers?**
- P. Are the ends of main drips piped?**
- Q. Are condensate return systems compatible?**

R. Have noise suppressors been provided on the reduced pressure side of PRVs? Will radiated noise be a problem? Are there adequate numbers of stages of pressure reduction for quiet operation and an adequate number of valves for capacity control?

S. Are steam and/or condensate flow meters and recorders required?

T. Is there adequate access to components requiring service on the boilers? Is a catwalk required?

U. Are boilers piped in accordance with the ASME code? Is there a nonreturn plus a shutoff valve on the HP boiler?

V. Is the condensate tank vented to the outside?

W. Are chemicals used in the treatment system suitable for humidification? Are chemical feed systems shown, detailed, and specified?

X. Is a feedwater heater or deaerator required?

Y. Are water softeners required on makeup? Are they shown, detailed, and specified?

Z. Are bottom blowdown and continuous blowdown shown, detailed, and specified?

AA. Avoid lifting steam condensate, if possible.

BB. Are proper traps being used? Have they been specified and scheduled?

CC. Are air conditioning and steam condensate (when wasted) piped to storm water or to sanitary? Is steam condensate cooled?

DD. Are large system isolation valves provided with the bypass warming valve?

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51.05. Low Temperature Hot Water and Dual Temperature Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

- B. Are balancing valves indicated? Are flow measuring stations needed and indicated?**
- C. Is pressure regulation needed?**
- D. Is a bypass filter required? Is GPM included in pump capacity?**
- E. Is a standby pump needed?**
- F. Converter support: Are details needed? Is elevation indicated?**
- G. Are service valves shown?**
- H. Will branch piping and ducts fit in the allotted space or enclosure?**
- I. Are riser shutoff valves shown?**
- J. Are riser drains and vents shown?**
- K. Is there adequate space for the installation and use of riser valves?**
- L. Will the minimum allowable circulation be maintained through the hot water boiler?**
- M. Is the distribution system reverse return? If not, will balancing problems result?**

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51.06. Chilled Water and Condenser Water Systems

- A. See the "Piping Systems—General" earlier for additional requirements.**
- B. Are balancing valves indicated? Are flow measuring stations needed? Have they been indicated?**
- C. Is pressure regulation needed?**
- D. Is a bypass filter required? Is the GPM included in the pump capacity?**
- E. Is a standby pump needed?**
- F. Are service valves shown?**
- G. Will branch piping and ducts fit in the allotted space or enclosure?**

- H. Are riser shutoff valves shown?**
- I. Are riser drains and vents shown?**
- J. Is there adequate space for the installation and use of riser valves?**
- K. Will the minimum allowable circulation be maintained through the chiller?**
- L. Is the distribution system reverse return? If not, will balancing problems result?**
- M. Condenser water piping: loop traps to avoid excessive drainage, submerged impeller. Has the available NPSH been calculated? Is the NPSH indicated in the pump schedule?**
- N. For cooling tower makeup, overflow, and drain splash blocks, are there balancing valves in branch lines to tower cells? Coordinate the makeup with the plumbing engineer.**

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51.07. Air Systems

- A. Are adequate balancing dampers provided to prevent noise at outlets due to excessive pressure, or to avoid complicated balancing procedures on extensive low-pressure systems or exhaust systems (e.g., each zone of a multizone system; to limit flow variation due to stack effect in vertical low pressure and exhaust systems)?**
- B. Are fire damper locations, type, and flow restrictions indicated? Is there adequate height for a damper recess pocket at the shaft wall? Is breakaway ductwork at the fire damper wall sleeve detailed or specified?**
- C. Are smoke damper locations, type, and flow restrictions indicated? Is there adequate height for a damper at the shaft wall? Is breakaway ductwork at the smoke damper wall sleeve detailed or specified? Is the smoke damper operator located on the supported duct and not on a breakaway duct?**
- D. Are access doors at fire dampers, smoke dampers, turning vanes, humidifiers, coils, etc., properly specified and included in the general notes?**

- E. Are proper relief air provisions provided?**
- F. Is a return air fan needed? Is an outside air fan needed?**
- G. Are condensate drains provided? Are outside air intake drains provided?**
- H. Are flexible connections shown and specified?**
- I. Is sound lining required? Is it properly located and specified?**
- J. Will the duct arrangement permit the transfer of excessive noise between offices, toilet rooms, and rooms of a different function?**
- K. Is there objectionable fan noise from intakes or exhaust points to nearby buildings?**
- L. Are outlets located in supply mains? Are there noisy conditions?**
- M. Do trunk ducts pass above quiet rooms? Will noise be a problem?**
- N. Have fan class, bearing arrangement, motor location, etc., been shown, scheduled, or specified?**
- O. Are air intakes on party walls?**
- P. Will outlets blow at lights, beams, sprinkler heads, or smoke detectors? Sprinkler head and smoke detector locations must meet code requirements. Locate them in accordance with code.**
- Q. Have outlet and return grille elevations been coordinated with the architect and indicated?**
- R. Adjust outlet air quantities for duct heat gain and duct leakage.**
- S. Are isotope and chemical exhaust ducts accessible?**
- T. Is there interference between sill grille discharge and drapes or blinds? Beware of the annoying movement of vertical blinds or light drapes caused by sill air discharge nearby.**
- U. Are the present and future duties for air terminal units, AHUs, fans, etc., specified and scheduled?**
- V. Is the exhaust or relief discharge or plumbing stack effluent near intakes? Maintain a minimum of 10 ft. of clearance.**

W. Is there an anti-stratification provision at intakes, large mixing box outlets, and downstream of steam coils or water coils? Are air blenders indicated on all AHUs?

X. Are there aluminum grilles on the shower, sterilizer, etc., exhaust? Is stainless steel ductwork or aluminum ductwork required? Is it clearly indicated on drawings as to extent? Has it been specified?

Y. Are there sealing and sloping of shower, cage washer, etc., exhaust ducts? When more than one type of duct material is used, is the extent and location clearly defined?

Z. Has adequate relief from rooms been provided? Are there door louvers, undercut doors, transfer grilles, and direct exhaust? Have they been coordinated?

AA. Will door louvers defeat the needed acoustical privacy (e.g., conference rooms, private offices, VP office)? Will door louvers defeat the needed door fire rating? Are door louvers located in accordance with code?

BB. Are the types of branch takeoffs and duct splits shown? Are details included on drawings?

CC. Are there intermediate drip pans on cooling coil banks? Are they piped to the floor drain? Include detail.

DD. Are there drains for kitchen exhaust duct risers?

EE. Is there excessive duct heat gain from nearby steam pipes and other heat sources?

FF. Are there combustion air intakes for boilers, water heaters, etc.? Are vents, stacks, breeching, and chimneys shown, specified, and detailed? Are termination heights clearly indicated?

GG. Locate exhaust grilles near the floor in operating rooms, flammable storage rooms, chlorine storage rooms, battery rooms (high and low), etc.

HH. Do not use corridors as return air plenums in hospitals, nursing homes, offices, and other facilities.

II. Have insulated louver blank-off panels or sheets been included where required?

JJ. Are filters provided in makeup air to elevator equipment rooms? Are filters provided for air-cooled condensers and condensing units located indoors?

KK. Are there motor-operated dampers in wall louvers? Do not use operable louvers. Use stationary louvers with motor-operated dampers behind when required.

LL. Are casings adequately described as prefabricated or field-fabricated? Is the extent of the sound paneling clear? Has an adequate pressure rating been specified?

MM. Has the architect provided adequate framing for the linear diffuser in the metal lath and plaster or dry wall bulkheads? Do not dimension diffuser lengths for wall-to-wall installations—note the dimension as "wall to wall."

NN. Have fan systems been checked for excessive sound transmission?

OO. Is there adequate space for servicing fans, motors, belts, etc.?

PP. Has sufficient space been provided between coils of AHUs to accommodate temperature sensors?

QQ. Are adequate service space or equipment size access panels noted on drawings for equipment installed above ceilings? Coordinate with the architect who furnishes, installs, provides.

RR. Are there adequate straight duct branch length or straightening vanes between the main duct and diffuser?

SS. Do ducts pierce partitions at 90-degree angles wherever possible?

TT. Are wash down systems or fire protection systems required for fume hoods or kitchen hoods?

UU. Are fume hood exhaust systems balanceable? Are orifice plates required?

VV. Are correct outside air quantities and pressurization included?

WW. Is a smoke control system required?

XX. Avoid contamination of air intake from exhaust air, contaminated vents, vehicle exhaust, etc. Are locations in accordance with code?

YY. Are static pressure sensors indicated or specified?

ZZ. Are fire and smoke dampers coordinated with fire and smoke walls? Are fire rated floor/ceiling assemblies used? Will diffusers, registers, and grilles require fire dampers? Are smoke dampers required for air handling units or fans?

AAA. Is the floor suitable for "built-up" air handling units?

BBB. Have ventilation systems been provided for equipment rooms and other non-air-conditioned spaces?

CCC. Are flow measuring devices located? Is there adequate straight run?

DDD. Is there adequate straight duct upstream of terminal units? VAV, constant volume reheat, dual duct, fan-powered, and other air terminal unit runouts should be sized based on the ductwork criteria established for sizing the ductwork upstream of the air terminal unit, and not on the terminal unit connection size. The transition from the runout size to the air terminal unit connection size should be made at the terminal unit. A minimum of 3 ft. of straight duct should be provided upstream of all air terminal units.

EEE. Is the system compatible with architectural floor/ceiling assemblies?

FFF. Do toilet rooms have the code-required minimum exhaust?

GGG. Locate exterior wall louvers, especially intake louvers, a minimum of 2'0" above the roof, finished grade, etc.

HHH. Locate gravity roof ventilators, especially intake ventilators, a minimum of 1'0" from the finished roof to the top of the roof curb.

III. Are air-conditioning condensate drains piped to storm water or sanitary as required by the local authority?

51.08. Process Exhaust Systems

- A. Branches and laterals should be connected above the duct centerline. If branches and laterals are connected below the duct centerline, drains will be required at the low point.**
- B. Provide blast gates or butterfly dampers at each branch, at each submain, and at each equipment or tool connection. Wind loading on blast gates needs to be considered when installed on the roof or outside the building, especially those blast gates that are normally open.**
- C. Blast gate blades for process exhaust systems should be specified with an EPDM wiper gasket to provide a tight seal. For blast gates installed for future use, it is recommended that the blade be removed and a gasketed blind flange be provided where the blade goes in the duct to reduce leakage.**
- D. Does duct pitch to low points and drains? Are drains provided at all low points?**
- E. Has correct duct material been specified? Is it Stainless Steel, Halar Coated Stainless Steel, FRP, or PVC? PVC is not recommended and the maximum size is 8" round.**
- F. Has the proper pressure class been specified upstream and downstream of scrubbers and other abatement equipment?**
- G. Is ductwork installed outside or in unconditioned spaces and will condensation occur on the outside or inside of this duct? Is duct insulation or heat tracing required?**
- H. Are adequate butterfly balancing dampers shown for system balancing?**
- I. Are bubble tight dampers specified and shown when and where required?**
- J. Are process exhaust fans on emergency power as required by code?**
- K. Process exhaust ductwork cannot penetrate fire-rated construction. Fire dampers are generally not desirable. If penetrating fire-rated construction cannot be avoided, process exhaust ductwork must be**

enclosed in a fire-rated enclosure until it exits the building, or sprinkler protection inside the duct may be used if approved by the authority having jurisdiction.

L. Are pressure ports provided at the ends of all laterals, submains, and mains?

M. Are drains required in fan scroll, scrubber, or other abatement equipment?

N. Are flexible connections provided at fans and are flexible connections specified suitable for application?

O. Are stacks properly located and is the discharge height adequate to prevent contamination of outside air intakes, CT intakes, and combustion air intakes? Are termination heights clearly indicated?

P. Have redundancy requirements been met?

Q. Are variable frequency drives required, located, and coordinated with the electrical engineer?

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51.09. Refrigeration

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Is future machine space indicated on the drawings?

C. Is the space for servicing indicated on the drawings?

D. Are there rigging supports for large water boxes and compressor shells?

E. Is noise transmission likely to occupied spaces?

F. Is there adequate control of chilled water temperature?

G. Are sprinklers required for wood fill towers? *NFPA 214.*

H. Is refrigerant relief piping shown on the drawings? Is it piped to the outside?

I. Is noise from the cooling towers likely to be a problem?

- J. Will cooling tower discharge air pocket or recirculate?**
- K. Should the cooling tower be winterized?**
- L. Have the cooling tower support locations been cleared with the structural engineer. When determining the cooling tower enclosure height, has the height of vibration isolators been considered (8-12 in. high) and has the height of the safety rail been considered?**
- M. Are cooling tower discharge duct connections necessary?**
- N. Are flow diagrams required? Have they been coordinated?**
- O. Are present and ultimate duties noted where applicable and coordinated with pumps and coils, etc.?**
- P. Is ethylene or propylene glycol required? Has it been specified and equipment capacities derated?**
- Q. Has additional insulation been included for low temperature systems?**
- R. Has single-phase protection been included for packaged (single and/or split systems) air conditioning and heat pump compressor motors?**

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51.10. Controls

- A. Are all panels located? Have they been coordinated with the Electrical Engineer? Are they local or central?**
- B. Are flow meter locations an adequate distance up- and downstream of the orifice?**
- C. Are thermostat and humidistat locations indicated? Do not mount stats on glass panels or door frames. Avoid middle-of-the-wall locations.**
- D. Are control settings, schedules, and diagrams indicated or specified?**
- E. Are temperature tolerances in lab areas clearly specified?**

- F. Are power and control wiring diagrams shown? Is interlocking wiring included?**
- G. Have reheat coils requiring full capacity in summer been supplied from a constant temperature hot water supply?**
- H. Are low-leak dampers specified on intakes and elsewhere as required?**
- I. Have compressor location and motor size been coordinated with the Electrical Engineer?**
- J. Are all AHUs and systems accounted for on control design?**
- K. Coordinate the purchase and installation of duct smoke detectors and duct fire stat locations with the Electrical Department for connection to the building fire detection system.**
- L. Are direct digital controls appropriate?**
- M. Are valve positions (normally open or normally closed) indicated where applicable?**
- N. Is the compressor sized for ultimate duty?**

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51.11. Sanitary and Storm Water Systems

- A. See the "Piping Systems—General" section earlier for additional requirements.**
- B. Adjust sewer inverts to keep the tops of pipes in line where the pipe's size changes (note this on the drawings).**
- C. Maintain at least a minimum cover on sewers for the entire run.**
- D. Has the sewer authority been contacted for the following:**
 - 1. Are sewer authority mains capable of handling additional discharge?
 - 2. The location, size, and depth of sanitary and storm sewer mains.
 - 3. Connection requirements.
 - 4. Requirements for grease traps, sand interceptors, oil/water separators, etc.

5. Has the DER or EPA been contacted?

6. Have storm water management requirements been determined?

E. Sewer profiles are usually required where contours vary extensively or where possible interference with other lines exists. Indicate contours where required.

F. Indicate sewer inverts at points of connection to public sewers, at building walls, at crossover points, and at points of possible interference. Are all underground utilities coordinated with foundations and grade beams?

G. Indicate foundation drain tile inverts. Provide back water valves (BWVs) at connections to the storm water system. Check accessibility. Is a manhole required?

H. Is there a dry manhole for BWVs outside the building or deep BWVs inside the building?

I. Provide headwall and rip rap for storm water discharge to a drainage ditch, storm water retention pond/tank, or stream.

J. Size site storm sewers large enough to prevent stoppage by leaves, paper, silt, etc. Except for light duty sewers, use an 8" or 10" pipe minimum.

K. Are all plumbing fixtures designated and scheduled?

L. Coordinate fixture locations with final architectural plans. Check ADA requirements. Are handicapped fixtures identified?

M. Provide BWVs for drains and groups of drains connected to the storm water below grade or where backflow is possible above grade.

N. Vent sumps for sanitary and storm water drainage.

O. Is the elevation of mains selected to be above the footings? Advise the Structural Engineer if mains must run below footings or through footings.

P. Is there adequate ceiling space for AHU floor drain traps on upper floors? Are deep seal traps required? Are they indicated?

Q. Are drains for overflows piped?

R. Are there separate vapor vents for sterilizer and bed pan washers?

S. Are grease traps required for commercial kitchens? Are sand interceptors and/or oil/water separators required for garages and parking areas? Is oil and/or water collected by the oil/water separator to be treated as hazardous waste?

T. If an oil-filled transformer is located inside the building, provide the transformer room with a drain and pipe to an accessible storage tank.

U. Provide floor drains for air handling units, boilers, chemical feed equipment, air compressors, pumps, generators, etc., especially for relief valve discharge and pump stuffing box discharge.

V. Are disposals directly connected to heavy flow mains? Do not connect to a grease interceptor.

W. Provide a floor drain to create an indirect waste connection for commercial dishwashers, kitchen sinks, and kitchen equipment processing food.

X. Is the plumbing fixture connection schedule included?

Y. Does the general piping or equipment interfere with the overhead door's travel?

Z. Do not run horizontal piping in solid masonry walls.

AA. Is there adequate AHU pad height to allow condensate drain from the pan to be properly trapped? Are condensate drains piped to the storm or sanitary made with indirect connections? Do local authorities require condensate drains to be piped to sanitary or to storm? Can condensate drains be discharged onto the roof or grade?

BB. Are floor drains, roof drains, and trench drains coordinated with the structural system? Are drains coordinated with building expansion joints?

CC. Are air conditioning and steam condensate (when wasted) piped to storm water or sanitary? Is steam condensate cooled?

DD. Are automatic trap priming systems required?

- EE. Are floor drain, roof drain, and trench drain types suitable for duty and traffic rating?**
- FF. Are flow or riser diagrams required by plumbing authorities? Are fixture units clearly indicated on riser diagrams when required?**
- GG. Is the minimum size of the vent through the roof indicated (e.g., recommend 3")? Has the minimum size pipe below floor been coordinated with local codes (e.g., Allegheny Co. 4" minimum pipe size below floor)?**
- HH. Are fixtures and drains trapped and vented in accordance with applicable code?**
- II. Will drainage to grade freeze and create a slippery condition?**
- JJ. Is tub overflow assembly accessible? Use a solid connection, if not.**
- KK. Are cooling tower and evaporative cooler overflows, bleeds, and drains piped to sanitary?**
- LL. Do not use cleanouts on Washington, D.C., projects. Verify requirements.**
- MM. Are acid waste and vent systems clearly indicated on the drawings and specified?**
- NN. Site drainage: Are adequate manholes, catch basins, and other items shown on the drawings and specified?**
- OO. Are future connections and/or expansions considered in the slope of piping, size of piping, and sewer connection sizing?**
- PP. Provide manways for septic and sewage holding tanks. Manholes and covers should be waterproof/watertight.**

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51.12. Domestic Water Systems

- A. See the "Piping Systems—General" section earlier for additional requirements.**
- B. Has the water authority been contacted to obtain the following:**

1. Water static and residual pressures and flows at the water main. Are these pressures and flows adequate?
2. The location and size of water mains.
3. Water hardness and the corrosiveness of the water.
4. Backflow prevention requirements.
5. Water meter location requirements and meter pit requirements if necessary.

C. Are pressure regulating valves required? Do pressures exceed 60 psi? If so, pressure reducing valves should be provided.

D. Are there submain section valves?

E. Are there provisions for piping and building expansion?

F. Have all wall, box, and yard hydrants been provided and specified?

G. Are water softeners for laundry and boiler makeup required?

H. Is makeup water connected to the boiler, heating, chilled, condenser, and other HVAC water systems? Is freeze protection required? Is sufficient pressure available to overcome static head?

I. Provide hose bibbs at cooling towers and in boiler rooms, mechanical rooms, large toilet rooms, dormitory toilet rooms, and kitchens.

J. In boiler and chiller rooms, provide service sink and water sampling connections.

K. Are flow or riser diagrams required by plumbing authorities? Are fixture units clearly indicated on riser diagrams when required?

L. Is a hot water recirculating pump required, located, scheduled, and specified?

M. Are all hospital, laboratory, kitchen, and other special equipment connections shown on the drawings? Are hospital, laboratory, kitchen, and other special equipment connection schedules required and included?

- N. Are backflow preventers provided at the service entrance, at the fire protection service, and at the connection to the HVAC water systems fill connections? Use reduced pressure backflow preventers on all HVAC systems and double-check backflow preventers on domestic water and fire protection service.**
- O. Is a pressure boosting system required?**
- P. Is a main shutoff valve provided? Are shutoff valves shown at each toilet room and groups of two or more plumbing fixtures?**
- Q. Are all plumbing fixtures shown on the drawings and specified?**
- R. Is a water meter required? Is submetering required?**
- S. Are balancing valves on the hot water recirculation system shown?**
- T. Use a 3/4" cold water connection to eye wash units.**
- U. Are water heater connections shown (gas, water, vents, etc.)?**
- V. Is a dishwasher booster heater connected?**
- W. Are future connections and/or expansions considered in the size of the piping and service entrance?**
- X. Are all underground utilities coordinated with foundations?**

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51.13. Fire Protection

- A. See the "Piping Systems—General" section earlier for additional requirements.**
- B. Are Siamese connections shown and coordinated with the architect?**
- C. Are check valves and shutoff valves shown on the drawings?**
- D. Have fire extinguishers and/or cabinets been specified by the architect or engineer? Have fire hoses and/or cabinets been specified by the architect or engineer?**
- E. Is fire protection for kitchen hoods required?**
- F. Is there adequate space for sprinkler mains?**

- G. Are dry systems provided for areas subject to freezing?**
- H. Is there a sprinkler for trash and linen chutes?**
- I. Are there drains for ball drips of Siamese connections?**
- J. Are pressures noted for hydraulically calculated systems?**
- K. Is the extent of the sprinklered area indicated? If more than one type of sprinkler system is required (wet, dry, pre-action, deluge, etc.), are they clearly indicated on the drawings?**
- L. Are fire department valves clearly indicated on the drawings?**
- M. Are special fire protection systems included?**
- N. Are standpipes and fire department valves shown?**
- O. Is sprinkler zoning compatible with the fire alarm zoning?**
- P. Are all test connections shown and locations coordinated with the Architect? Are drains for test connections provided?**
- Q. Has the water authority been contacted to obtain the following:**
1. Water static and residual pressures and flows at the water main. Are these pressures and flows adequate or is a fire pump required?
 2. The location and size of water mains.
 3. The water hardness and the corrosiveness of the water.
 4. Backflow prevention requirements.
 5. Water meter location requirements and meter pit requirements if necessary.
 6. Street or onsite fire hydrant requirements.
 7. The fire hydrant and fire department connection size, thread type, etc.
- R. Have electrical requirements for the fire pump, tamper switches, flow switches, etc., been coordinated with the electrical department?**
- S. Have fire pump requirements been coordinated between the spec and the drawings?**
- T. Have the fire hose and fire extinguisher locations been coordinated**

with the Electrical Department for the wiring of the blue indicator light?

U. Who paints fire protection piping and what color (red)?

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51.14. Natural Gas Systems

A. See the "Piping Systems—General" section earlier for additional requirements.

B. Determine the minimum gas pressure required. Is the gas company pressure available at the street adequate for the equipment? Has the gas company been contacted to obtain the following:

1. Pressures and flows at the gas main. Are these pressures and flows adequate?
2. The location and size of the gas mains.
3. Gas meter location requirements and meter pit requirements if necessary.

C. Has the gas meter size been coordinated with the gas company? Has the capacity requirement and site location been given to the gas company? Is the meter required to be located inside or outside? Who provides gas meter and regulator assembly? The gas company? Who provides gas piping from the main to the curb box, from the curb box to the meter assembly, from the meter assembly to the building, and inside the building?

D. Have gas pressure regulators been evaluated for low-load conditions and during startup? It is recommended that multiple gas pressure regulators be used, especially on large central utility plant natural gas systems, not only for low-load conditions but for the replacement of regulators without a shutdown of the entire plant. For instance, the natural gas system design may use two regulators sized at 50-50, 33-67, or 40-60 percent, or it may use three regulators sized at 15-35-50 or 25-25-50 percent.

E. Is there gas meter access and room ventilation (when required)?

F. Are there drip pockets if gas lines cannot drain back to the meter, and adequate space for the pitch?

G. Are there submain section gas cocks?

- H. Are gas vent valves and vents from pressure regulating valves piped to the outside?**
- I. Do not locate natural draft burners in the room under "negative" pressure.**
- J. Coordinate the gas train with gas pressure available and with the Owner's insurance carrier.**
- K. Are stacks, vents, and breeching shown on the drawings and are they properly sized and specified? Coordinate with the design team other equipment requiring gas vents (e.g., water heaters, shop equipment, kitchen equipment, lab equipment, hospital equipment).**
- L. Is combustion air for fuel-fired equipment properly designed in accordance with code? Watch for water heaters in janitor closets.**
- M. What pressures are permitted to be run inside the building?**
- N. Is piping run in plenum? If so, valves cannot be located in plenum, including walls.**
- O. Check with the local gas company for welded and screwed pipe requirements (concealed, exposed, etc.). Screwed pipes and fittings may only be used if gas service is less than 1 psig and vertical runs are less than four stories. Otherwise, use welded pipe.**
- P. Plastic pipe can only be used for underground service. Require the contractor to install #14 insulated tracer wire 4 to 6 in. above all underground plastic lines.**

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51.15. Fuel Oil Systems

- A. See the "Piping Systems—General" section earlier for additional requirements.**
- B. Do not locate natural draft burners in rooms under "negative" pressure.**
- C. Is the suction lift within allowable limits of the fuel oil pump?**
- D. Is the underground fuel oil tank location coordinated with the site plan? Does it have adequate cover? Has truck traffic been considered?**

Are leak detection systems and double wall piping systems shown on the drawings and specified?

E. Are the tank vent and fill indicated and away from air intakes? Are vents properly sized?

F. Are fuel oil heaters required (#4, #5, #6 fuel oils)?

G. Is a tank heater required? (They are not permitted with fiberglass tanks.)

H. Is compressed air for the tank gauge provided?

I. Is a specified tank suitable for installation? Has it been coordinated with the owner? Is future conversion to heavy oil a consideration?

J. Are leak detection, double wall piping, spill containment, double wall tanks, etc., properly specified and shown on the drawings?

K. Are stacks, vents, and breeching shown on the drawings and properly sized and specified? Coordinate with the design team other equipment requiring vents (e.g., water heaters, shop equipment, lab equipment, hospital equipment).

L. Is combustion air for fuel-fired equipment properly designed in accordance with code? Watch for water heaters in janitor closets.

M. Are EPA tank requirements met? Have state police requirements been met?

N. Are emergency vents properly sized for indoor tanks?

O. Are manholes and covers for fill and access openings specified and/or detailed to be waterproof/watertight?

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51.16. Laboratory and Medical Gas Systems

A. Is a separate zone valve required?

B. Are medical gas alarm panels required?

C. Is the air intake for the hospital compressor indicated? Is it outside? Does it provide clean air?

D. Vacuum pump discharge should not be at rubber membrane roofs, due to the adverse reaction of oil with membrane materials.

E. Are *NFPA 99* requirements met?

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51.17. General

A. Are all mechanical items specified and coordinated with other disciplines as to who provides, furnishes, and/or installs? Have all items on the specification coordination list been coordinated? Do all disciplines have the most current drawings showing mechanical equipment?

B. Is there a north arrow, title block, and engineer's stamp with signature?

C. Are scales noted on the plans? Does the project or client require graphic scales?

D. Are there client and project numbers on all projects, and the company name, logo, address, etc., on all drawings?

E. Check for completeness of general notes, legend, abbreviations, and title blocks.

F. Check column numbers and grids.

G. Check room names and numbers.

H. Is the extent of the demolition clearly defined? Is what is to remain clearly defined? Are points of connection between the new and old clearly defined?

I. Check the coordination and contrast of new and existing work.

J. Coordinate the following with architectural, structural, and electrical departments:

1. Clearances between lighting fixtures, structure, and ducts and pipes.
2. Clearances between conduits out of electrical panels and pull boxes, structure, and ducts and pipes.

3. Wiring of filters (roll filters and air purification systems).

K. Does the electrical department have the final motor list and heater list?

L. Have existing mechanical/electrical services and available space for new work been adequately field checked?

M. Advise the electrical department of any relocated mechanical equipment having electrical components.

N. Has the division of work between the architectural, structural, mechanical, and electrical disciplines been coordinated (as to who furnishes, installs, and/or provides) on such items as:

1. Starters and disconnect switches.
2. Line and low voltage control wiring and power wiring to control panels.
3. Access panels.
4. Fire extinguishers, fire hoses, and/or cabinets.
5. Catwalks and ladders.
6. Under-window unit discharge grilles on built-in cabinets.
7. Louvers.
8. Door grilles, undercut doors.
9. Generators, mufflers, fuel oil piping, engine exhausts, engine cooling air ductwork, and accessories.
10. Painting and priming.
11. Mechanical equipment screens.
12. Equipment supports and concrete housekeeping pads.
13. Roof curbs (equipment, ductwork, and piping), flashing, and counter flashing.
14. Site work/building utility design termination (5'0" outside of the foundation wall).
15. Foundation drains.

16. Excavation.
17. Kitchenette units.
18. Bus washer, vehicle lifts, hydraulic piping and accessories, and paint booths and accessories.
19. Countertop plumbing fixtures; built-in showers.
20. Kitchen hoods.
21. Laboratory fume hoods.

O. Where the ceiling height and door or window head heights provide no leeway to lower ceiling, have mechanical and electrical work space above the ceiling been closely checked?

P. Check the framing of holes in existing structures.

Q. Is the structure adequate for new mechanical equipment in existing buildings?

R. Is there adequate clearance for the removal of ceiling systems for access to equipment? A tee bar system requires 3" minimum from the underside of the ceiling to the equipment.

S. Have the heating and ventilation of bathrooms and toilet rooms been provided?

T. Is there equipment room, PRV room, electrical room, and electrical closet ventilation?

U. Has insulation or ventilation been provided to overcome radiant heat from boiler or incinerator stacks?

V. Has specified equipment been properly described by current model designation?

W. Have all items specified "As indicated on the drawings" been coordinated? Coordinate references between drawings, details, sections, risers, and specifications.

X. Is there any material or equipment for which there is no catalog data in the office library?

Y. Have details been coordinated?

Z. Has space for future ducts, pipes, fans, pumps, chillers, boilers, cooling towers, water heaters, and other equipment been clearly indicated?

AA. Are "floating floors" required for noise control? Have they been specified and detailed?

BB. Has the existing area been adequately field checked?

CC. Are elevator machine rooms free of piping, ductwork, and equipment except elevator machine equipment? Is the elevator machine room ventilated? Does the elevator machine room need to be air conditioned?

DD. Have chemical treatment systems been included?

EE. Have handwash sinks been included in mechanical equipment rooms?

FF. Have chain operators for valves more than 7'0" above the finished floor been specified?

GG. Are general notes, drawing notes, and keyed notes included?

HH. Is a key plan needed?

II. Are applicable standard details included and coordinated?

JJ. Have applicable codes been researched?

KK. Should smoke and fire walls be indicated?

LL. Are present and ultimate duties included in schedules where applicable and coordinated with the Electrical Engineer? Are future flows accounted for in duct and pipe sizing and appropriate provisions made?

MM. Have authorities having jurisdiction been consulted regarding fire detection and protection systems, applicable codes, etc.?

NN. Is the minimum head room (6'8") maintained in equipment rooms?

OO. Is verification that the building meets *ASHRAE Standard 90.1* or other Energy Conservation Codes required?

PP. Is access to equipment with electrical connections (such as ceiling-mounted heat pumps) adequate to satisfy the NEC?

QQ. Have all equipment housekeeping pads been indicated, specified, and coordinated?

RR. Is asbestos present in the existing building? Is preparation of the removal documents part of the contract?

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51.18. Architect and/or Owner Coordination

A. Have all shafts/chases been coordinated? Are they large enough?

B. Do shafts/chases line up floor to floor? Are structural members located in the shaft space?

C. Have pipe or duct chases been provided where required?

D. Will partitions accommodate piping and plumbing fixtures?

E. Has a suitable type stationary louver been specified?

F. Are bird screens (not insect screens) specified? Are bird screens located on the inside or outside of louver? The outside of louver is easier to clean but its appearance is undesirable.

G. Have louver locations and sizes been coordinated? Who provides, furnishes, and/or installs louvers?

H. Have plumbing fixtures, as required, been specified under the architectural section?

I. Have all plumbing fixtures been coordinated?

J. Has all special equipment been coordinated?

K. Have not in contract (NIC) or future items requiring "stub-up" services been identified?

L. Have masonry air shafts been avoided? If not, are they specified to be airtight?

- M. Has proper access to roof mounted equipment been provided?**
- N. Have provisions for equipment replacement been made?**
- O. Have supply air ceiling plenums been coordinated? Are partitions floor-to-floor where required? Is the supply air plenum area sealed where required?**
- P. Have return air ceiling plenums been coordinated? Are partitions floor-to-floor? If so, have provisions been provided to return air from these spaces?**
- Q. Have trenches, sumps, and covers been coordinated?**
- R. Have under-window units been coordinated?**
- S. Have air outlet types been coordinated?**
- T. Have thermostat types been selected and approved by the owner?**
- U. Have plumbing fixtures and types been approved? Have countertop fixtures been coordinated? Who provides, furnishes, and/or installs countertop fixtures?**
- V. Include vibration isolators, grillage, and cooling tower safety rails when dimensioning the height of the cooling tower for the architectural screen.**
- W. Have all skylights, roof hatches, bulkheads, and multiple height ceilings been coordinated with ductwork, piping, and other mechanical equipment?**
- X. Who provides, furnishes, and/or installs roof curbs for mechanical equipment?**
- Y. Who provides, furnishes, and/or installs flashing and counterflashing?**
- Z. Who provides cutting and patching?**

- A. Have equipment locations, sizes, and weights been given to the Structural Engineer? Have equipment housekeeping pad locations and sizes been coordinated? Has the final and complete structural list been given to the Structural Engineer?**
- B. Have all floor, roof, and wall openings been coordinated?**
- C. Have pipes 6 in. and larger been located and coordinated with the Structural Engineer?**
- D. Have all sleeved beams, grade beams, and foundations been coordinated? Have pipes and ducts been coordinated?**
- E. Has structural framing in the shafts been considered?**
- F. Has the mechanical layout been coordinated with the structural system, especially in post-tensioned concrete structural systems? (Penetrations at columns and column lines are not normally possible.)**
- G. Is the structural system adequate for future equipment?**
- H. Where equipment must be "rolled" into place, is the structure over which equipment will be rolled adequate?**
- I. Have catwalks been coordinated?**
- J. Have pipe risers been coordinated?**
- K. Do structural openings allow for insulation and ductwork reinforcing?**
- L. Have anchor locations and associated forces been given to the Structural Engineer? Avoid locating anchors at joist or joist girder locations.**
- M. Have louver openings, sizes, and framing been coordinated with the Structural Engineer?**

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51.20. Electrical Engineer Coordination

- A. Has the final and complete motor list been given to the Electrical Engineer?**

- B. Have all electrical and telecommunication rooms and closets been ventilated? Do they need to be air conditioned?**
- C. Have duct smoke detectors, duct fire stats, and/or smoke dampers been coordinated?**
- D. Have valve position indicators/tamper switches been coordinated?**
- E. Have sprinkler flow switches and alarms been coordinated?**
- F. Have fuel tank level alarms and gauges been coordinated?**
- G. Have cooling tower electric basin heaters and vibration switches for propeller fans been coordinated?**
- H. Have medical gas alarms been coordinated?**
- I. Have the automatic trap priming systems for the kitchen and other areas been coordinated?**
- J. Has the automatic trap priming system for the AHUs been coordinated?**
- K. Has lighting inside the AHUs been coordinated?**
- L. Has power at the pneumatic tube stations been coordinated?**
- M. Has power for the ATC compressors and refrigerated air dryers been coordinated?**
- N. Who provides starters and disconnect switches? Who provides line voltage and low-voltage control wiring? Who provides power wiring to the control panels? Have starters, wall switches, remote starter pushbuttons, and disconnect switches been located on the mechanical drawings?**
- O. Have two disconnects been provided at duplex pumps?**
- P. Are there automatic fire suppression systems for fume hoods and kitchen hoods?**
- Q. Are there alarms on sump pumps, condensate pumps, sewage pumps, hot water generators, and similar items?**

- R. Are there chiller oil heaters and control circuits (winterize air-cooled chillers)?**
- S. Are there diesel generator fuel oil pumps on emergency power? Who provides the engine exhaust, fuel-oil piping, day tank, muffler, cooling air, fuel storage tank, etc.?**
- T. Steam or water flow on the BTU meter recorders?**
- U. Have shower controls been coordinated?**
- V. Are there automatic fire suppression systems for the computer rooms? Are AHUs interlocked with the computer room shutdown system?**
- W. Are there smoke or thermal detectors for AHUs and RA fans? Who furnishes, installs, and/or provides them?**
- X. Has heat tracing for piping systems been coordinated?**
- Y. Are there electric fuel tank heating systems?**
- Z. Is there auxiliary equipment on the water chillers?**
- AA. Has the motor list been coordinated with equipment schedules?**
- BB. Has the motor list been coordinated with control diagrams?**
- CC. Have electric humidifiers been coordinated?**
- DD. Have hot water generator or boiler circulating pumps been coordinated?**
- EE. Has relocated equipment been coordinated?**
- FF. Have allowances been made for lighting fixture access? Have the heights of lighting fixtures been coordinated, especially high hat fixtures?**
- GG. No ductwork, piping, or other mechanical equipment should be in electrical rooms or closets.**
- HH. Are motor control centers (MCCs) shown and specified? Are starters shown and specified?**
- II. Is there adequate space for MCCs?**

JJ. Is there enough space for electric water level detectors?

KK. Are electric motor-operated dampers wired?

LL. Are there air handling light fixtures, supply, return, and heat transfer?

MM. Has the extent of return air ceilings been coordinated with the Electrical Engineer?

NN. Is the equipment on emergency power clearly defined and coordinated? Include the control air compressor and dryer.

OO. Are explosion proof motors, starters, disconnect switches, etc., required?

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Part 52: Professional Societies and Trade Organizations

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52.01. Professional Societies and Trade Organizations

AABC	Associated Air Balance Council
AACC	American Automatic Control Council
AAHC	American Association of Health Care Consultants
ABMA	American Boiler Manufacturers' Association
ACCA	Air Conditioning Contractors of America
ACGIH	American Conference of Governmental and Industrial Hygienists
ACI	American Concrete Institute
ACS	American Ceramic Society
ACS	American Chemical Society
ACSM	American Congress on Surveying and Mapping
ADA	Americans with Disabilities Act

ADA	AMERICANS WITH DISABILITIES ACT
ADAAG	ADA Accessibility Guidelines for Buildings and Facilities
ADC	Air Diffusion Council
AEE	Association of Energy Engineers
AEI	Architectural Engineering Institute
AFBMA	American Fan and Bearing Manufacturers' Association
AFS	American Foundrymen's Society
AGA	American Gas Association
AGMA	American Gear Manufacturers Association
AHA	American Hospital Association
AHCA	American Health Care Association
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AIA	American Institute of Architects
AIA	American Insurance Association
AICE	American Institute of Consulting Engineers
AIChE	American Institute of Chemical Engineers
AIHA	American Industrial Hygiene Association
AIIE	American Institute of Industrial Engineers, Inc.
AIPE	American Institute of Plant Engineers
AISC	American Institute of Steel Construction
AISE	Association of Iron and Steel Engineers

AISI	American Iron and Steel Institute
AMCA	Air Movement and Control Association International, Inc.
ANSI	American National Standards Institute
APCA	Air Pollution Control Association
APFA	American Pipe and Fittings Association
APHA	American Public Health Association
API	American Petroleum Institute
APWA	American Public Works Association
ASA	Acoustical Society of America
ASCE	American Society of Civil Engineers
ASCET	American Society of Certified Engineering Technicians
ASEE	American Society for Engineering Education
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASLE	American Society of Lubricating Engineers
ASME	American Society of Mechanical Engineers International
ASNT	American Society for Nondestructive Testing
ASPE	American Society of Plumbing Engineers
ASQC	American Society of Quality Control, Inc.
ASSE	American Society of Safety Engineers
ASSE	American Society of Sanitary

	Engineers
ASTM	American Society for Testing and Materials
ATBCB	Architectural and Transportation Barrier Compliance Board
AWS	American Welding Society
AWWA	American Water Works Association, Inc.
BCMC	Board for the Coordination of Model Codes (a Board of CABO)
BDC	Building Design and Construction
BEPS	Building Energy Performance Standards
BICSI	Building Industries Consulting Services International
BOCA	Building Officials and Code Administrators
BOMA	Building Owners' and Managers' Association
BRI	Building Research Institute
BSI	British Standards Institute
CABO	Council of American Building Officials
CAGI	Compressed Air and Gas Institute
CANENA	North American Electro/Technical Standards Harmonization Council
CEC	Consulting Engineers Council of the United States
CEN	European Standards Organization
CENELEC	European Committee for Electro/Technical Standardization
CGA	Compressed Gas Association, Inc.

CISPI	Cast Iron Soil Pipe Institute
CSA	Canadian Standards Association
CSI	Construction Specifications Institute
CTI	Cooling Tower Institute
DER	Department of Environmental Resources
DOE	Department of Energy
DOH	Department of Health
ECPD	Engineers' Council for Professional Development
EF	Engineering Foundation
EJC	Engineers' Joint Council
EJMA	Expansion Joint Manufacturers' Association
EPA	Environmental Protection Agency
ETL	ETL Testing Laboratories
FM	Factory Mutual System
FPS	Fluid Power Society
HAP	Hospital & Healthsystem Association of Pennsylvania
HEI	Heat Exchange Institute
HI	Hydraulic Institute
HTFMI	Heat Transfer and Fluid Mechanics Institute
HYDI	Hydronics Institute
IAHHS	International Association for Healthcare Security and Safety
IAPMO	International Association of Plumbing and Mechanical Officials
IBR	Institute of Boiler and Radiator

	Manufacturers
ICBO	International Conference of Building Officials
ICC	International Code Council (BOCA, CABO, ICBO, and SBCCI combined)
ICET	Institute for the Certification of Engineering Technicians
IEC	International Electro/Technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IFCI	International Fire Code Institute
IFI	Industrial Fasteners Institute
IFMA	International Facility Managers' Association
IHCA	Integrated Health Care Association
IIAR	International Institute of Ammonia Refrigeration
IRI	HSB Industrial Risk Insurers
IRI	Industrial Research Institute, Inc.
ISA	Instrument Society of America
ISO	International Organization for Standardization
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
MCAA	Mechanical Contractors Association of America
MSS	Manufacturers' Standardization

	Society of the Valve and Fittings Industry
NACE	National Association of Corrosion Engineers
NAE	National Academy of Engineering
NAHC	National Association of Health Consultants
NAHSE	National Association of Health Services Executives
NAIMA	North American Insulation Manufacturers Association
NAPE	National Association of Power Engineers, Inc.
NAPHCC	National Association of Plumbing-Heating-Cooling Contractors
NAS	National Academy of Sciences
NBFU	National Board of Fire Underwriters
NBS	National Bureau of Standards
NCEE	National Council of Engineering Examiners
NCPWB	National Certified Pipe Welding Bureau
NCSBCS	National Conference of States on Building Codes and Standards
NEBB	National Environmental Balancing Bureau
NEC	National Electric Code
NEMA	National Electrical Manufacturers' Association
NEMI	National Energy Management Institute
NFPA	National Fire Protection Association
NFRC	National Fenestration Rating Council

NFRC	National Fire Sprinkler Association
NFSA	National Fire Sprinkler Association
NIAOP	National Association of Industrial and Office Properties
NICE	National Institute of Ceramic Engineers
NICET	National Institute of Certified Engineering Technicians
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NRC	National Research Council
NRCA	National Roofing Contractors' Association
NRCC	National Research Council of Canada
NSAE	National Society of Architectural Engineers
NSF	National Sanitation Foundation International
NSPE	National Society of Professional Engineers
NUSIG	National Uniform Seismic Installation Guidelines
OSHA	Occupational Safety and Health Administration
PDI	Plumbing and Drainage Institute
PFI	Pipe Fabrication Institute
RESA	Scientific Research Society of America
SAE	Society of Automotive Engineers
SAME	Society of American Military Engineers
SAVE	Society of American Valve Engineers

SAVE	Society of American Value Engineers
SBCCI	Southern Building Code Congress International
SES	Solar Energy Society
SFPE	Society of Fire Protection Engineers
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SPE	Society of Plastics Engineers, Inc.
SSPC	Structural Steel Painting Council
SSPMA	Sump and Sewage Pump Manufacturers' Association
SWE	Society of Women Engineers
TEMA	Tubular Exchanger Manufacturers Association
TIMA	Thermal Insulation Manufacturers' Association
UL	Underwriters' Laboratories, Inc.
WPCF	Water Pollution Control Federation

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53.01. References and Design Manuals

- A. **The references listed in the paragraphs to follow form the basis for most of the information contained in this manual. In addition, these references are excellent HVAC design manuals and will provide expanded explanations of the information contained within this text. These references are recommended for all HVAC engineers' libraries.**
- B. **American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbooks**

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Part 54: Equipment Schedules

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54. Part 54: Equipment Schedules

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54.01. General

A. The equipment requirements listed in this section are general in nature and should be edited to suit the project. The items listed for a particular piece of equipment are generally not all required. For example, a variable volume terminal unit will have either a hot water coil or a steam coil, but not both. Also some Clients and Authorities Having Jurisdiction may not permit some of this information to be included on the drawings (i.e., Manufacturer's Name and Model No.).

B. Abbreviations

1. CFM	= Air Flow Rate (Cubic Feet per Minute)
2. GPM	= Water Flow Rate (Gallons per Minute)
3. MBH	= 1,000 Btu/h
4. hp	= Horsepower
5. DB	= Dry Bulb Temperature (°F)
6. WB	= Wet Bulb Temperature (°F)
7. RH	= Relative Humidity (%)
8. EAT	= Entering Air Temperature (°F)
9. LAT	= Leaving Air Temperature (°F)

10. EWT	= Entering Water Temperature (°F)
11. LWT	= Leaving Water Temperature (°F)
12. SP	= Static Pressure (in. W.G.)
13. ESP	= External Static Pressure (in. W.G.)
14. TSP	= Total Static Pressure (in. W.G.)
15. FLA	= Full Load Amps
16. LRA	= Locked Rotor Amps
17. MCA	= Minimum Circuit Amps
18. MOCP	= Maximum Overcurrent Protection
19. FPM	= Feet per Minute
20. RPM	= Revolutions per Minute
21. APD	= Air Pressure Drop (in. W.G.)
22. WPD	= Water Pressure Drop (ft. H ₂ O)
23. PRV	= Pressure Reducing Valve (psig)
24. RV	= Relief Valve (psig)
25. psig	= Pounds per Square Inch
26. SA	= Supply Air CFM
27. RA	= Return Air CFM
28. OA	= Outside Air CFM
29. EXH	= Exhaust Air CFM
30. RFA	= Relief Air CFM
31. CC	= Cooling Coil
32. HC	= Heating Coil
33. PHC	= Preheat Coil
34. RHC	= Reheat Coil
35. ΔT	= Delta T, Temperature Difference, °F
36. CHWS	= Chilled Water Supply Temperature °F

	Temperature, °F
37. CHWR	= Chilled Water Return Temperature, °F
38. CWS	= Condenser Water Supply Temperature, °F
39. CWR	= Condenser Water Return Temperature, °F
40. HWS	= Heating Water Supply Temperature, °F
41. HWR	= Heating Water Return Temperature, °F
42. LPS	= Low Pressure Steam, psig
43. MPS	= Medium Pressure Steam, psig
44. HPS	= High Pressure Steam, psig

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54.02. Air Balance Schedule

Room Number

Room Name

Room Area

Source

Number of Occupants

Code Requirements:

OA CFM

SA CFM

Supply CFM

Return CFM

Relief CFM

Exhaust CFM

Outdoor CFM

Transfer Air:

CFM

To Room

From Room

Remarks

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54.03. Air Compressors

Designation

Location

Service

Type (Reciprocating, Rotary Screw, Duplex, Simplex)

CFM

Pressure psig

Receiver Size:

Gallons

Diameter

Length

Motor:

hp

RPM

Volts-phase-hertz

Operating Weight lbs.

Manufacturer's Name and Model No.

Remarks

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54.04. Air-Cooled Condensers

Designation

Location

Service

Type

Tons or MBH

Refrigerant Type

Saturated Condenser Temperature

Condenser EAT °F DB/°F WB

Minimum OA Temperature

Fans:

Number

hp

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.05. Air-Cooled Condensing Units

Designation

Location

Service

Type

Tons or MBH

Refrigerant Type

Saturated Condenser Temperature

Condenser EAT °F DB/°F WB

Minimum OA Temperature

Compressor:

Number

kW or hp

FLA

LRA

MCA

MOCP

Volts-phase-hertz

Fans:

Number

hp

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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Holdings

54.06. Air Conditioning Units

Designation

Location

Service

Min. OA CFM

Fan:

CFM

ESP

TSP

Number of Wheels

Wheel Diameter In.

Motor hp

Filters:

Type

Efficiency

Cooling Coil:

Refrigerant Type

Sensible MBH

Total MBH

EAT °F DB/°F WB

LAT °F DB/°F WB

Compressor:

Number

FLA

LRA

kW or hp

Condenser:

EAT

Number of Fans

Motor hp

Exhaust Fan Motor hp

Electric Heat:

kW

No. of Control Steps

EAT

LAT

Gas Heater:

Output MBH

Input MBH

EAT

LAT

Hot Water Coil:

MBH

EAT

LAT

EWT

LWT

GPM

WPD

Steam Coil:

MBH

EAT

LAT

Steam/h

Steam Pressure psig

Electric:

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.07. Air Filters (Pre-Filters, Filters, Final-Filters)

Designation

Location

Equipment Served

Service (Pre-Filters, Filters, Final-Filters)

Number

Type

Width

Height

Depth

Efficiency %

Initial APD

Final APD

Remarks

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54.08. Air Handling Units—Custom, Factory Assembled, Factory Packaged, or Field Fabricated

Designation

Location

Service

Min. OA CFM

Fan:

CFM

Type (AF, BI, FC, DWDI, SWSI)

Class (I, II, III, IV)

Number of Wheels

Wheel Diameter

ESP

TSP

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Filters (see Air Filters)

Coils (see Coils—DX, Electric, Steam, Water)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.09. Air Handling Units—Packaged, Central Station

Designation

Location

Service

Min. OA CFM

Fan:

CFM

Type (AF, BI, FC, DWDI, SWSI)

No. of Wheels

Wheel Diameter In.

ESP

TSP

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Filters (see Air Filters)

Coils (see Coils—DX, Electric, Steam, Water)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.10. Boilers, Hot Water

Designation

Location

Service

Output MBH

Water:

GPM

EWT

LWT

WPD

Heater:

Gas Input MBH

Oil Input GPH

Electric:

kW

No. of Control Steps

Volts-phase-hertz

RV Setting

Accessories:

hp

kW

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.11. Boilers, Steam

Designation

Location

Service

Output # Steam/h

Steam Pressure psig

Feedwater Temperature

Heating Surface sq.ft.

Steam Drum Diameter

Lower Drum Diameter

Gas Input MBH

Oil Input GPH

Electric:

kW

No. of Control Steps

Volts-phase-hertz

RV Setting

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.12. Cabinet Unit Heaters

Designation

Location

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, Up Discharge, Down Discharge, Hot Water, Steam, Electric, etc.)

Fan:

CFM

RPM

Motor hp

Volts-phase-hertz

Hot Water Coil:

Capacity MBH

EAT

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Steam/h

Steam Pressure psig

Electric Coil:

kW

No. of Control Steps

Volts-phase-hertz

Runouts:

Supply

Return

Manufacturers' Name and Model No.

Remarks

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54.13. Chemical Feed Systems

Designation

Location

Service

Pump:

Type (Positive Displacement)

GPH

psi

hp

Volts-phase-hertz

Tank Gallons

Agitator:

hp

RPM

Volts-phase-hertz

Remarks

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54.14. Chillers, Absorption

Designation

Location

Service

Type

Refrigerant Type

Capacity:

Tons Cooling

MBH Heating

Evaporator:

EWT

LWT

GPM

WPD

Condenser:

EWT

LWT

GPM

WPD

Absorber:

Steam Pressure psig

Steam/h

Gas Pressure in. W.G.

Gas Input MBH

Oil Input GPH

Heating Water GPM

EWT

LWT

WPD

Heating:

EWT

LWT

GPM

WPD

Electrical:

hp

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.15. Chillers, Air Cooled

Designation

Location

Service

Type

Refrigerant Type

Capacity Tons

Evaporator:

EWT

LWT

GPM

WPD

Condenser Temperature

Condenser:

EAT

Fans:

Number

hp

Compressor:

Compressor

kW

FLA

LRA

MCA

MOCP

Volts-phase-hertz

Starter Type (Wye-Delta, Solid State, Reduced Voltage, Auto Transformer, VFD, etc.)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.16. Chillers, Water Cooled

Designation

Location

Service

Type

Refrigerant Type

Capacity Tons

Evaporator:

EWT

LWT

GPM

WPD

Condenser:

EWT

LWT

GPM

WPD

Heating (Heat Recovery Type):

EWT

LWT

GPM

WPD

Compressor:

Number

kW

FLA

LRA

MCA

MOCP

Volts-phase-hertz

Starter Type (Wye-Delta, Solid State, Reduced Voltage, Auto Transformer, VFD, etc.)

Evaporator Temperature

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.17. Coils, Direct Expansion (DX)

Designation

Location

Equipment Served

Service (CC, Heat Recovery)

Refrigerant Type

MBH

CFM

EAT °F DB/°F WB

LAT °F DB/°F WB

Maximum Face Velocity FPM

APD

Remarks

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54.18. Coils, Electric

Designation

Location

Equipment Served

Service (PHC, HC, RHC)

MBH

CFM

EAT

LAT

Maximum Face Velocity FPM

APD

kW

Volts-phase-hertz

Number of Control Steps

Manufacturers' Name and Model No.

Remarks

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54.19. Coils, Steam

Designation

Location

Equipment Served

Service (HC, PHC, RHC)

MBH

CFM

EAT

LAT

Maximum Face Velocity FPM

APD

Steam/h

Steam Pressure psig

Runout Sizes:

Supply

Return

Remarks

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54.20. Coils, Water

Designation

Location

Equipment Served

Service (PHC, CC, HC, RHC)

MBH

CFM

Cooling:

EAT °F DB/°F WB

LAT °F DB/°F WB

Max. Face Velocity FPM

GPM

EWT

LWT

APD

WPD

Heating:

EAT

LAT

Max. Face Velocity FPM

GPM

EWT

LWT

APD

WPD

Runout Size:

Supply

Return

Remarks

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54.21. Condensate Pump and Receiver Sets

Designation

Location

Service

Type (Simplex, Duplex)

GPM

Head ft. H₂O

Motor hp

Volts-phase-hertz

Tank Capacity Gallons

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.22. Convectors

Designation

Location

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)

Capacity MBH

EAT

GPM

EWT

WPD

Steam/h

Steam Pressure psig

kW

No. of Control Steps

Volts-phase-hertz

Runout Size:

Supply

Return

Manufacturers' Name and Model No.

Remarks

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54.23. Cooling Towers

Designation

Location

Service

Type (Induced Draft, Forced Draft, etc.)

GPM

EWT

LWT

Ambient Air °F WB

Fans:

Number of Fans

CFM

No. of Motors

hp

ESP

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Nozzle PD

Height Difference (Static Lift)

Basin Heaters:

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.24. Deaerators

Designation

Location

Service

Type

Number of Stages

Outlet Capacity lbs./h

Storage Capacity:

Pounds

Minutes

Steam:

lbs./h

psig

Size (Length × Diameter)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

54.25. Design Conditions—Airside

Summer:

Outside: °F DB/°F WB

Inside: °F DB/%RH

Winter:

Outside: °F DB/°F WB

Inside: °F DB/%RH

Remarks

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54.26. Design Conditions—Waterside

Chilled Water System:

CHWS

CHWR

ΔT

Condenser Water System:

CWS

CWR

ΔT

Heating Water System:

HWS

HWR

ΔT

Steam System:

LPS

MPS

HPS

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54.27. Electric Baseboard Radiation

Designation

Type (see Specification for Type Designation)

Style (Wall Mounted, Floor Mounted, Flat Top, Sloped Top, Extruded Aluminum Grille, etc.)

Number of Elements

Electric:

kW

Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

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54.28. Electric Radiant Heaters

Designation

Type (see Specification for Type Designation)

Style

Number of Elements

Length of Unit

Electric:

kW

Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

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54.29. Evaporative Condensers

Designation

Location

Service

Type

Tons or MBH

Refrigerant Type

Saturated Condenser Temperature

Condenser EAT °F DB/°F WB

Minimum OA Temperature

Fans:

Number

ESP

hp

Volts-phase-hertz

Pump:

Number

hp

Head ft H₂O

Volts-phase-hertz

Basin Heaters:

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.30. Expansion Tanks

Designation

Location

Service (Hot Water, Chilled Water, Condenser Water, etc.)

Type (Closed, Open, Diaphragm)

Capacity Gallons

Size Diameter × Length

PRV Setting psig

RV Setting psig

Connection Size:

Fill

System

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.31. Fans (Supply, Return, Exhaust, Relief)

Designation

Location

Service (SA, RA, EA)

CFM

RPM

Drive (Belt, Direct)

Type (BI, AF, FC, Roof, Propeller, etc.)

Class (I, II, III, IV)

Wheel Diameter Inches

SP

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.32. Fan Coil Units

Designation

Nominal CFM

Type (2-Pipe, 4-Pipe, 2-Pipe with Electric Heat)

Style (Recessed, Semi-recessed, Exposed, Concealed, Cabinet, Vertical Hi-Rise, Ceiling, Floor, etc.)

Fan:

CFM

Motor hp

ESP

Volts-phase-hertz

Cooling:

Sensible MBH

Total MBH

GPM

EWT

LWT

EAT °F DB/°F WB

WPD

Runout Size:

Supply

Return

Drain Size

Heating:

MBH

GPM

WPD

EWT

LWT

EAT °F DB/°F WB

Runout Size:

Supply

Return

kW

No. of Control Steps

Volts-phase-hertz

Number of Control Steps

Manufacturers' Name and Model No.

Remarks

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54.33. Finned Tube Radiation

Designation

Type (see Specification for Type Designation)

Style (Wall Mounted, Floor Mounted, Flat Top, Sloped Top, Extruded Aluminum Grille, etc.)

Number of Elements

Element Size:

Fins

Tube

Water:

Capacity MBH

EWT

LWT

EAT

GPM

WPD

Steam:

Capacity MBH

EAT

Steam/h

Steam Pressure

Manufacturers' Name and Model No.

Remarks

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54.34. Flash Tanks

Designation

Location

Service

Type

Discharge Steam Pressure psig

Tanks Size (Diameter × Height)

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.35. Fluid Coolers/Closed Circuit Evaporative Coolers

Designation

Location

Service

Type

Fluid Type

GPM

EWT

LWT

Ambient Air °F WB

Fans:

CFM

Number of Motors

hp

ESP

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Pumps:

Number

hp

Head ft H₂O

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Basin Heaters:

kW

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.36. Fuel Oil Tanks

Designation

Location

Fuel Type

Tank Type (Double Wall, Steel, Fiberglass, Below Ground, Above Ground)

Capacity Gallons

Size:

Length

Diameter

Approximate Weight

Connection Sizes:

Supply

Return

Fill

Vent

Gauge

Heating Supply and Return

Sounding Drop (Tank, Storage)

Pad Size (L × W × Th)

Manhole Size

Manufacturers' Name and Model No.

Remarks

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54.37. Gas Pressure Regulators

Designation

Location

Capacity cu.ft./h

Inlet:

psig

Pipe Size

Outlet:

psig

Pipe Size

Manufacturers' Name and Model No.

Remarks

54.38. Gravity Ventilators

Designation

Location

Service

Type (Dome, Louvered, Filters, No Filters)

Throat Size (L × W)

Physical Size (L × W × H)

Manufacturers' Name and Model No.

Remarks

54.39. Heat Exchangers, Plate and Frame, Steam to Water

Designation

Location

Service

Capacity MBH

Cold Side:

GPM

EWT

LWT

WPD

Hot Side:

Steam/h

Steam Pressure psig

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.40. Heat Exchangers, Plate and Frame, Water to Water

Designation

Location

Service

Capacity MBH

Cold Side:

GPM

EWT

LWT

WPD

Hot Side:

GPM

EWT

LWT

WPD

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.41. Heat Exchangers, Shell and Tube, Steam to Water (Converter)

Designation

Location

Service

Capacity MBH

Shell:

Steam/h

Steam Pressure psig

Tubes:

GPM

EWT

LWT

WPD

Minimum Surface Area sq. ft.

Number of Passes

Approximate Length ft.

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.42. Heat Exchangers, Shell and Tube, Water to Water

Designation

Location

Service

Capacity MBH

Shell:

GPM

EWT

LWT

WPD

Tubes:

GPM

EWT

LWT

WPD

Minimum Surface Area sq. ft.

Number of Passes

Approximate Length ft.

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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Holdings

54.43. Heat Pumps, Air Source

Designation

Location

Service

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)

Fan:

Total CFM

OA CFM

ESP

Cooling:

Sensible MBH

Total MBH

EAT °F DB/°F WB

LAT °F DB/°F WB

Sink Air Temperature

Heating Capacity:

Compressor MBH

Total MBH

Source Air Temperature

Electrical:

Evaporator Fan hp

Condenser Fan hp

Compressor kW

Heater kW

No. of Control Steps

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

Designation

Location

Service

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)

Fan:

Total CFM

OA CFM

ESP

Cooling:

Sensible MBH

Total MBH

EAT °F DB/°F WB

LAT °F DB/°F WB

EWT

Heating Capacity:

Compressor MBH

Total MBH

EWT

Source Water:

GPM

WPD

Runout Size:

Supply

Return

Electrical:

Fan hp

Compressor kW

Heater kW

No. of Control Steps

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.45. Humidifiers

Designation

Location

Service

Capacity:

Steam/h

Steam Pressure psig

Electric:

kW

Volts-phase-hertz

Duct/Air Handling Unit Size

Number of Manifolds

Runout Size:

Supply

Return

Drain

Manufacturers' Name and Model No.

Remarks

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54.46. Motor Control Centers

Item Number

hp/kW

FLA

Starter Size

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Circuit Breaker Size

Auxiliary Equipment (Specifications)

Nameplate Designation

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

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54.47. Packaged Terminal AC Systems

Designation

Location

Service

Minimum OA CFM

Fan:

CFM

ESP

Number of Wheels

Motor hp

Filters:

Type

Efficiency %

DX Cooling:

Sensible MBH

Total MBH

EAT °F DB/°F WB

LAT °F DB/°F WB

Compressors:

Number

kW

Condenser:

EAT

Motor hp

Electric Heat:

kW

No. of Control Steps

EAT

LAT

Hot Water:

MBH

EAT

LAT

EWT

LWT

GPM

WPD

Steam Heat:

MBH

EAT

LAT

Steam/h

Steam Pressure psig

Electric:

MCA

MOCP

Volts-phase-hertz

Operating Weight lbs.

Remarks

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54.48. Pumps

Designation

Location

Service (Chilled, Heating, Condenser Water, etc.)

Type (End Suction, Horizontal Split Case, In-Line, etc.)

GPM

Head ft.

NPSH

RPM

Motor hp

Volts-phase-hertz

Starter Type (Combination Starter/Disc. Switch, VFD, etc.)

Operating Weight lbs.

Manufacturers: Name and Model No.

Remarks

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54.49. Radiant Heaters

Designation

Output Capacity MBH

Gas Input MBH

Burner:

FLA

LRA

Volts-phase-hertz

Vacuum Pump:

FLA

LRA

Motor hp

Volts-phase-hertz

Length of Reflector

Manufacturers' Name and Model No.

Remarks

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54.50. Radiant Ceiling Panels

Designation

Type

Width

Average Water Temperature

Capacity Btu/h

WPD

Manufacturers' Name and Model No.

Remarks

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54.51. Steam Pressure Reducing Valves

Designation

Location

Capacity # Steam/h

Inlet:

Pressure psig

Pipe Size

Outlet:

Pressure psig

Pipe Size

Manufacturers' Name and Model No.

Remarks

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54.52. Steam Pressure Relief Valve

Designation

Location

Capacity # Steam/h

Relief Valve Setting psig

Discharge Pipe Size

Manufacturers' Name and Model No.

Remarks

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54.53. Sound Attenuators (Duct Silencers, Sound Traps)

Designation

Location

Service

Type

CFM

Noise Reduction:

63 Hz

125 Hz

250 Hz

500 Hz

1,000 Hz

2,000 Hz

4,000 Hz

8,000 Hz

Face Velocity FPM

Maximum APD

Length ft.

Manufacturers' Name and Model No.

Remarks

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54.54. Terminal Units, Constant Volume Reheat

Designation

CFM Range

Inlet Duct Size

Hot Water Coil:

Capacity MBH

EAT

Number of Rows

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Number of Rows

#Steam/h

Steam Pressure psig

Runout Size:

Supply

Return

Electric Coil:

kW

Volts-phase-hertz

No. of Control Steps

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

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54.55. Terminal Units, Dual Duct Mixing Box

Designation

CFM Range

Minimum/Maximum CFM:

Cold Deck

Hot Deck

Inlet Duct Size:

Cold

Hot

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

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54.56. Terminal Units, Fan Powered

Designation

CFM Range

Minimum CFM Setting

Inlet Duct Size

Fan:

Type (Series, Parallel)

CFM

ESP

Motor hp

Volts-phase-hertz

Hot Water Coil:

Capacity MBH

EAT

Number of Rows

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Number of Rows

Steam/h

Steam Pressure psig

Runout Size:

Supply

Return

Electric Coil:

kW

Volts-phase-hertz

Number of Control Steps

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

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Holdings

54.57. Terminal Units, Variable Air Volume (VAV)

Designation

CFM Range

Minimum CFM Setting

Inlet Duct Size

Hot Water Coil:

Capacity MBH

EAT

Number of Rows

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Number of Rows

Steam/h

Steam Pressure psig

Runout Size:

Supply

Return

Electric Coil:

kW

Volts-phase-hertz

Number of Control Steps

Type of Control (DDC, Electric, Pneumatic)

Control Power Volts-phase-hertz

Manufacturers' Name and Model No.

Remarks

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Holdings

54.58. Unit Heaters

Designation

Location

Type (Horizontal Discharge, Vertical Discharge, Hot Water, Steam, Electric, Gas
Fired, Oil Fired, etc.)

Fan:

CFM

RPM

Motor hp

Volts-phase-hertz

Hot Water Coil:

Capacity MBH

EAT

GPM

EWT

WPD

Steam Coil:

Capacity MBH

EAT

Steam/h

Steam Pressure psig

Gas Heater:

Output Capacity MBH

Input MBH

EAT

Oil Heater:

Output Capacity MBH

Input GPH

EAT

Electric Coil:

kW

Volts-phase-hertz

No. of Control Steps

Runouts:

Supply

Return

Manufacturers' Name and Model No.

Remarks

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54.59. Water Softeners

Designation

Location

Service

Number of Tanks

Capacity:

Minimum Grains

Maximum Grains

GPM

Tank Size (Diameter × Height)

Brine Tank (Diameter × Height)

Electrical Volts-phase-hertz

Operating Weight lbs.

Manufacturers' Name and Model No.

Remarks

Citation

EXPORT

Arthur A. Bell, Jr., PE; W. Larsen Angel, PE: HVAC Equations, Data, and Rules of Thumb, Third Edition. Part 54: Equipment Schedules, Chapter (McGraw-Hill Professional, 2016), AccessEngineering



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Part 55: Equipment Manufacturers

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55. Part 55: Equipment Manufacturers

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55.01. General

- A. **The manufacturers listed in the following are organized using the new six-digit AIA Masterspec specifications sections.**
- B. **The manufacturers listed in the following are not all inclusive of the manufacturers that may produce the particular product.**

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55.02. Section 230500—Common Work Results for HVAC

- A. **Plastic-to-Metal Transition Fittings**
 - 1. Charlotte Pipe and Foundry Company.
 - 2. Eslon Thermoplastic.
 - 3. IPEX Inc.
 - 4. Kbi.
- B. **Plastic-to-Metal Transition Adaptors**
 - 1. Thompson Plastics, Inc.
- C. **Plastic-to-Metal Transition Unions**
 - 1. Charlotte Pipe and Foundry Company.
 - 2. IPEX Inc.
 - 3. Kbi.

4. NIBCO, Inc.
5. NIBCO, Inc., Chemtrol Div.

D. Dielectric Unions

1. Capitol Manufacturing Co.
2. Central Plastics Company.
3. Eclipse, Inc.
4. Epco Sales, Inc.
5. Hart Industries International, Inc.
6. Watts Industries, Inc., Water Products Div.
7. Zurn Industries, Inc., Wilkins Div.

E. Dielectric Flanges

1. Capitol Manufacturing Co.
2. Central Plastics Company.
3. Epco Sales, Inc.
4. Watts Industries, Inc., Water Products Div.
5. Wilkins; Zurn Plumbing Products Group.

F. Dielectric-Flange Kits

1. Advance Products & Systems, Inc.
2. Calpico, Inc.
3. Central Plastics Company.
4. Pipeline Seal and Insulator, Inc.

G. Dielectric Couplings

1. Calpico, Inc.
2. Lochinvar Corp.

H. Dielectric Nipples

1. Perfection Corp.

2. Precision Plumbing Products, Inc.
3. Sioux Chief Manufacturing Co., Inc.
4. Victaulic Co. of America.

I. Mechanical Sleeve Seals

1. Advance Products & Systems, Inc.
2. Calpico, Inc.
3. Metraflex Co.
4. Pipeline Seal and Insulator, Inc.

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55.03. Section 230513—Common Motor Requirements for HVAC Equipment

- A. **Baldor.**
- B. **Century.**
- C. **Dayton.**
- D. **General Electric Company.**
- E. **Leeson Electric.**
- F. **Lincoln Electric.**
- G. **Louis Allis.**
- H. **Magnetek.**
- I. **Maraton Electric.**
- J. **Reliance Motors.**
- K. **Toshiba.**
- L. **US Motors.**

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55.04. Section 230516—Expansion Fittings and Loops for HVAC Piping

A. Metal-Bellows Expansion Joints

1. Badger Industries.
2. Expansion Joint Systems, Inc.
3. Flex-Hose Co., Inc.
4. Hyspan Precision Products, Inc.
5. Metraflex, Inc.
6. Proco Products, Inc.
7. Senior Flexonics, Inc., Pathway Division.
8. Unaflex Inc.

B. Expansion Compensators

1. Flexicraft Industries.
2. Flex-Weld, Inc.
3. Hyspan Precision Products, Inc.
4. Metraflex, Inc.
5. Senior Flexonics, Inc., Pathway Division.
6. Unaflex Inc.

C. Rubber Expansion Joints

1. Flex-Hose Co., Inc.
2. General Rubber Corp.
3. Mason Industries, Inc.; Mercer Rubber Co.
4. Metraflex, Inc.
5. Proco Products, Inc.
6. Senior Flexonics, Inc., Pathway Division.
7. Unaflex Inc.
8. Vibration Mountings & Controls, Inc.

D. Flexible-Hose Expansion Joints

1. Flex-Hose Co., Inc.
2. Flexicraft Industries.
3. Flex-Pression Ltd.
4. Mason Industries, Inc.; Mercer Rubber Co.
5. Metraflex, Inc.

E. Packed Slip Expansion Joints

1. Adsco Manufacturing, LLC.
2. Advanced Thermal Systems, Inc.
3. Senior Flexonics, Inc., Pathway Division.
4. Hyspan Precision Products, Inc.

F. Flexible Ball Joints

1. Advanced Thermal Systems, Inc.
2. Hyspan Precision Products, Inc.

G. Alignment Guides

1. Adsco Manufacturing, LLC.
2. Advanced Thermal Systems, Inc.
3. Flex-Hose Co., Inc.
4. Hyspan Precision Products, Inc.
5. Metraflex, Inc.
6. Piping Technology & Products, Inc.
7. Senior Flexonics, Inc., Pathway Division.

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55.05. Section 230519—Meters and Gages for HVAC Piping

A. Metal-Case, Liquid-In-Glass Thermometers

1. Palmer—Wahl Instruments Inc.

2. Trerice, H. O. Co.
3. Weiss Instruments, Inc.
4. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.

B. Plastic-Case, Liquid-In-Glass Thermometers

1. Marsh Bellofram.
2. Miljoco Corp.
3. Trerice, H. O. Co.
4. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
5. Winters Instruments.

C. Duct-Type, Liquid-In-Glass Thermometers

1. Miljoco Corp.
2. Palmer—Wahl Instruments Inc.
3. Trerice, H. O. Co.
4. Weiss Instruments, Inc.

D. Direct-Mounting, Vapor-Actuated Dial Thermometers

1. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
2. Marsh Bellofram.
3. Trerice, H. O. Co.
4. Weiss Instruments, Inc.
5. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.

E. Remote-Mounting, Vapor-Actuated Dial Thermometers

1. AMETEK, Inc.; U.S. Gauge Div.
2. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
3. Marsh Bellofram.
4. Miljoco Corp.

5. Palmer—Wahl Instruments Inc.
6. REO TEMP Instrument Corporation.
7. Tel-Tru Manufacturing Company.
8. Trerice, H. O. Co.; Weiss Instruments, Inc.
9. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
10. Winters Instruments.

F. Bimetallic-Actuated Dial Thermometers

1. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
2. Marsh Bellofram.
3. Miljoco Corp.
4. Palmer—Wahl Instruments Inc.
5. Tel-Tru Manufacturing Company.
6. Trerice, H. O. Co.
7. Weiss Instruments, Inc.
8. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
9. WIKA Instrument Corporation.
10. Winters Instruments.

G. Thermowells

1. AMETEK, Inc.; U.S. Gauge Div.
2. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
3. Marsh Bellofram.
4. Palmer—Wahl Instruments Inc.
5. Tel-Tru Manufacturing Company.
6. Trerice, H. O. Co.

7. Weiss Instruments, Inc.
8. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
9. WIKA Instrument Corporation.
10. Winters Instruments.

H. Pressure Gauges

1. AMETEK, Inc., U.S. Gauge Div.
2. Ashcroft Commercial Instrument Operations, Dresser Industries, Instrument Div.
3. Marsh Bellofram.
4. Miljoco Corp.
5. Palmer—Wahl Instruments Inc.
6. Trerice, H. O. Co.
7. Weiss Instruments, Inc.
8. Weksler Instruments Operating Unit, Dresser Industries, Instrument Div.
9. WIKA Instrument Corporation.
10. Winters Instruments.

I. Test Plugs

1. Flow Design, Inc.
2. MG Piping Products Co.
3. National Meter, Inc.
4. Peterson Equipment Co., Inc.
5. Sisco Manufacturing Co.
6. Trerice, H. O. Co.
7. Watts Industries, Inc., Water Products Div.

J. Wafer-Orifice Flow Meters

1. ABB, Inc.; ABB Instrumentation.

2. Armstrong Pumps, Inc.
3. Badger Meter, Inc., Industrial Div.
4. Bell & Gossett; ITT Industries.
5. Meriam Instruments Div., Scott Fetzer Co.

K. Venturi Flow Meters

1. Armstrong Pumps, Inc.
2. Badger Meter, Inc., Industrial Div.
3. Bailey-Fischer & Porter Co.
4. Flow Design, Inc.
5. Gerand Engineering Co.
6. Hyspan Precision Products, Inc.
7. Preso Meters Corporation.
8. Victaulic Co. of America.

L. Turbine Flow Meters

1. Badger Meter, Inc., Industrial Div.
2. Bailey-Fischer & Porter Co.
3. Data Industrial Corp.
4. Engineering Measurements Company.
5. Fischer, George Inc.
6. ISTECH Corporation.
7. ONICON Incorporated.
8. Thermo Measurement Ltd.
9. Venture Measurement.

M. Vortex-Shedding Flow Meters

1. Bailey-Fischer & Porter Co.

2. Engineering Measurements Company.
3. ISTECH Corporation.
4. MCO/Eastech, Inc.
5. Schlumberger Limited, Measurement Div.
6. Venture Measurement.

N. Pitot-Tube Flow Meters

1. Dieterich Standard, Inc.
2. Meriam Instruments Div., Scott Fetzer Co.
3. Preso Meters Corporation.
4. Taco, Inc.
5. Veris Industries.

O. Flow Indicators

1. Brooks Instrument Div., Emerson Electric Co.
2. Dwyer Instruments, Inc.
3. Ernst Gage Co.
4. Eugene Ernst Products Co.
5. OPW Engineered Systems; Dover Corp.
6. Penberthy, Inc.

P. Insertion-Turbine, Thermal-Energy Meter Systems

1. Data Industrial Corp.
2. ONICON Incorporated.
3. Thermo Measurement Ltd.

Q. Inline-Turbine, Thermal-Energy Meter Systems

1. Engineering Measurements Company.
2. Hoffer Flow Controls, Inc.
3. ISTECH Corporation.

4. Thermo Measurement Ltd.

5. Venture Measurement.

R. Ultrasonic, Thermal-Energy Meter Systems

1. Controlotron Corporation.

2. Engineering Measurements Company.

3. Mesa Laboratories, Inc., Nusonics Div.

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55.06. Section 230523—General-Duty Valves for HVAC Piping

A. Hydronic System Valve Schedule

1. Shutoff/isolation valves:

a. 2" and smaller:

1. Full port, bronze ball valves—copper piping systems.

2. Full port, iron ball valves—steel piping systems.

b. 2-1/2" and larger:

1. Standard performance, butterfly valves.

2. Medium performance, butterfly valves—mains and risers, hospitals, laboratories, and other critical facilities.

3. High performance, butterfly valves—critical equipment and piping mains, central plants, hospitals, laboratories, and other critical facilities.

2. Balancing valves:

a. 2" and smaller:

1. Reduced port, bronze ball valves—copper piping systems.

2. Reduced port, iron ball valves—steel piping systems.

3. Calibrated balancing valves: see "section 23211—hydronic piping."

b. 2-1/2" and larger:

1. Standard performance, butterfly valves.

2. Medium performance, butterfly valves—mains and risers, hospitals, laboratories, and other critical facilities.

3. High performance, butterfly valves—critical equipment and piping mains, central plants, hospitals, laboratories, and other critical facilities.
4. Calibrated balancing valves: see "section 23211—hydronic piping."

3. Control valves:

a. 2" and smaller:

1. Reduced port, bronze ball valves.
2. Reduced port, iron ball valves—steel piping systems.
3. Bronze globe valves—copper piping systems.
4. Iron globe valves—steel piping systems.

b. 2-1/2" and larger:

1. Standard performance, butterfly valves.
2. Medium performance butterfly valves—mains and risers, hospitals, laboratories, and other critical facilities.
3. High performance, butterfly valves—critical equipment and piping mains, central plants, hospitals, laboratories, and other critical facilities.
4. Globe valves.

4. Check valves:

a. Pumps:

1. 2" and smaller:

- a. Bronze swing check valves—copper piping systems.
- b. Iron swing check valves—steel piping systems.

2. 2-1/2" and larger: ductile iron center guided check valve, spring loaded, metal seat.

b. All other locations:

1. Bronze swing or lift check valves—copper piping systems.
2. Iron swing or lift check valves—steel piping systems.

B. Steam System Valve Schedule

1. Shutoff/isolation valves:

a. 2" and smaller:

1. Full port, bronze ball valves—copper piping systems.

2. Full port, iron ball valves—steel piping systems.

3. Bronze gate valves—copper piping systems.

4. Iron gate valves—steel piping systems.

b. 2-1/2" and larger:

1. Gate valves.

2. High performance, butterfly valves—rated for steam service

2. Control valves:

a. 2" and smaller:

1. Bronze globe valves—copper piping systems.

2. Iron globe valves—steel piping systems.

b. 2-1/2" and larger:

1. Iron globe valves—steel piping systems.

3. Check valves:

a. Pumps:

1. 2" and smaller:

a. Bronze swing check valves—copper piping systems.

b. Iron swing check valves—steel piping systems.

2. 2-1/2" and larger: ductile iron center guided check valve, spring loaded, metal seat.

b. All other locations:

1. Bronze swing or lift check valves—copper piping systems.

2. Iron swing or lift check valves—steel piping systems.

C. Bronze Angle Valves—Class 150, with Nonmetallic Disc

1. Crane Co., Crane Valve Group, Crane Valves.

2. Crane Co., Crane Valve Group, Jenkins Valves.

3. Crane Co., Crane Valve Group, Stockham Division.

4. Hammond Valve.

5. Milwaukee Valve Company.

6. NIBCO, Inc.
7. Powell Valves.

D. Bronze Ball Valves

1. Bronze ball valves—two-piece, full-port, or regular (reduced) port, with bronze trim:
 - a. Conbraco Industries, Inc.; Apollo Valves.
 - b. Crane Co., Crane Valve Group, Crane Valves.
 - c. Hammond Valve.
 - d. Milwaukee Valve Company.
 - e. Watts Regulator Co., a division of Watts Water Technologies, Inc.
2. Bronze ball valves—two-piece, full-port, or regular (reduced)-port, with stainless-steel trim:
 - a. Conbraco Industries, Inc.; Apollo Valves.
 - b. Crane Co., Crane Valve Group, Crane Valves.
 - c. Hammond Valve.
 - d. Milwaukee Valve Company.
 - e. Watts Regulator Co., a division of Watts Water Technologies, Inc.

E. Iron Ball Valves—Class 125

1. American Valve, Inc.
2. Conbraco Industries, Inc.; Apollo Valves.
3. Kitz Corporation.
4. Sure Flow Equipment, Inc.
5. Watts Regulator Co., a division of Watts Water Technologies, Inc.

F. Standard Performance, Butterfly Valves—150 CWP, Iron, Single-Flange (Lug Type), with EPDM Seat and Aluminum-Bronze or Stainless Steel Disc

1. Bray Controls; a division of Bray International.
2. Centerline.

3. Conbraco Industries, Inc.; Apollo Valves.
4. Cooper Cameron Valves, a division of Cooper Cameron Corp.
5. DeZurik Water Controls.
6. Keystone.
7. Norriseal, a Dover Corporation Company.
8. W-K-M.
9. Iron, Grooved-End Butterfly Valves—175 CWP:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products LP; Grinnell Mechanical Products.
 - c. Victaulic Company.

G. Medium Performance, Butterfly Valves—200 CWP, Iron, Single-Flange (Lug Type), with EPDM Seat and Aluminum-Bronze or Stainless Steel Disc

1. Centerline.
2. Cooper Cameron Valves; a division of Cooper Cameron Corp.
3. Demco.
4. DeZurik Water Controls.
5. Keystone.
6. Norriseal, a Dover Corporation Company.
7. Iron, Grooved-End Butterfly Valves—300 CWP:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products LP; Grinnell Mechanical Products.
 - c. Victaulic Company.

H. High Performance Butterfly Valves—Class 150 or 300, Iron, Single-Flange (Lug Type), with TFE or RTFE Seat and Stainless Steel Disc

1. Bray Controls, a division of Bray International.
2. Cooper Cameron Valves, a division of Cooper Cameron Corp.

3. DeZurik Water Controls.
4. Flowseal.
5. Jamesbury, a subsidiary of Metso Automation.
6. Norriseal, a Dover Corporation company.
7. Posiseal
8. W-K-M.
9. Iron, Grooved-End Butterfly Valves—300 CWP:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products LP; Grinnell Mechanical Products.
 - c. Victaulic Company.
- I. **Iron, Grooved-End Butterfly Valves—Class 175 or 300, Iron, Grooved, with EPDM Seat and Stainless Steel Disc**
 1. Anvil International, Inc.
 2. Tyco Fire Products LP; Grinnell Mechanical Products.
 3. Victaulic Company.
- J. **Bronze Lift Check Valves—Class 125 with Bronze Disc**
 1. Crane Co., Crane Valve Group, Crane Valves.
 2. Crane Co., Crane Valve Group, Jenkins Valves.
 3. Crane Co., Crane Valve Group, Stockham Division.
- K. **Bronze Swing Check Valves—Class 150 with Bronze Disc**
 1. American Valve, Inc.
 2. Crane Co., Crane Valve Group, Crane Valves.
 3. Crane Co., Crane Valve Group, Jenkins Valves.
 4. Crane Co., Crane Valve Group, Stockham Division.
 5. Milwaukee Valve Company.
- L. **Iron Swing Check Valves**
 1. Iron Swing Check Valves—Class 125 with Metal Seats:

- a. Crane Co., Crane Valve Group, Crane Valves.
 - b. Crane Co., Crane Valve Group, Jenkins Valves.
 - c. Crane Co., Crane Valve Group, Stockham Division.
 - d. Hammond Valve.
 - e. Milwaukee Valve Company.
 - f. Powell Valves.
 - g. Watts Regulator Co., a division of Watts Water Technologies, Inc.
2. Iron Swing Check Valves—Class 250 with Metal Seats:
- a. Crane Co., Crane Valve Group, Crane Valves.
 - b. Crane Co., Crane Valve Group, Jenkins Valves.
 - c. Crane Co., Crane Valve Group, Stockham Division.
 - d. Hammond Valve.
 - e. Milwaukee Valve Company.
 - f. Watts Regulator Co., a division of Watts Water Technologies, Inc.

M. Iron, Grooved-End Swing Check Valves—300 CWP, Grooved-End Swing Check Valves

1. Anvil International, Inc.
2. Tyco Fire Products LP; Grinnell Mechanical Products.
3. Victaulic Company.

N. Center-Guided Check Valves—Metal Seat

1. Ductile iron, Class 150, globe, spring loaded:
 - a. APCO Willamette Valve and Primer Corporation.
 - b. Crispin Valve.
 - c. Miller Manufacturing Company.
 - d. Val-Matic Valve & Manufacturing Corp.
2. Ductile iron, Class 300, compact-wafer, spring loaded:
 - a. APCO Willamette Valve and Primer Corporation.

- b. Crispin Valve.
 - c. Miller Manufacturing Company.
 - d. Val-Matic Valve & Manufacturing Corp.
3. Ductile iron, Class 300, globe, spring loaded:
- a. APCO Willamette Valve and Primer Corporation.
 - b. Crispin Valve.
 - c. Miller Manufacturing Company.
 - d. Val-Matic Valve & Manufacturing Corp.

O. Center-Guided Check Valves—EPDM Resilient Seat

1. Ductile Iron, Class 150, globe, spring loaded:
- a. APCO Willamette Valve and Primer Corporation.
 - b. Crispin Valve.
 - c. DFT Inc.
 - d. Val-Matic Valve & Manufacturing Corp.
2. Ductile Iron, Class 300, compact-wafer, spring loaded:
- a. APCO Willamette Valve and Primer Corporation.
 - b. Crispin Valve.
 - c. Val-Matic Valve & Manufacturing Corp.
3. Ductile Iron, Class 300, globe, spring loaded:
- a. APCO Willamette Valve and Primer Corporation.
 - b. Crispin Valve.
 - c. Val-Matic Valve & Manufacturing Corp.

P. Bronze Gate Valves

1. Bronze Gate Valves—Class 125, NRS and RS:
- a. Crane Co., Crane Valve Group, Crane Valves.
 - b. Crane Co., Crane Valve Group, Jenkins Valves.
 - c. Crane Co., Crane Valve Group, Stockham Division.

- d. Hammond Valve.
 - e. Milwaukee Valve Company.
 - f. Powell Valves.
 - g. Watts Regulator Co., a division of Watts Water Technologies, Inc.
2. Bronze Gate Valves—Class 150, NRS and RS:
- a. Crane Co., Crane Valve Group, Crane Valves.
 - b. Crane Co., Crane Valve Group, Stockham Division.
 - c. Hammond Valve.
 - d. Milwaukee Valve Company.
 - e. Powell Valves.
 - f. Watts Regulator Co., a division of Watts Water Technologies, Inc.

Q. Iron Gate Valves

1. Iron Gate Valves—Class 125, NRS:
- a. Crane Co., Crane Valve Group, Crane Valves.
 - b. Crane Co., Crane Valve Group, Jenkins Valves.
 - c. Crane Co., Crane Valve Group, Stockham Division.
 - d. Hammond Valve.
 - e. Milwaukee Valve Company.
 - f. Powell Valves.
 - g. Watts Regulator Co., a division of Watts Water Technologies, Inc.
2. Iron Gate Valves—Class 125, OS&Y:
- a. Crane Co., Crane Valve Group, Crane Valves.
 - b. Crane Co., Crane Valve Group, Jenkins Valves.
 - c. Crane Co., Crane Valve Group, Stockham Division.
 - d. Hammond Valve.
 - e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

3. Iron Gate Valves—Class 250, NRS:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Stockham Division.

4. Iron Gate Valves—Class 250, OS&Y:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Stockham Division.

c. Hammond Valve.

d. Milwaukee Valve Company.

e. Powell Valves.

f. Watts Regulator Co., a division of Watts Water Technologies, Inc.

R. Bronze Globe Valves—Class 150 with Nonmetallic Disc

1. Crane Co., Crane Valve Group, Crane Valves.

2. Crane Co., Crane Valve Group, Stockham Division.

3. Hammond Valve.

4. Milwaukee Valve Company.

5. Powell Valves.

6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

S. Iron Globe Valves

1. Iron Globe Valves—Class 125:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Jenkins Valves.

c. Crane Co., Crane Valve Group, Stockham Division.

d. Hammond Valve.

e. Milwaukee Valve Company.

f. Powell Valves.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

2. Iron Globe Valves—Class 250:

a. Crane Co., Crane Valve Group, Crane Valves.

b. Crane Co., Crane Valve Group, Jenkins Valves.

c. Crane Co., Crane Valve Group, Stockham Division.

d. Hammond Valve.

e. Milwaukee Valve Company.

f. NIBCO Inc.

g. Watts Regulator Co., a division of Watts Water Technologies, Inc.

T. Lubricated Plug Valves—Class 125 or 250, Cylindrical with Threaded or Flanged Ends

1. Homestead Valve, a division of Olson Technologies, Inc.

2. Milliken Valve Company.

3. R & M Energy Systems, a unit of Robbins & Myers, Inc.

U. Eccentric Plug Valves—175 CWP with Resilient Seating

1. DeZurik Water Controls.

2. Homestead Valve, a division of Olson Technologies, Inc.

3. M&H Valve Company, a division of McWane, Inc.

4. Milliken Valve Company.

V. Chainwheels

1. Babbitt Steam Specialty Co.

2. Roto Hammer Industries.

3. Trumbull Industries.

W. Backflow Preventers and Pressure Reducing Valves

1. Conbraco Industries, Inc.; Apollo Valves.

2. Watts Regulator Co., a division of Watts Water Technologies, Inc.

55.07. Section 230529—Hangers and Supports for HVAC Piping and Equipment

A. Steel Pipe Hangers and Supports

1. Basic Engineering.
2. Bergen-Power Pipe Supports.
3. B-Line Systems, Inc., a division of Cooper Industries.
4. Carpenter & Paterson, Inc.
5. Empire Industries, Inc.
6. ERICO/Michigan Hanger Co.
7. Grinnell Corp.
8. PHS Industries, Inc.
9. Unistrut.
10. Superstrut.

B. Fiberglass Pipe Hangers

1. B-Line Systems, Inc., a division of Cooper Industries.
2. Champion Fiberglass, Inc.
3. Cope, T. J., Inc.; Tyco International Ltd.
4. Seasafe, Inc.

C. Thermal-Hanger Shield Inserts

1. Bergen Pre-Insulated Pipe Supports, Inc.
2. Carpenter & Paterson, Inc.
3. ERICO/Michigan Hanger Co.
4. Insul-Shield.
5. PHS Industries, Inc.
6. Pipe Shields, Inc.

7. Rilco Manufacturing Company, Inc.

8. Value Engineered Products, Inc.

D. Fastener Systems—Powder-Actuated Fasteners

1. Hilti, Inc.

2. ITW Ramset/Red Head.

3. Masterset Fastening Systems, Inc.

4. MKT Fastening, LLC.

5. Powers Fasteners.

E. Fastener Systems—Mechanical-Expansion Anchors

1. B-Line Systems, Inc., a division of Cooper Industries.

2. Empire Industries, Inc.

3. Hilti, Inc.

4. ITW Ramset/Red Head.

5. MKT Fastening, LLC.

6. Powers Fasteners.

F. Pipe Stand Fabrication

1. ERICO/Michigan Hanger Co.

2. MIRO Industries.

3. Portable Pipe Hangers.

G. Equipment Curbs and Rails

1. Roof Product Systems Corp. (RPS).

2. The Pate Co.

3. Thycurb.

H. Pipe Portals

1. Roof Product Systems Corp. (RPS).

2. The Pate Co.

3. Thycurb.

I. Pipe Mounting Pedestals

1. Roof Product Systems Corp. (RPS).

2. The Pate Co.

3. Thycurb.

J. Duct Mounting Pedestals

1. Roof Product Systems Corp. (RPS).

2. The Pate Co.

3. Thycurb.

K. Non-Penetrating Support Systems

1. MIRO Industries, Inc.

2. Portable Pipe Hangers, Inc.

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55.08. Section 230533—Heat Tracing for HVAC Piping

A. Plastic-Insulated, Series-Resistance Heating Cables

1. Delta-Therm Corporation.

2. Easy Heat Inc.

3. Pyrotenax, a division of Tyco Thermal Controls.

4. Raychem, a division of Tyco Thermal Controls.

5. Watts Radiant Inc.

B. Self-Regulating, Parallel-Resistance Heating Cables

1. Chromalox, Inc., Wiegard Industrial Division, Emerson Electric Company.

2. Delta-Therm Corporation.

3. Easy Heat Inc.

4. Pyrotenax, a division of Tyco Thermal Controls.

5. Raychem, a division of Tyco Thermal Controls.

6. Thermon Manufacturing Co.

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55.09. Section 230548—Vibration and Seismic Controls for HVAC Piping and Equipment

A. Vibration Isolators

1. Amber/Booth Company, Inc.
2. Kinetics Noise Control.
3. Korfund Dynamics Corp.
4. Mason Industries.
5. Peabody Noise Control.
6. Vibration Eliminator Co., Inc.
7. Vibration Isolation.
8. Vibration Mountings & Controls, Inc.

B. Air-Mounting Systems

1. Kinetics Noise Control.
2. Mason Industries.
3. Vibration Eliminator Co., Inc.

C. Restrained Vibration Isolation Roof-Curb Rails

1. Amber/Booth Company, Inc.
2. Kinetics Noise Control.
3. Korfund Dynamics Corp.
4. Mason Industries.
5. Peabody Noise Control.
6. Vibration Eliminator Co., Inc.
7. Vibration Isolation.
8. Vibration Mountings & Controls, Inc.

D. Vibration Isolation Equipment Bases

1. Amber/Booth Company, Inc.
2. Kinetics Noise Control.
3. Korfund Dynamics Corp.
4. Mason Industries.
5. Peabody Noise Control.
6. Vibration Eliminator Co., Inc.
7. Vibration Isolation.
8. Vibration Mountings & Controls, Inc.

E. Seismic-Restraint Devices

1. Amber/Booth Company, Inc.
2. Cooper B-Line, Inc., a division of Cooper Industries.
3. Hilti, Inc.
4. Kinetics Noise Control.
5. Mason Industries.
6. Unistrut; Tyco International Ltd.

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55.10. Section 230553—Identification for HVAC Piping and Equipment

- A. **Bunting.**
- B. **Brady USA, Inc.**
- C. **Carlton Industries, Inc.**
- D. **Industrial Safety Supply Co., Inc.**
- E. **MSI.**
- F. **Seton Name Plate Corp.**
- G. **W.H. Brady Co.**

55.11. Section 230700—HVAC Insulation

A. Thermal Insulation

1. Calcium Silicate: Industrial Insulation Group.
2. Cellular glass:
 - a. Cell-U-Foam Corporation.
 - b. Pittsburgh Corning Corporation.
3. Flexible elastomeric (Armaflex):
 - a. Aeroflex USA Inc.
 - b. Armacell LLC (Armstrong).
 - c. RBX Corporation (Rubatex).
4. Mineral-fiber blanket insulation:
 - a. CertainTeed Corp.
 - b. Johns Manville.
 - c. Knauf Insulation.
 - d. Owens Corning.
5. High-temperature, mineral-fiber blanket insulation:
 - a. Johns Manville.
 - b. Owens Corning.
6. Mineral-fiber board insulation:
 - a. CertainTeed Corp.
 - b. Fibrex Insulations Inc.
 - c. Johns Manville.
 - d. Knauf Insulation.
 - e. Owens Corning.
7. High-temperature, mineral-fiber board insulation:
 - a. Fibrex Insulations, Inc.

- b. Johns Manville.
 - c. Owens Corning.
 - d. Rock Wool Manufacturing Company.
 - e. Thermafiber.
8. Mineral-fiber, preformed pipe insulation:
- a. Fibrex Insulations, Inc.
 - b. Johns Manville.
 - c. Knauf Insulation.
 - d. Owens Corning.
9. Mineral-fiber, pipe insulation wicking system:
- a. Knauf Insulation; Permawick Pipe Insulation.
 - b. Owens Corning; VaporWick Pipe Insulation.
10. Mineral-fiber, pipe and tank insulation:
- a. CertainTeed Corp.
 - b. Johns Manville.
 - c. Knauf Insulation.
 - d. Owens Corning.
11. Phenolic: Kingspan Corp.
12. Polyisocyanurate:
- a. Apache Products Company.
 - b. Dow Chemical Company.
 - c. Duna USA Inc.
 - d. Elliott Company.
13. Polyolefin:
- a. Armacell LLC.
 - b. Nomaco Inc.

c. RBX Corporation.

14. Polystyrene:

a. Dow Chemical Company.

b. Knauf Insulation.

15. Fire-rated insulation systems:

a. Fire-rated board: Johns Manville.

b. Fire-rated blanket:

1. CertainTeed Corp.

2. Johns Manville.

3. Nelson Firestop Products.

4. Thermal Ceramics.

5. 3M.

6. Vesuvius.

16. Insulating cements:

a. Insulco, Division of MFS, Inc.

b. P. K. Insulation Mfg. Co., Inc.

c. Rock Wool Manufacturing Company.

B. Adhesives

1. Childers Products, a division of ITW.

2. Foster Products Corporation, H. B. Fuller Company.

3. ITW TACC, a division of Illinois Tool Works.

4. Marathon Industries, Inc.

5. Mon-Eco Industries, Inc.

6. Vimasco Corporation.

C. Flexible Elastomeric and Polyolefin Adhesives

1. Aeroflex USA, Inc.

2. Armacell LCC.

3. Foster Products Corporation, H. B. Fuller Company.

4. RBX Corporation.

D. PVC Jacket Adhesives

1. Dow Chemical Company.

2. Johns-Manville.

3. P.I.C. Plastics, Inc.

4. Speedline Corporation.

E. Mastics

1. Childers Products, a division of ITW.

2. Foster Products Corporation, H. B. Fuller Company.

3. ITW TACC, Division of Illinois Tool Works.

4. Marathon Industries, Inc.

5. Mon-Eco Industries, Inc.

6. Vimasco Corporation.

F. Sealants

1. Childers Products, a division of ITW.

2. Foster Products Corporation, H. B. Fuller Company.

3. Marathon Industries, Inc.

4. Mon-Eco Industries, Inc.

5. Pittsburgh Corning Corporation.

6. Vimasco Corporation.

G. Factory-Applied Jackets: Dow Chemical Company

H. Field-Applied Fabric-Reinforcing Mesh

1. Vimasco Corporation.

2. Childers Products, a division of ITW.

3. Foster Products Corporation, H. B. Fuller Company.

4. Vimasco Corporation.

I. Field-Applied Cloths: Alpha Associates, Inc.

J. PVC Jacket

1. Johns Manville.
2. P.I.C. Plastics, Inc.
3. Proto PVC Corporation.
4. Speedline Corporation.

K. Metal Jacket

1. Childers Products, a division of ITW.
2. PABCO Metals Corporation.
3. RPR Products, Inc.

L. Underground Direct-Buried Jacket

1. Pittsburgh Corning Corporation.
2. Polyguard.

M. Tapes

1. Avery Dennison Corporation, Specialty Tapes Division.
2. Compac Corp.
3. Ideal Tape Co., Inc., an American Biltrite Company.
4. Venture Tape.
5. Dow Chemical Company.

N. Bands

1. Childers Products.
2. PABCO Metals Corporation.
3. RPR Products, Inc.

O. Insulation Pins, Hangers, and Weld Pins

1. AGM Industries, Inc.
2. GEMCO.

3. Midwest Fasteners, Inc.

4. Nelson Stud Welding.

P. Wire

1. C & F Wire.

2. Childers Products.

3. PABCO Metals Corporation.

4. RPR Products, Inc.

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55.12. Section 230900—Instrumentation and Control for HVAC

A. HVAC Control Systems—Commercial

1. Alerton Inc.

2. American Auto-Matrix.

3. Andover Controls Corporation.

4. Automated Logic Corporation.

5. Carrier Corporation, a member of the United Technologies Family.

6. Combustion Service & Equipment Co. (CS&E).

7. Delta Controls Inc.

8. Honeywell International Inc.; Home & Building Control.

9. Invensys Building Systems.

10. Johnson Controls, Inc.; Controls Group.

11. KMC Controls/Kreuter Manufacturing Company.

12. McQuay International.

13. Siemens Building Technologies, Inc.

14. TAC Americas, Inc.

15. Trane.

16. Voltec, Inc.

B. HVAC Control Systems—Hospital

1. American Auto-Matrix.
2. Automated Logic Corporation.
3. Johnson Controls, Inc.; Controls Group.
4. Siemens Building Technologies, Inc.

C. HVAC Control Systems—Laboratory

1. American Auto-matrix.
2. Auto Flow.
3. CMR Controls, a division of C.M. Richter Ltd.
4. Phoenix Controls Incorporated.
5. TSI Incorporated.
6. Siemens Building Technologies, Inc.

D. Time Clocks

1. ATC-Diversified Electronics.
2. Grasslin Controls Corporation.
3. Paragon Electric Co., Inc.
4. Precision Multiple Controls, Inc.
5. SSAC Inc.; ABB USA.
6. TCS/Basys Controls.
7. Time Mark Corporation.

E. Thermistor Temperature Sensors and Transmitters

1. BEC Controls Corporation.
2. Ebtron, Inc.
3. Heat-Timer Corporation.
4. I.T.M. Instruments Inc.

5. MAMAC Systems, Inc.

6. RDF Corporation.

F. RTDs and Transmitters

1. BEC Controls Corporation.

2. MAMAC Systems, Inc.

3. RDF Corporation.

G. Humidity Sensors

1. BEC Controls Corporation.

2. General Eastern Instruments.

3. MAMAC Systems, Inc.

4. ROTRONIC Instrument Corp.

5. TCS/Basys Controls.

6. Vaisala.

H. Pressure Transmitters/Transducers

1. BEC Controls Corporation.

2. General Eastern Instruments.

3. MAMAC Systems, Inc.

4. ROTRONIC Instrument Corp.

5. TCS/Basys Controls.

6. Vaisala.

I. Digital-to-Pneumatic Transducers

1. BEC Controls Corporation.

2. MAMAC Systems, Inc.

J. Water-Flow Switches

1. BEC Controls Corporation.

2. ITM Instruments, Inc.

K. Gas Detection Equipment

1. ACME Engineering Products, Inc.
2. Ebtron, Inc.
3. MSA Canada Inc.
4. Rel-Tek Corporation.
5. Sauter Controls Corporation.
6. TSI Incorporated.
7. Vaisala.
8. Vulcain, Inc.

L. Duct Airflow Station

1. Air Monitor Corporation.
2. Cambridge Air Sentinel.
3. Wetmaster Co., Ltd.

M. Water Flow Measuring Systems, Portable and Permanent

1. Barco.
2. Barton.
3. Bell and Gossett.
4. Dietrich Standard.
5. Fisher and Porter.
6. Girand.
7. Rockwell International, Inc.
8. Taco.

N. Thermostats

1. Erie Controls.
2. Danfoss, Inc., Air-Conditioning and Refrigeration Div.
3. Heat-Timer Corporation.

4. Sauter Controls Corporation.
5. Tekmar Control Systems, Inc.
6. Theben AG—Lumilite Control Technology, Inc.

O. Humidistats

1. MAMAC Systems, Inc.
2. ROTRONIC Instrument Corp.

P. Control Valves (see also "Section 230523—General-Duty Valves for HVAC Piping")

1. Danfoss, Inc., Air Conditioning & Refrigeration Div.
2. Erie Controls.
3. Hayward Industrial Products, Inc.
4. Magnatrol Valve Corporation.
5. Neles-Jamesbury.
6. Parker Hannifin Corporation, Skinner Valve Division.
7. Pneuline Controls.
8. Sauter Controls Corporation.

Q. Control Dampers

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. Arrow United Industries, a division of Mestek, Inc.
4. Duro Dyne, Inc.
5. Greenheck Fan Corporation.
6. McGill AirFlow LLC.
7. Nailor Industries, Inc.
8. Pottorff, a division of PCI Industries, Inc.
9. Ruskin Company.

10. SEMCO Incorporated.
11. United Air/Safe Air.
12. Vent Products Company, Inc.
13. Young Regulator Company.

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55.13. Section 231113—Facility Fuel-Oil Piping

A. Double-Containment Pipe and Fittings

1. Flexible, double-containment piping:
 - a. Environ Products, Inc.
 - b. OPW.
2. Rigid, double-containment piping:
 - a. Ameron International; Fiberglass Pipe Group.
 - b. Conley Corporation.
 - c. Perma-Pipe, Inc.
 - d. Smith Fibercast.

B. Piping specialties

1. Metallic Flexible Connectors:
 - a. American Flexible Hose Co., Inc.
 - b. Metraflex Company (The).
 - c. Proco Products, Inc.
 - d. Tru-Flex Metal Hose Corp.
 - e. Unaflex.
2. Nonmetallic flexible connectors:
 - a. American Flexible Hose Co., Inc.
 - b. Hose Master, Inc.; Metraflex Company (The); Tru-Flex Metal Hose Corp.
3. Strainers:
 - a. Boylston.

- b. Metraflex.
- c. McAlear.
- d. Mueller.
- e. Nicholson.
- f. Sarco.
- g. Spence.
- h. Tate Tempco.

C. Manual Fuel-Oil Shutoff Valves—Two-Piece, Full-Port, or Regular Port, Bronze Ball Valves with Bronze Trim

- 1. BrassCraft Manufacturing Company, a Masco company.
- 2. Conbraco Industries, Inc., Apollo Div.
- 3. McDonald, A. Y. Mfg. Co.
- 4. Perfection Corporation, a subsidiary of American Meter Company.

D. Specialty Valves

- 1. Pressure relief valves:
 - a. Anderson Greenwood, a division of Tyco Flow Control.
 - b. Fulflo Specialties, Inc.
 - c. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.
- 2. Oil safety valves:
 - a. Anderson Greenwood, a division of Tyco Flow Control.
 - b. Suntec Industries Incorporated.
 - c. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.
- 3. Emergency shutoff valves:
 - a. Ameron International; Fiberglass Pipe Group.
 - b. Conley Corporation.
 - c. EMCO Wheaton, a Gardner Denver Company.
 - d. Environ Products, Inc.

e. OPW.

4. Mechanical leak detector:

a. FE Petro, Inc.

b. Red Jacket Pumps, a division of Veeder-Root.

E. Fuel Oil Storage Tank—Above-Ground, Vertical, Horizontal, Steel

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Buffalo Tank Company, Inc.

4. Containment Solutions, Inc.

5. Highland Tank & Manufacturing Company, Inc.

6. Palmer Manufacturing & Tank, Inc.

7. Safe-T-Tank Corp.

8. Steel Tank & Fabricating Co., Inc.

9. Watco Tanks, Inc.

F. Fuel Oil Storage Tank—Above-Ground, Containment-Dike, Steel

1. Buffalo Tank Company, Inc.

2. Containment Solutions, Inc.

3. Highland Tank & Manufacturing Company, Inc.

4. Palmer Manufacturing & Tank, Inc.

5. Safe-T-Tank Corp.

6. Watco Tanks, Inc.

G. Fuel Oil Storage Tank—Above-Ground, Insulated, Steel

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Containment Solutions, Inc.

4. Highland Tank & Manufacturing Company, Inc.

5. Palmer Manufacturing & Tank, Inc.

6. Steel Tank & Fabricating Co., Inc.

H. Fuel Oil Storage Tank—Above-Ground, Concrete-Vaulted, Steel

1. Cardinal Tank Corp.

2. ConVault, Inc.

3. Earthsafe Systems, Inc.

4. EcoVault, Inc.

I. Fuel Oil Storage Tank—Under-Ground, Steel, STI-P3

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Containment Solutions, Inc.

4. Highland Tank & Manufacturing Company, Inc.

5. Palmer Manufacturing & Tank, Inc.

6. Steel Tank & Fabricating Co., Inc.

7. Watco Tanks, Inc.

J. Fuel Oil Storage Tank—Under-Ground, Composite, Steel

1. Ace Tank & Equipment Company.

2. Adamson Global Technology Corporation.

3. Containment Solutions, Inc.

4. Palmer Manufacturing & Tank, Inc.

5. Watco Tanks, Inc.

K. Fuel Oil Storage Tank—Under-Ground, Jacketed, Steel

1. Ace Tank & Equipment Company.

2. Highland Tank & Manufacturing Company, Inc.

3. Palmer Manufacturing & Tank, Inc.

L. Fuel Oil Storage Tank—Under-Ground, FRP

1. Containment Solutions, Inc.
2. Xerxes Corporation.

M. Fuel Oil Storage Tank Piping Specialties

1. EBW, Inc.
2. Environ Products, Inc.
3. Morrison Bros. Co.
4. OPW.
5. Preferred Utilities Manufacturing Corporation.
6. Universal Valve Company.

N. Submersible Fuel-Oil Pumps

1. FE Petro, Inc.
2. Red Jacket Pumps; a division of Veeder-Root.

O. Simplex Fuel-Oil Transfer Pumps

1. DESMI Inc./Rotan Pumps.
2. Haight Pumps, a division of Baker Mfg.
3. Preferred Utilities Manufacturing Corporation.
4. Suntec Industries Incorporated.
5. Tuthill Corporation; Tuthill Pump Div.
6. Viking Pump Inc., a unit of IDEX Corporation.
7. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.

P. Duplex or Triplex Fuel-Oil Transfer Pump Sets

1. Alyan Pump Company.
2. Hydronic Modules Corporation.
3. Preferred Utilities Manufacturing Corporation.
4. Smith-Koch, Inc.
5. Viking Pump, Inc., a unit of IDEX Corporation.

6. Webster Fuel Pumps & Valves, a division of Capital City Tool, Inc.

Q. Fuel Maintenance System

1. Fuel Technologies, International, LLC.
2. Veeder-Root, a Danaher Corporation Company.

R. Liquid-Level Gage System

1. Clawson Tank Company.
2. EBW, Inc.
3. Highland Tank & Manufacturing Company, Inc.
4. INCON, Inc.
5. Krueger Sentry Gauge.
6. Tuthill Corporation; Tuthill Transfer Systems; Sotera Systems.
7. Venture Measurement Company, LLC.

S. Leak-Detection and Monitoring System

1. Cable and sensor system:
 - a. Containment Solutions, Inc.
 - b. EBW, Inc.
 - c. Highland Tank & Manufacturing Company, Inc.
 - d. INCON, Inc.
 - e. MSA; Instrument Div.
 - f. Perma-Pipe, Inc.
 - g. Raychem Corp; Tyco Electronics Corporation.
 - h. Tuthill Corporation; Tuthill Transfer Systems; Sotera Systems.
 - i. Veeder-Root, a Danaher Corporation Company.
2. Hydrostatic system:
 - a. Containment Solutions, Inc.
 - b. EBW, Inc.

- c. Highland Tank & Manufacturing Company, Inc.
- d. INCON, Inc.
- e. MSA, Instrument Div.
- f. Perma-Pipe, Inc.
- g. Raychem Corp; Tyco Electronics Corporation.
- h. Tuthill Corporation; Tuthill Transfer Systems; Sotera Systems.
- i. Veeder-Root, a Danaher Corporation Company.

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55.14. Section 231123—Facility Natural-Gas Piping

A. Mechanical Couplings

- 1. Dresser Piping Specialties, a division of Dresser, Inc.
- 2. Smith-Blair, Inc.

B. Corrugated, Stainless-Steel Tubing

- 1. OmegaFlex, Inc.
- 2. Parker Hannifin Corporation, the Parflex Division.
- 3. Titeflex.
- 4. Tru-Flex Metal Hose Corp.

C. Plastic Mechanical Couplings

- 1. Lyall, R. W. & Company, Inc.
- 2. Mueller Co.; Gas Products Div.
- 3. Perfection Corporation; a subsidiary of American Meter Company.

D. Steel Mechanical Couplings

- 1. Dresser Piping Specialties; Division of Dresser, Inc.
- 2. Smith-Blair, Inc.

E. Bronze Ball Valves—Two-Piece, Full-Port, or Regular Port, with Bronze Trim

- 1. BrassCraft Manufacturing Company; a Masco company.

2. Conbraco Industries, Inc.; Apollo Div.
3. Lyall, R. W. & Company, Inc.
4. McDonald, A. Y. Mfg. Co.
5. Perfection Corporation, a subsidiary of American Meter Company.

F. Bronze Plug Valves

1. Lee Brass Company.
2. McDonald, A. Y. Mfg. Co.

G. Cast-Iron, Nonlubricated Plug Valves

1. McDonald, A. Y. Mfg. Co.
2. Mueller Co.; Gas Products Div.
3. Xomox Corporation, a Crane company.

H. Cast-Iron, Lubricated Plug Valves

1. Flowserve.
2. Homestead Valve, a division of Olson Technologies, Inc.
3. McDonald, A. Y. Mfg. Co.
4. Milliken Valve Company.
5. Mueller Co., Gas Products Div.
6. R&M Energy Systems, a unit of Robbins & Myers, Inc.

I. Polyethylene (PE) Ball Valves

1. Kerotest Manufacturing Corp.
2. Lyall, R. W. & Company, Inc.
3. Perfection Corporation, a subsidiary of American Meter Company.

J. Automatic Gas Valves

1. ASCO Power Technologies, LP; Division of Emerson.
2. Eaton Corporation; Controls Div.
3. Eclipse Combustion, Inc.

4. Honeywell International, Inc.

5. Johnson Controls.

K. Electrically Operated Valves

1. ASCO Power Technologies, LP, a division of Emerson.

2. Eclipse Combustion, Inc.

3. Magnatrol Valve Corporation.

4. Parker Hannifin Corporation; Climate & Industrial Controls Group; Skinner Valve Div.

5. Watts Regulator Co., a division of Watts Water Technologies, Inc.

L. Service Pressure Regulators

1. Actaris.

2. American Meter Company.

3. Fisher Control Valves and Regulators, a division of Emerson Process Management.

4. Invensys.

5. Richards Industries, the Jordan Valve Div.

M. Line Pressure Regulators

1. Actaris.

2. American Meter Company.

3. Eclipse Combustion, Inc.

4. Fisher Control Valves and Regulators, a division of Emerson Process Management.

5. Invensys.

6. Maxitrol Company.

7. Richards Industries, Jordan Valve Div.

N. Appliance Pressure Regulators

1. Canadian Meter Company, Inc.

2. Eaton Corporation, Controls Div.
3. Harper Wyman Co.
4. Maxitrol Company.
5. SCP, Inc.

O. Service Meters

1. Diaphragm-type service meters:
 - a. Actaris.
 - b. American Meter Company.
 - c. Invensys.
2. Rotary-type service meters:
 - a. American Meter Company.
 - b. Invensys.
3. Turbine meters:
 - a. American Meter Company.
 - b. Invensys.
4. Service-meter bars:
 - a. Actaris.
 - b. American Meter Company.
 - c. Lyall, R. W. & Company, Inc.
 - d. McDonald, A. Y. Mfg. Co.
 - e. Mueller Co., Gas Products Div.
 - f. Perfection Corporation, a subsidiary of American Meter Company
5. Service-meter bypass fittings:
 - a. Lyall, R. W. & Company, Inc.
 - b. Williamson, T. D., Inc.

A. Mechanical Couplings

1. Dresser Piping Specialties, a division of Dresser, Inc.
2. Smith-Blair, Inc.

B. Corrugated, Stainless-Steel Tubing

1. OmegaFlex, Inc.
2. Parker Hannifin Corporation, Parflex Division.
3. Titeflex.\Tru-Flex Metal Hose Corp.

C. Plastic Mechanical Couplings

1. Lyall, R. W. & Company, Inc.
2. Mueller Co., Gas Products Div.
3. Perfection Corporation, a subsidiary of American Meter Company.

D. Steel Mechanical Couplings

1. Dresser Piping Specialties; Division of Dresser, Inc.
2. Smith-Blair, Inc.

E. Bronze Ball Valves—Two-Piece, Full-Port, or Regular Port, with Bronze Trim

1. BrassCraft Manufacturing Company, a Masco company.
2. Conbraco Industries, Inc., Apollo Div.
3. Lyall, R. W. & Company, Inc.
4. McDonald, A. Y. Mfg. Co.
5. Perfection Corporation, a subsidiary of American Meter Company.

F. Bronze Plug Valves

1. Lee Brass Company.
2. McDonald, A. Y. Mfg. Co.

G. Cast-Iron, Nonlubricated Plug Valves

1. McDonald, A. Y. Mfg. Co.
2. Mueller Co., Gas Products Div.

3. Xomox Corporation, a Crane Company.

H. Cast-Iron, Lubricated Plug Valves

1. Flowserve.
2. Homestead Valve, a division of Olson Technologies, Inc.
3. McDonald, A. Y. Mfg. Co.
4. Milliken Valve Company.
5. Mueller Co., Gas Products Div.

I. Polyethylene Ball Valves

1. Kerotest Manufacturing Corp.
2. Lyall, R. W. & Company, Inc.
3. Perfection Corporation, a subsidiary of American Meter Company.

J. Hydrostatic Relief Valves

1. Engineered Controls International, Inc.; RegO Products.
2. Fisher Control Valves and Regulators, a division of Emerson Process Management.
3. Murray Equipment, Inc.
4. Sherwood, a division of Harsco Corporation.

K. Automatic Gas Valves

1. ASCO.
2. ASCO Power Technologies, LP, division of Emerson.
3. ASCO Valve Canada, division of Emerson Electric Canada Limited.
4. Eaton Corporation, Controls Div.
5. Eclipse Combustion, Inc.
6. Honeywell International Inc.
7. Johnson Controls.

L. Electrically Operated Valves

1. ASCO.

2. ASCO Power Technologies, LP, a division of Emerson.
3. Eclipse Combustion, Inc.
4. Magnatrol Valve Corporation.
5. Parker Hannifin Corporation; Climate & Industrial Controls Group; Skinner Valve Div.
6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

M. Service Pressure Regulators

1. Actaris.
2. American Meter Company.
3. Fisher Control Valves and Regulators, a division of Emerson Process Management.
4. Invensys.
5. Richards Industries, Jordan Valve Div.

N. Line Pressure Regulators

1. Actaris.
2. American Meter Company.
3. Eclipse Combustion, Inc.
4. Fisher Control Valves and Regulators, a division of Emerson Process Management.
5. Invensys.
6. Maxitrol Company.
7. Richards Industries, Jordan Valve Div.

O. Appliance Pressure Regulators

1. Canadian Meter Company, Inc.
2. Eaton Corporation, Controls Div.
3. Harper Wyman Co.
4. Maxitrol Company.

5. SCP, Inc.

P. Service Meters

1. Diaphragm-type service meters:

- a. Actaris.
- b. American Meter Company.
- c. Invensys.

2. Rotary-type service meters:

- a. American Meter Company.
- b. Invensys.

3. Turbine meters:

- a. American Meter Company.
- b. Invensys.

4. Service-meter bars:

- a. Actaris.
- b. American Meter Company.
- c. Lyall, R. W. & Company, Inc.
- d. McDonald, A. Y. Mfg. Co.
- e. Mueller Co.; Gas Products Div.
- f. Perfection Corporation, a subsidiary of American Meter Company.

5. Service-meter bypass fittings:

- a. Lyall, R. W. & Company, Inc.
- b. Williamson, T. D., Inc.

Q. Storage Containers

- 1. American Welding & Tank.
- 2. Hanson, Roy E. Jr. Mfg.
- 3. Trinity Industries, Inc.
- 4. United Industries Group, Inc.

R. **Pumps**

1. Blackmer, a Dover Resources company.
2. Corken, Inc., a unit of IDEX Corporation.

S. **Vaporizers**

1. Algas-SDI.
2. Alternate Energy Systems, Inc.
3. Ely Energy, Inc.
4. Ransome Manufacturing, a division of Meeder Equipment Company.

T. **Air Mixers**

1. Algas-SDI.
2. Alternate Energy Systems, Inc.
3. Ely Energy, Inc.
4. Ransome Manufacturing, a division of Meeder Equipment Company.

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55.16. Section 232113—Hydronic Piping

A. **Copper, Mechanically Formed Tee Option: T-DRILL Industries Inc.**

B. **Grooved Mechanical-Joint Fittings and Couplings**

1. Anvil International, Inc.
2. Tyco Fire Products LP; Grinnell Mechanical Products.
3. Victaulic Company of America.

C. **Steel Pressure-Seal Fittings: Victaulic Company of America.**

D. **Bronze, Calibrated-Orifice, Balancing Valves**

1. Armstrong Pumps, Inc.
2. Autoflow.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. DeZurik.

5. Flow Design Inc.
6. Griswold Controls.
7. Rockwell.
8. Sarco.
9. Taco.
10. Tour & Andersson; available through Victaulic Company of America.
11. Grooved balancing valves:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products LP; Grinnell Mechanical Products.
 - c. Victaulic Company of America.

E. Cast-Iron or Steel, Calibrated-Orifice, Balancing Valves

1. Armstrong Pumps, Inc.
2. Autoflow.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. DeZurik
5. Flow Design, Inc.
6. Griswold Controls.
7. Rockwell.
8. Sarco.
9. Taco.
10. Tour & Andersson; available through Victaulic Company of America.
11. Grooved balancing valves:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products, LP; Grinnell Mechanical Products.
 - c. Victaulic Company of America.

F. Diaphragm-Operated, Pressure-Reducing Valves

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. Conbraco Industries, Inc.
5. Spence Engineering Company, Inc.
6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

G. Diaphragm-Operated Safety Valves

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.
3. Bell & Gossett Domestic Pump, a division of ITT Industries.
4. Conbraco Industries, Inc.
5. Spence Engineering Company, Inc.
6. Watts Regulator Co., a division of Watts Water Technologies, Inc.

H. Relief Valves

1. Crosby.
2. Farris.
3. Kunkle.
4. Lonnergan.

I. Automatic Flow-Control Valves

1. Bell & Gossett Domestic Pump, a division of ITT Industries.
2. Flow Design, Inc.
3. Griswold Controls.

J. Manual and Automatic Air Vents

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.

3. Bell & Gossett Domestic Pump, a division of ITT Industries.

4. Taco.

K. Expansion Tanks

1. Amtrol, Inc.

2. Armstrong Pumps, Inc.

3. Bell & Gossett Domestic Pump, a division of ITT Industries.

4. Taco.

5. Thrush Company, Inc.

6. Wood Industries.

L. Air Separators

1. Amtrol, Inc.

2. Armstrong Pumps, Inc.

3. Bell & Gossett Domestic Pump, a division of ITT Industries.

4. Taco.

M. Chemical Shot Feeders

1. Burnham Chemical Feed Systems.

2. Cleaver Brooks.

3. Neptune Chemical Pump Co.

4. J.L. Wingert Company.

N. Strainers

1. Boylston.

2. McAlear.

3. Metraflex.

4. Mueller.

5. Nicholson.

6. Sarco.

7. Spence.
8. Tate Tempco.
9. Grooved strainers:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products, LP; Grinnell Mechanical Products.
 - c. Victaulic Company of America.

O. Inhibited Glycols

1. Dow Chemical Company.
2. Interstate Chemical Company.

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55.17. Section 232123—Hydronic Pumps

A. Close-Coupled, In-Line Centrifugal Pumps

1. Armstrong Pumps, Inc.
2. Aurora Pump; Division of Pentair Pump Group.
3. Bell & Gossett; Division of ITT Industries.
4. Grundfos Pumps Corporation.
5. PACO Pumps.
6. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
7. Peerless Pump; a Member of the Sterling Fluid Systems Group.
8. Taco, Inc.
9. Thrush Company, Inc.
10. Weinman, a division of Crane Pumps & Systems.

B. Close-Coupled, End-Suction Centrifugal Pumps

1. Armstrong Pumps, Inc.
2. Aurora Pump; Division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.

4. Goulds Pumps; Water Technologies Group.
5. PACO Pumps.
6. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
7. Peerless Pump, a member of the Sterling Fluid Systems Group.
8. Taco, Inc.
9. Thrush Company Inc.
10. Weinman, a division of Crane Pumps & Systems.

C. Separately Coupled, Horizontal, In-Line Centrifugal Pumps

1. Armstrong Pumps Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. Grundfos Pumps Corporation.
5. PACO Pumps.
6. Peerless Pump, a member of the Sterling Fluid Systems Group.
7. Taco, Inc.
8. Thrush Company, Inc.

D. Separately Coupled, Vertical, In-Line Centrifugal Pumps

1. Armstrong Pumps Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
6. Thrush Company Inc.
7. Weinman, a division of Crane Pumps & Systems.

E. Separately Coupled, Base-Mounted, End-Suction Centrifugal Pumps

1. Armstrong Pumps, Inc.

2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Peerless Pump, a member of the Sterling Fluid Systems Group.
6. Taco, Inc.
7. Thrush Company Inc.
8. Weinman, a division of Crane Pumps & Systems.

F. Separately Coupled, Base-Mounted, Double-Suction Centrifugal Pumps

1. Armstrong Pumps Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
6. Peerless Pump, a member of the Sterling Fluid Systems Group.
7. Taco, Inc.
8. Weinman, a division of Crane Pumps & Systems.

G. Separately Coupled, Vertical-Mounted, Double-Suction Centrifugal Pumps

1. Armstrong Pumps, Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Peerless Pump, a member of the Sterling Fluid Systems Group
6. Taco, Inc.

H. **Separately Coupled, Vertical-Mounted, Turbine Centrifugal Pumps**

1. Armstrong Pumps, Inc.
2. Aurora Pump, a division of Pentair Pump Group.
3. Bell & Gossett, a division of ITT Industries.
4. PACO Pumps.
5. Patterson Pump Co., a subsidiary of The Gorman-Rupp Co.
6. Weinman, a division of Crane Pumps & Systems.

I. **Automatic Air Conditioning Condensate Pump Units**

1. Aurora Pump, a division of Pentair Pump Group.
2. Little Giant Pump Co., a subsidiary of Tecumseh Products Co.
3. MEPCO (Marshall Engineered Products Co.).

J. **Suction Diffusers and Triple Duty Valves**

1. Armstrong Pumps, Inc.
2. Bell & Gossett Domestic Pump, a division of ITT Industries.
3. PACO Pumps.
4. Peerless Pump, a member of the Sterling Fluid Systems Group.
5. Taco, Inc.
6. Grooved suction diffusers and triple duty valves:
 - a. Anvil International, Inc.
 - b. Tyco Fire Products LP; Grinnell Mechanical Products.
 - c. Victaulic Company of America.

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55.18. Section 232213—Steam and Condensate Heating Piping

A. **Dielectric Unions**

1. Capitol Manufacturing Company.
2. Central Plastics Company.

3. Hart Industries International, Inc.

4. Watts Regulator Co., a division of Watts Water Technologies, Inc.

B. Dielectric Flanges

1. Capitol Manufacturing Company.

2. Central Plastics Company.

3. Watts Regulator Co., a division of Watts Water Technologies, Inc.

4. Wilkins; Zurn Plumbing Products Group.

C. Dielectric-Flange Kits

1. Advance Products & Systems, Inc.

2. Calpico, Inc.

3. Central Plastics Company.

4. Pipeline Seal and Insulator, Inc.

D. Stop-Check Valves

1. Crane Co.

2. Jenkins Valves, a Crane Company.

3. Lunkenheimer Valves.

4. A.Y. McDonald Mfg. Co.

E. Strainers

1. Boylston.

2. McAlear.

3. Metraflex.

4. Mueller.

5. Nicholson.

6. Sarco.

7. Spence.

8. Tate Tempco.

F. Steam Control Valves and Regulators

1. Leslie.
2. Spirax Sarco, Inc.

G. Bronze, Brass, and Cast-Iron Safety Valves

1. Armstrong International, Inc.
2. Crosby.
3. Farris.
4. Kunkle Valve, a Tyco International Ltd. Company.
5. Lonnergan.
6. Spirax Sarco, Inc.
7. Watts Water Technologies, Inc.

H. Pressure-Reducing Valves

1. Armstrong International, Inc.
2. Fisher.
3. Hoffman Specialty, a division of ITT Industries.
4. Leslie Controls, Inc.
5. Masoneilan.
6. Spence Engineering Company, Inc.
7. Spirax Sarco, Inc.

I. Steam Traps (Thermostatic, Thermodynamic, Float and Thermostatic, Inverted Bucket)

1. Armstrong International, Inc.
2. Dunham-Bush, Inc.
3. Hoffman Specialty, a division of ITT Industries.
4. Spirax Sarco, Inc.
5. Sterling.

J. Thermostatic Air Vents and Vacuum Breakers

1. Armstrong International, Inc.
2. Dunham-Bush, Inc.
3. Hoffman Specialty, a division of ITT Industries.
4. Spirax Sarco, Inc.
5. Sterling.

K. Steam Meters

1. EMCO Flow Systems; Division of Advanced Energy Company.
2. ISTECH Corp.
3. Preso Meters, a division of Racine Federated, Inc.
4. Spirax Sarco, Inc.

L. Steam Condensate Meters

1. Central Station Steam Co.
2. Lincoln Meter Company.

M. Steam Separators

1. Penn Separator Corporation.
2. Spence Engineering Company, Inc., a division of Circor International, Inc.
3. Spirax Sarco, Inc.

N. Flash Tanks, Blowdown Tanks (Separators), and Condensate Coolers

1. Cemline Corporation.
2. Colton Industries.
3. Penn Separator Corporation.
4. Shippensburg Pump Company (Shipco).
5. Wessels Company.

A. Electric-Driven Steam Condensate Pumps

1. Aurora Pump, a division of Pentair Pump Group.
2. Domestic Pump, a division of ITT Industries.
3. Shippensburg Pump Company (Shipco).
4. Skidmore Division, Vent-Rite Valve Corp.
5. Spence Engineering Company, Inc., a division of Circor International, Inc.
6. Spirax Sarco, Inc.
7. Sterling, Inc.
8. Weinman.

B. Pressure-Powered Steam Condensate Pumps

1. Armstrong Fluid Handling, a division of Armstrong International, Inc.
2. MEPCO (Marshall Engineered Products Co.).
3. Nicholson Steam Trap, a division of Spence Engineering Company, Inc.
4. Shippensburg Pump Company (Shipco).
5. Spence Engineering Company, Inc., a division of Circor International, Inc.
6. Spirax Sarco, Inc.

C. Condensate Storage Units

1. Adamson Global Technology Corporation.
2. Buffalo Tank Company, Inc.
3. Cemline Corporation.
4. Cleaver Brooks.
5. Crane-Cochrane.
6. Wessels Company.

55.20. Section 232300—Refrigerant Piping

A. Refrigerants

1. Atofina Chemicals, Inc.
2. DuPont Company, Fluorochemicals Div.
3. Honeywell, Inc.; Genetron Refrigerants.
4. INEOS Fluor Americas LLC.

B. Refrigeration System Specialties

1. Alco Controls.
2. Henry Valve.
3. Parker Hannifin.
4. Sporlan Valve.

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55.21. Section 232500—HVAC Water Treatment

A. Water Treatment Companies

1. Anderson Chemical Co, Inc.
2. Aqua-Chem, Inc., Cleaver-Brooks Div.
3. Barclay Chemical Co.; Water Management, Inc.
4. Chardon Labs.
5. GE Betz.
6. ONDEO Nalco Company.

B. HVAC Makeup Water Softener

1. Cleaver Brooks.
2. Cocran.
3. Columbia Water Conditioning Systems, Inc.
4. CSI, a division of Chandler Systems, Inc.
5. Culligan International.
6. Diamond Water Conditioning.
7. Elgin.

8. Environmental Dynamics Corporation.
9. Marlo Incorporated.
10. Parker Boiler Company.
11. Rainsoft Div., Aquion Partners L. P. Water King.

C. RO Equipment for HVAC Makeup Water

1. Cleaver Brooks.
2. Cocran.
3. Columbia Water Conditioning Systems, Inc.
4. CSI, a division of Chandler Systems, Inc.
5. Culligan International.
6. Diamond Water Conditioning.
7. Elgin
8. Environmental Dynamics Corporation.
9. Marlo Incorporated.
10. Parker Boiler Company.
11. RainSoft Div., Aquion Partners L. P. Water King.

D. Filtration Equipment

1. LAKOS, a division of Claude Laval Corporation.
2. Miami Filter LLC.
3. PEP Filters, Inc.
4. Puroflux Corporation.
5. United Industries, Inc.

E. Water Filters

1. Filterite.
2. Filter Specialists, Inc.

3. Filtration Systems, a division of Mechanical Mfg. Corporation.
4. Parker Hannifin Corp., Process Filtration Div.
5. Paul Filter Corporation.
6. PEP Filters, Inc.
7. RainSoft Div., Aquion Partners L. P.
8. USFilter.
9. 3M Filtration Products.

F. Centrifugal Separators

1. Culligan International.
2. Griswold Controls.
3. LAKOS, a division of Claude Laval Corporation.
4. PEP Filters, Inc.
5. USFilter.
6. 3M Filtration Products.

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55.22. Section 233113—Metal Ducts

A. Single-Wall Rectangular Ducts and Fittings: SMCNA HVAC Duct Construction Standards

B. Double-Wall Rectangular Ducts and Fittings

1. McGill AirFlow, LLC.
2. Sheet Metal Connectors, Inc.

C. Single-Wall Round and Flat-Oval Ducts and Fittings

1. McGill AirFlow, LLC.
2. SEMCO Incorporated.
3. Sheet Metal Connectors, Inc.
4. Spiral Manufacturing Co., Inc.

D. Double-Wall Round and Flat-Oval Ducts and Fittings

1. McGill AirFlow, LLC.
2. SEMCO Incorporated.
3. Sheet Metal Connectors, Inc.

E. Fibrous-Glass Duct Liner

1. CertainTeed Corporation; Insulation Group.
2. Johns Manville.
3. Knauf Insulation.
4. Owens Corning.

F. Flexible Elastomeric Duct Liner

1. Aeroflex USA, Inc.
2. Armacell, LLC.
3. Rubatex International, LLC.

G. PVC Coated Galvanized Steel Ducts

1. Metal Manufacturing, Inc.
2. United McGill.

H. Halar Coated Stainless Steel Ducts

1. Fabtech Incorporated.
2. GDS Manufacturing Co.
3. PSI.
4. Viron.

I. Teflon Coated Stainless Steel Ducts

1. Fabtech Incorporated.
2. GDS Manufacturing Co.
3. PSI.
4. Viron.

55.23. Section 233116—Nonmetal Ducts

A. Fibrous-Glass Ducts and Fittings

1. CertainTeed Corporation; Insulation Group.
2. Johns Manville.
3. Knauf Insulation.
4. Owens Corning.

B. Thermoset FRP Ducts and Fittings

1. ATS Products, Inc.
2. Beverly-Pacific.
3. Corrosion Products.
4. Environmental Corrections.
5. Fiber Dyne.
6. Harrington.
7. McGill AirFlow, LLC.
8. Perry Fiberglass Products, Inc.
9. Spunstrand, Inc.
10. Viron.

C. FRP Resins

1. Atlac Type 711-05 AS.
2. Dion Corres 9300FR.
3. Hetron FR992.
4. Derakane 510A.
5. Interplastics VE8440.

D. PVC Ducts and Fittings

1. General Plastics, Inc.
2. GPK Products, Inc.

3. Harvel Plastics, Inc.
4. Kroy Industries, Inc.
5. Northern Pipe Product, Inc., an Otter Tail Company.
6. Plastinetics, Inc.
7. Spears Manufacturing Company.

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55.24. Section 233119—HVAC Casings

A. Manufactured Casings

1. Acoustical Surfaces, Inc.
2. AeroSonics, Inc., a division of TUTCO, Inc.
3. Buffalo Air Handling.
4. CertainTeed Corp., Insulation Group.
5. CLEANPAK International.
6. Gale Corp.
7. Industrial Acoustics Company.
8. Industrial Noise Control, Inc.
9. McGill AirSilence, LLC.
10. SEMCO Incorporated.
11. United Sheet Metal Co.
12. Vibro-Acoustics.

B. Fibrous-Glass Casing Liner

1. CertainTeed Corp., Insulation Group.
2. Johns Manville.
3. Knauf Insulation.
4. Owens Corning.

C. Flexible-Elastomeric Casing Liner

1. Aeroflex USA, Inc.
2. Armacell, LLC.
3. Rubatex International, LLC.

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55.25. Section 233300—Air Duct Accessories

A. Backdraft, Pressure Relief, and Barometric Relief Dampers

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. Duro Dyne Inc.
4. Greenheck Fan Corporation.
5. Nailor Industries Inc.
6. Pottorff, a division of PCI Industries, Inc.
7. Ruskin Company.
8. SEMCO Incorporated.
9. Vent Products Company, Inc.

B. Manual Volume Dampers

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. McGill AirFlow LLC.
4. METALAIRE, Inc.
5. Nailor Industries Inc.
6. Pottorff, a division of PCI Industries, Inc.
7. Ruskin Company.
8. Vent Products Company, Inc.

C. Control Dampers

1. Air Balance Inc., a division of Mestek, Inc.
2. American Warming and Ventilating, a division of Mestek, Inc.
3. Arrow United Industries, a division of Mestek, Inc.
4. Duro Dyne Inc.
5. Greenheck Fan Corporation.
6. McGill AirFlow, LLC.
7. Nailor Industries, Inc.
8. Pottorff, a division of PCI Industries, Inc.
9. Ruskin Company.
10. SEMCO Incorporated.
11. United Air/Safe Air.
12. Vent Products Company, Inc.
13. Young Regulator Company.

D. Fire Dampers, Smoke Dampers, Fire/Smoke Dampers, and Ceiling Dampers

1. Air Balance, Inc., a division of Mestek, Inc.
2. Arrow United Industries, a division of Mestek, Inc.
3. Greenheck Fan Corporation.
4. McGill AirFlow, LLC.
5. Nailor Industries, Inc.
6. Pottorff, a division of PCI Industries, Inc.
7. Ruskin Company.
8. Vent Products Company, Inc.
9. Ward Industries, Inc., a division of Hart & Cooley, Inc.

E. Flange Connectors

1. Ductmate Industries, Inc.

2. Nexus PDQ; Division of Shilco Holdings, Inc.
3. Ward Industries, Inc., a division of Hart & Cooley, Inc.

F. Duct Silencers (Sound Attenuators)

1. Aero Sonics
2. Commercial Acoustics
3. Gale Corp.
4. Industrial Acoustics Company (IAC)
5. Industrial Noise Control, Inc.
6. Koppers.
7. McGill AirFlow LLC.
8. Ruskin Company.
9. SEMCO Incorporated.
10. Vibro-Acoustics.
11. Vibration Mountings, Inc.

G. Sound Attenuators (Active Noise Control): Digisonix

H. Turning Vanes

1. Ductmate Industries, Inc.
2. Duro Dyne, Inc.
3. METALAIRE, Inc.
4. SEMCO Incorporated.
5. Ward Industries, Inc., a division of Hart & Cooley, Inc.

I. Remote Damper Operators

1. Pottorff, a division of PCI Industries, Inc.
2. Ventfabrics, Inc.
3. Young Regulator Company.

J. Duct Mounted Access Doors

1. American Warming and Ventilating, a division of Mestek, Inc.
2. Ductmate Industries, Inc.
3. Greenheck Fan Corporation.
4. McGill AirFlow, LLC.
5. Nailor Industries Inc.
6. Pottorff; a division of PCI Industries, Inc.
7. Ventfabrics, Inc.
8. Ward Industries, Inc., a division of Hart & Cooley, Inc.

K. Duct Access Panel Assemblies

1. Ductmate Industries, Inc.
2. Flame Gard, Inc.
3. 3M.

L. Flexible Connectors

1. Ductmate Industries, Inc.
2. Duro Dyne, Inc.
3. Ventfabrics, Inc.
4. Ward Industries, Inc., a division of Hart & Cooley, Inc.

M. Flexible Ducts

1. Ductmate Industries, Inc.
2. Genflex.
3. McGill AirFlow, LLC.
4. Thermaflex.
5. Ward Industries, Inc., a division of Hart & Cooley, Inc.
6. Wiremold.

N. Duct Security Bars

1. Carnes.
2. KEES, Inc.
3. Lloyd Industries, Inc.
4. Metal Form Manufacturing, Inc.
5. Price Industries.

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55.26. Section 233413—Axial HVAC Fans

A. Tubeaxial and Vaneaxial Fans

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Barry Blower Div., Penn Ventilation Companies, Inc.
5. Bayley Fans, a division of Lau Industries, Inc.
6. Carnes Company HVAC.
7. Chicago Blower Corporation.
8. Cincinnati Fan.
9. Greenheck Fan Corporation.
10. Industrial Air, a division of Lau Industries, Inc.
11. Joy.
12. Loren Cook Company.
13. New York Blower Company.
14. Trane.
15. Woods Fan Company.

B. Mixed Flow Fans

1. Loren Cook Company.

2. Greenheck Fan Corporation.
3. Howden Fan Co.
4. New Philadelphia Fan Co.

C. Tubular Centrifugal Fans

1. Aerovent, a Twin City Fan Company.
2. Barry Blower Div., Penn Ventilation Companies, Inc.
3. Greenheck Fan Corporation.
4. New York Blower.
5. Peerless.

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55.27. Section 233416—Centrifugal HVAC Fans

A. Airfoil, Backward Inclined, and Forward Curved Centrifugal Fans

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. Barry Blower Div., Penn Ventilation Companies, Inc.
4. Bayley Fans, a division of Lau Industries, Inc.
5. Carrier Corporation.
6. Chicago Blower Corporation.
7. Cincinnati Fan.
8. Greenheck Fan Corporation.
9. Industrial Air, a division of Lau Industries, Inc.
10. Loren Cook Company.
11. New York Blower Company.
12. Trane.

B. Plenum or Plug Fans

1. Acme Engineering & Mfg. Corp.

2. Aerovent, a Twin City Fan Company.
3. Barry Blower Div., Penn Ventilation Companies, Inc.
4. Bayley Fans, a division of Lau Industries, Inc.
5. Carrier Corporation.
6. Chicago Blower Corporation.
7. Cincinnati Fan.
8. Greenheck Fan Corporation.
9. Industrial Air, a division of Lau Industries, Inc.
10. Loren Cook Company.
11. New York Blower Company.
12. Trane.

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55.28. Section 233423—HVAC Power Ventilators

A. Utility Set Fans

1. Aerovent, a Twin City Fan Company.
2. American Coolair Corp.
3. Bayley Fans, a division of Lau Industries, Inc.
4. Carnes Company HVAC.
5. Industrial Air, a division of Lau Industries, Inc.
6. Loren Cook Company.
7. New York Blower Company.
8. Trane.

B. Centrifugal Roof Ventilators and Upblast Centrifugal Roof Ventilators

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.

3. American Coolair Corp.
4. Carnes Company HVAC.
5. Greenheck Fan Corporation.
6. Loren Cook Company.

C. Axial Roof Ventilators

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Bayley Fans, a division of Lau Industries, Inc.
5. Carnes Company HVAC.
6. Greenheck Fan Corporation.
7. Industrial Air, a division of Lau Industries, Inc.
8. Loren Cook Company.
9. New York Blower Company.

D. Upblast Propeller Roof Exhaust Fans

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Carnes Company HVAC.
5. Cincinnati Fan.
6. Greenheck Fan Corporation.
7. Industrial Air, a division of Lau Industries, Inc.
8. Loren Cook Company.
9. New York Blower Company.

E. Centrifugal Wall Ventilators

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Carnes Company HVAC.
5. Greenheck Fan Corporation.
6. Loren Cook Company.

F. Ceiling-Mounting Ventilators

1. American Coolair Corp.
2. Broan Mfg. Co., Inc.
3. Carnes Company HVAC.
4. Greenheck Fan Corporation.
5. Loren Cook Company.
6. Penn Ventilation.

G. In-Line Centrifugal Fans

1. Acme Engineering & Mfg. Corp.
2. American Coolair Corp.
3. Bayley Fans, a division of Lau Industries, Inc.
4. Carnes Company HVAC.
5. Greenheck Fan Corporation.
6. Loren Cook Company.

H. Propeller Fans

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan Company.
3. American Coolair Corp.
4. Bayley Fans, a division of Lau Industries, Inc.

5. Carnes Company HVAC.
6. Chicago Blower Corporation.
7. Cincinnati Fan.
8. Greenheck Fan Corporation.
9. Industrial Air, a division of Lau Industries, Inc.
10. Loren Cook Company.
11. New York Blower Company.

I. Ceiling Type Fans

1. Greenheck Fan Corporation
2. Loren Cook.
3. Penn Ventilator Company.

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55.29. Section 233433—Air Curtains

- A. **Berner International Corp.**
- B. **Cambridge Engineering, Inc.**
- C. **KING.**
- D. **Loren Cook Company.**
- E. **Marley Engineered Products.**
- F. **Mars Air Products, Dynaforce Division.**
- G. **Mars Air Products, Mars Air Door Division.**

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55.30. Section 233600—Air Terminal Units

- A. **Single and Dual Duct Air Terminal Units—Commercial**
 1. Anemostat, a Mestek Company.
 2. Carnes.
 3. Carrier.

4. Environmental Technologies, Inc., Enviro-Air Div.
5. Krueger.
6. METALAIRE, Inc.; Metal Industries Inc.
7. Nailor Industries of Texas Inc.
8. Price Industries.
9. Titus.
10. Trane.

B. Single and Dual Duct Air Terminal Units—Hospitals, Laboratories

1. Anemostat, a Mestek Company.
2. Krueger.
3. Nailor Industries of Texas Inc.
4. Price Industries.
5. Titus.

C. Fan-Powered Air Terminal Units—Commercial

1. Anemostat, a Mestek Company.
2. Carnes.
3. Carrier.
4. Environmental Technologies, Inc., Enviro-Air Div.
5. Krueger.
6. METALAIRE, Inc., Metal Industries Inc.
7. Nailor Industries of Texas Inc.
8. Price Industries.
9. Titus.
10. Trane.

D. Fan-Powered Air Terminal Units—Hospitals, Laboratories

1. Anemostat, a Mestek Company.
2. Krueger.
3. Nailor Industries of Texas Inc.
4. Price Industries.
5. Titus.

E. Induction Air Terminal Units

1. Price Industries.
2. Tuttle & Bailey.

F. Laboratory Air Valves

1. American Auto-matrix.
2. Auto Flow.
3. CMR Controls, a division of C.M. Richter Ltd.
4. Phoenix Controls Incorporated.
5. Tek-Air.
6. TSI Incorporated.
7. Siemens Building Technologies, Inc.

G. Integral-Diffuser Air Terminal Units

1. Acutherm.
2. Kreuger.
3. Price.
4. Titus.
5. Thermal Products Corp.
6. Warren Technology.

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55.31. Section 233713—Diffusers, Registers, and Grilles

A. Diffusers, Registers, and Grilles—Commercial

1. Anemostat Products, a Mestek company.
2. Carnes.
3. Hart & Cooley Inc.
4. Krueger.
5. METALAIRE, Inc.
6. Nailor Industries Inc.
7. Price Industries.
8. Titus.
9. Tuttle & Bailey.

B. Diffusers, Registers, and Grilles—Hospital/Laboratory

1. Anemostat Products; a Mestek company.
2. Krueger.
3. Price Industries.
4. Titus.

C. Continuous Tubular Diffuser

1. DuctSox Corp.
2. Patron Products Inc.

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55.32. Section 233723—HVAC Gravity Ventilators

A. Louver Penthouses

1. Acme Engineering & Mfg. Corp.
2. Aerovent, a Twin City Fan company.
3. American Warming and Ventilating, a division of Mestek, Inc.
4. Arrow United Industries, a division of Mestek, Inc.
5. Carnes.
6. Greenheck Fan Corporation.

7. Loren Cook Company.

8. Penn Ventilation.

B. Roof Hoods

1. Acme Engineering & Mfg. Corp.

2. Aerovent, a Twin City Fan company.

3. Carnes.

4. Greenheck Fan Corporation.

5. Loren Cook Company.

C. Louvers

1. Air Balance, Inc.

2. Airline Products.

3. Airstream Products.

4. American Warming and Ventilating, Inc.

5. Arrow United Industries.

6. Construction Specialties, Inc.

7. Phillips Industries, Inc.

8. Ruskin.

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55.33. Section 233813—Commercial-Kitchen Hoods

A. Exhaust Hood Fabrication

1. Captive-Aire Systems.

2. Gaylord Industries, Inc.

3. Grease Master, a division of Custom Industries, Inc.

4. Greenheck Fan Corporation.

5. Halton Company.

6. Vent Master, a division of Garland Commercial Ranges Ltd.

B. Wet-Chemical Fire-Suppression System

1. Ansul Incorporated, a Tyco International Ltd. Company.
2. Badger Fire Protection.
3. Kidde Fire Systems.
4. Pyro Chem.

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55.34. Section 234100—Particulate Air Filtration

A. Air Filters, Electrostatic Air Cleaners, and Filter-Holding Systems

1. AAF International.
2. Bioclimatic, Inc.
3. CRS Industries, Inc., CosaTron Div.
4. Farr Co.
5. Flanders/CSC Corp.
6. Flanders Filters, Inc.
7. International Air Filtration Corporation.
8. Mine Safety Appliances.
9. NiCon Filter Corp., Continental Air Filter Div.
10. Purafil, Inc.
11. Puralator.

B. Filter Gauges

1. Airguard Industries, Inc.
2. Dwyer Instruments, Inc.

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55.35. Section 235100—Breechings, Chimneys, and Stacks

A. Listed Chimney Liners

1. Heat-Fab, Inc.

2. Industrial Chimney Company.
3. Metal-Fab, Inc.
4. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

B. Listed Type-B and BW Vents

1. Cleaver-Brooks, a division of Aqua-Chem, Inc.
2. Hart & Cooley, Inc.
3. Heat-Fab, Inc.
4. Industrial Chimney Company.
5. Metal-Fab, Inc.
6. Selkirk Inc.; Selkirk Metalbestos and Air Mate.
7. Van-Packer Company, Inc.

C. Listed Type-L Vents

1. Heat-Fab, Inc.
2. Industrial Chimney Company.
3. Metal-Fab, Inc.
4. Selkirk Inc.; Selkirk Metalbestos and Air Mate.
5. Van-Packer Company, Inc.

D. Listed Special Gas Vents

1. Heat-Fab, Inc.
2. Metal-Fab, Inc.
3. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

E. Listed Building-Heating-Appliance Chimneys

1. Cleaver-Brooks, a division of Aqua-Chem Inc.
2. Heat-Fab, Inc.
3. Industrial Chimney Company.
4. Metal-Fab, Inc.

5. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

6. Van-Packer Company, Inc.

F. Listed Grease Ducts

1. Heat-Fab, Inc.

2. Industrial Chimney Company.

3. Metal-Fab, Inc.

4. Selkirk Inc.; Selkirk Metalbestos and Air Mate.

5. Van-Packer Company, Inc.

G. Listed, Refractory-Lined Metal Breechings and Chimneys

1. Van-Packer Company, Inc.

2. Warren Environment, Inc.

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55.36. Section 235113—Draft Control Devices

A. Draft Inducer Fans

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

4. Wing Draft Inducers, a subsidiary of Smiths Industries.

B. Mechanical-Draft Vent Fans

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

4. Wing Draft Inducers, a subsidiary of Smiths Industries.

C. Vent Exhaust Fans

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

D. Barometric Dampers

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

4. Wing Draft Inducers, a subsidiary of Smiths Industries.

E. Vent Dampers

1. Effikal International Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Johnson Controls, Inc.; Controls Group.

F. Combustion-Air Fans

1. EXHAUSTO, Inc.

2. Field Controls LLC; Venting Solutions Company.

3. Tjernlund Products, Inc.

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55.37. Section 235213—Electric Boilers

A. Acme Engineering Prod. Inc.

B. Brasch.

C. Bryan Steam, LLC.

D. Cemline Corporation.

E. Cleaver-Brooks, a division of Aqua-Chem, Inc.

F. Fulton Boiler Works, Inc.

G. Indeeco.

H. Lattner Boiler Manufacturing.

I. Lochinvar Corporation.

J. Patterson-Kelley.

K. Precision Boilers.

L. PVI Industries, LLC.

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55.38. Section 235216—Condensing Boilers

A. Fulton Boiler Works, Inc.

B. Hydrotherm, Inc., a division of Mestek, Inc.

C. AERCO International.

D. Heat Transfer Products, Inc.

E. Laars Heating Systems, a division of Waterpik Technologies, Inc.

F. Lochinvar Corporation.

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55.39. Section 235223—Cast-Iron Boilers

A. Burnham Hydronics.

B. H.B. Smith

C. Hydrotherm, Inc.; a division of Mestek, Inc.

D. Lennox Industries Inc.

E. Peerless Boilers.

F. Slant/Fin Corp.

G. Smith Cast Iron Boilers.

H. Weil-McLain; a United Dominion Company.

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55.40. Section 235233—Water-Tube Boilers

A. Finned Water-Tube Boilers

1. Hydrotherm, Inc., a division of Mestek, Inc.

2. Laars Heating Systems, a division of Waterpik Technologies, Inc.

3. Lochinvar Corporation.
4. Patterson-Kelley.
5. Precision Boilers.
6. Raypak.
7. Smith, A. O. Water Products Company.
8. Triad.

B. Steel Flexible Water-Tube Boilers

1. Bryan Steam, LLC.
2. Cleaver-Brooks, a division of Aqua-Chem, Inc.
3. Parker Boiler Company.

C. Steel Water-Tube Boilers

1. Babcock & Wilcox.
2. Cleaver Brooks.
3. Keeler.

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55.41. Section 235239—Fire-Tube Boilers

A. Horizontal, Fire-Tube Boilers

1. Burnham Hydronics.
2. Cleaver-Brooks, a division of Aqua-Chem, Inc.
3. Johnston.
4. Lattner Boiler Manufacturing.
5. Superior Boiler Works, Inc.
6. York Shipley.

B. Vertical, Fire-Tube Boilers

1. Fulton Boiler Works, Inc.
2. Lattner Boiler Manufacturing.

3. Patterson-Kelley.
4. Precision Boilers.
5. PVI Industries, LLC.

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55.42. Section 235313—Boiler Feedwater Pumps

A. Feedwater Units

1. Bryan Boilers; Bryan Steam, LLC.
2. Cleaver-Brooks, a division of Aqua-Chem, Inc.
3. Domestic Pump; a unit of ITT Fluid Technology.
4. Lattner Boiler Manufacturing.
5. Parker Boiler Co.
6. Shippensburg Pump Co., Inc.
7. Skidmore.
8. Superior Boiler Works, Inc.
9. U.S. Deaerator Co.

B. Feedwater Unit with Vacuum Producer

1. Domestic Pump, a unit of ITT Fluid Technology.
2. Shippensburg Pump Co., Inc.
3. Skidmore.
4. U.S. Deaerator Co.

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55.43. Section 235316—Deaerators and Feedwater Heaters

A. Bryan Steam LLC.

B. Cleaver-Brooks; Div. of Aqua-Chem Inc.

C. Deaerating Designs; a division of Precision Boilers, Inc.

D. Industrial Steam; Custom Steam and Pressure Vessel Systems.

E. **Permutit.**

F. **Skidmore.**

G. **U.S. Deaerator Co.**

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55.44. Section 235400—Furnaces

A. Gas-Fired Furnaces, Noncondensing

1. Bryant Heating & Cooling Systems, a division of United Technologies Corp.
2. Carrier Corporation, a division of United Technologies Corp.
3. Goodman Manufacturing Company, LP
4. Lennox Industries Inc.
5. Rheem Manufacturing Company; Air Conditioning Division.
6. Ruud Air Conditioning Division.
7. Trane.
8. York International Corp., a division of Unitary Products Group.

B. Gas-Fired Furnaces, Condensing

1. Bryant Heating & Cooling Systems, a division of United Technologies Corp.
2. Carrier Corporation, a division of United Technologies Corp.
3. Goodman Manufacturing Company, LP
4. Lennox Industries Inc.
5. Rheem Manufacturing Company; Air Conditioning Division.
6. Ruud Air Conditioning Division.
7. Trane.
8. York International Corp., a division of Unitary Products Group.

C. Oil-Fired Furnaces

1. Carrier Corporation, a division of United Technologies Corp.

2. Lennox Industries Inc.
3. Rheem Manufacturing Company; Air Conditioning Division.
4. Ruud Air Conditioning Division.
5. York International Corp., a division of Unitary Products Group.

D. Electric Furnaces

1. Bryant Heating & Cooling Systems, a division of United Technologies Corp.
2. Carrier Corporation, a division of United Technologies Corp.
3. Lennox Industries Inc.
4. Rheem Manufacturing Company; Air Conditioning Division.
5. Ruud Air Conditioning Division.
6. York International Corp., a division of Unitary Products Group.

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55.45. Section 235513—Fuel-Fired Duct Heaters

- A. Lennox Industries, Inc.**
- B. Modine Manufacturing Company.**
- C. Reznor/Thomas & Betts Corporation.**
- D. Sterling HVAC Products, a division of Mestek Technology, Inc.**

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55.46. Section 235523—Gas-Fired Radiant Heaters

A. Tubular Infrared Heaters

1. Combustion Research Corporation.
2. Reznor/Thomas & Betts Corporation.
3. Roberts-Gordon, Inc.
4. Sterling HVAC Products, a division of Mestek Technology, Inc.

B. High-Intensity Infrared Heaters

1. Combustion Research Corporation.

2. Reznor/Thomas & Betts Corporation.
3. Roberts-Gordon, Inc.
4. Sterling HVAC Products, a division of Mestek Technology, Inc.

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55.47. Section 235533—Fuel-Fired Unit Heaters

A. Gas-Fired Unit Heaters

1. Lennox Industries, Inc.
2. Modine Manufacturing Company.
3. Reznor/Thomas & Betts Corporation.
4. Sterling HVAC Products, a division of Mestek Technology, Inc.

B. Oil-Fired Unit Heaters

1. Modine Manufacturing Company.
2. Reznor/Thomas & Betts Corporation.
3. Sterling HVAC Products, a division of Mestek Technology, Inc.

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55.48. Section 235700—Heat Exchangers for HVAC

A. Shell-and-Tube Heat Exchangers

1. Amtrol, Inc.
2. Armstrong Pumps, Inc.
3. ITT Industries; Bell & Gossett.
4. Patterson-Kelley.
5. Taco, Inc.
6. Thrush Company, Inc.

B. Plate and Frame Heat Exchangers

1. Alfa Laval Thermal, Inc.
2. Armstrong Pumps, Inc.

3. Baltimore Air Coil.
4. ITT Industries; Bell & Gossett.
5. Paul Mueller Company.
6. Tranter PHE, Inc.

C. Brazed Plate and Frame Heat Exchangers

1. Alfa Laval Thermal, Inc.
2. Armstrong Pumps, Inc.
3. Baltimore Air Coil
4. ITT Industries; Bell & Gossett.
5. Paul Mueller Company.
6. Tranter PHE, Inc.

D. Ice Storage Systems

1. Baltimore Air Coil.
2. Calmac.
3. Turbo.
4. Marley Cooling Technologies; an SPX Corporation.

E. Steam Generators—Unfired, Steam to Steam, High Temperature Hot Water to Steam

1. API Ketema.
2. Cemline Corporation.
3. Power and Process Control Corporation.
4. Thermaflow Engineering Company.

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55.49. Section 236200—Packaged Compressor and Condenser Units

A. Condensing Units, Air Cooled

1. Carrier Corporation; Carrier Air Conditioning Div.

2. Lennox Industries, Inc.
3. McQuay International.
4. Rheem Manufacturing; Air Conditioning Div.
5. Trane.
6. York International Corp.

B. Condensing Units, Water Cooled

1. Carrier Corporation; Carrier Air Conditioning Div.
2. McQuay International.
3. Trane.
4. York International Corp.

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55.50. Section 236313—Air-Cooled Refrigerant Condensers

- A. **Bohn Refrigeration Products; Heatcraft, Inc.**
- B. **Carrier Corporation; Carrier Air Conditioning Div.**
- C. **Dunham-Bush, Inc.**
- D. **McQuay International.**
- E. **Trane.**
- F. **York International Corp.**

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55.51. Section 236333—Evaporative Refrigerant Condensers

- A. **Baltimore Aircoil Company.**
- B. **Recold.**

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55.52. Section 236413.13—Direct-Fired Absorption Water Chillers

- A. **Broad Corporation.**

B. Carrier; a United Technologies Company.

C. Hitachi International.

D. Trane.

E. YORK International Corporation.

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55.53. Section 236413.16—Indirect-Fired Absorption Water Chillers

A. Carrier Corporation; a United Technologies company.

B. Trane.

C. YORK, a Johnson Controls company.

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55.54. Section 236416—Centrifugal Water Chillers

A. Carrier Corporation; Carrier Air Conditioning Div.

B. McQuay International.

C. Trane.

D. York International Corp.

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55.55. Section 236419—Reciprocating Water Chillers

A. Packaged Water-Cooled Water Chillers

1. Bohn.

2. Dunham-Bush.

3. Carrier Corporation; Carrier Air Conditioning Div.

4. McQuay International.

5. Trane.

6. York International Corp.

B. Packaged Air-Cooled Water Chillers

1. Bohn.
2. Dunham-Bush.
3. Carrier Corporation; Carrier Air Conditioning Div.
4. McQuay International.
5. Trane.
6. York International Corp.

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55.56. Section 236423—Scroll Water Chillers

A. Packaged Water-Cooled Water Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. McQuay International.
3. Trane.
4. York International Corp.

B. Packaged Air-Cooled Water Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. McQuay International.
3. Trane.
4. York International Corp.

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55.57. Section 236426—Rotary-Screw Water Chillers

A. Packaged, Water-Cooled, Single-Compressor Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. Dunham-Bush, Inc.
3. Trane.
4. York International Corp.

B. Packaged, Water-Cooled, Multiple-Compressor Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. Dunham-Bush, Inc.
3. Trane.
4. York International Corp.

C. Packaged, Air-Cooled Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. Dunham-Bush, Inc.
3. McQuay International.
4. Trane.
5. York International Corp.

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55.58. Section 236427—Medical, Laboratory, and Process Chillers

- A. **ArtiChill, Inc.**
- B. **Filtrine Manufacturing Company.**
- C. **Liebert Corporation.**

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55.59. Section 236500—Cooling Towers

- A. **Closed-Circuit, Evaporative Cooling Towers (Forced Draft, Induced Draft)**
 1. Baltimore Aircoil Company.
 2. Evapco, Inc.
 3. Marley Cooling Technologies; an SPX Corporation.
- B. **Open-Circuit, Cooling Towers (Forced Draft, Induced Draft)**
 1. Baltimore Aircoil Company.
 2. Evapco, Inc.
 3. Marley Cooling Technologies; an SPX Corporation.

4. Tower Tech, Inc.

C. Ejector Cooling Towers

1. Baltimore Aircoil Company.
2. Evapco, Inc.
3. Marley Cooling Technologies; an SPX Corporation.

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55.60. Section 237200—Air-to-Air Energy Recovery Equipment

A. Heat Wheels

1. American Energy Exchange, Inc.
2. AAON, Inc.
3. Loren Cook Company.
4. SEMCO Incorporated.
5. Trane.

B. Heat-Pipe Heat Exchangers

1. Applied Air, a company of Mestek Technology, Inc.
2. Des Champs Technologies.
3. Engineered Air.
4. Gaylord Industries, Inc.
5. Heat Pipe Technology, Inc.

C. Fixed-Plate Sensible Heat Exchangers

1. American Energy Exchange, Inc.
2. Des Champs Technologies.
3. Engineered Air.
4. Exothermics, a brand of Eclipse, Inc.
5. RenewAire, LLC.
6. United Air Specialists, Inc., a CLARCOR company.

D. Fixed-Plate Total Heat Exchangers

1. Mitsubishi Electric Sales Canada, Inc.
2. RenewAire, LLC.

E. Packaged Energy Recovery Units

1. American Energy Exchange, Inc.
2. Applied Air, a company of Mestek Technology, Inc.
3. Des Champs Technologies.
4. Engineered Air.
5. Gaylord Industries, Inc.
6. Greenheck Fan Corporation.
7. Loren Cook Company.
8. Mitsubishi Electric & Electronics USA, Inc.; HVAC Advanced Products Division.
9. Mitsubishi Electric Sales Canada, Inc.
10. RenewAire, LLC.
11. SEMCO Incorporated.
12. Trane.
13. Wing, L. J.; Mestek Technology, Inc.

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55.61. Section 237313—Modular Indoor Central Station Air Handling Units

- A. Air Enterprises, Inc.**
- B. Buffalo Air Handling.**
- C. Carrier Corporation, a member of the United Technologies Corporation Family.**
- D. Engineered Air.**
- E. Mammoth, Inc.**

- F. **McQuay International.**
- G. **Trane.**
- H. **YORK International Corporation.**

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55.62. Section 237314—Custom Indoor Air Handling Units

- A. **Acousti Flo.**
- B. **Air Enterprises.**
- C. **Buffalo Air Handling.**
- D. **Cambridgeport.**
- E. **Gamewell.**
- F. **Gaylord Industries.**
- G. **Governair.**
- H. **Ingenia.**
- I. **Mammoth.**
- J. **SEMCO Incorporated.**
- K. **Trane.**
- L. **YORK International Corporation.**

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55.63. Section 237333—Indoor Indirect-Fuel-Fired Heating and Ventilating Units

- A. **AbsolutAire, Inc.**
- B. **Applied Air; Mestek, Inc.**
- C. **BessamAire, Inc.**
- D. **Cambridge Engineering, Inc.**
- E. **Captive-Air Systems, Inc.**

- F. **Des Champs Laboratories Incorporated, a unit of Entrodyne Corporation.**
- G. **Engineered Air.**
- H. **Greenheck Fan Corporation.**
- I. **Jackson & Church, a division of Donlee Technologies, Inc.**
- J. **KING.**
- K. **Modine Mfg. Co., Commercial HVAC&R Division.**
- L. **Rapid Engineering, Inc.**
- M. **Reznor-Thomas & Betts Corporation, Mechanical Products Division.**
- N. **Trane.**
- O. **Weather-Rite, Inc.**

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55.64. Section 237339—Indoor, Direct Gas-Fired Heating and Ventilating Units

- A. **AbsolutAire, Inc.**
- B. **Applied Air; Mestek, Inc.**
- C. **BessamAire, Inc.**
- D. **Cambridge Engineering, Inc.**
- E. **Captive-Air Systems, Inc.**
- F. **Des Champs Laboratories Incorporated, a unit of Entrodyne Corporation.**
- G. **Engineered Air.**
- H. **Greenheck Fan Corporation.**
- I. **Jackson & Church, Division of Donlee Technologies, Inc.**
- J. **KING.**
- K. **Modine Mfg. Co., Commercial HVAC&R Division.**

- L. **Rapid Engineering, Inc.**
- M. **Reznor-Thomas & Betts Corporation, Mechanical Products Division.**
- N. **Sterling Gas; Mestek, Inc.**
- O. **Trane.**
- P. **Weather-Rite, Inc.**

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55.65. Section 237413—Packaged, Outdoor, Central-Station Air-Handling Units

- A. **AAON, Inc.**
- B. **Carrier Corporation.**
- C. **Engineered Air.**
- D. **McQuay International.**
- E. **Trane.**
- F. **YORK International Corporation.**

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55.66. Section 237414—Custom Outdoor Air Handling Units

- A. **AcoustiFLO**
- B. **Air Enterprises.**
- C. **Buffalo Air Handling.**
- D. **Cambridgeport.**
- E. **Gamewell.**
- F. **Gaylord Industries.**
- G. **Governair.**
- H. **Ingenia.**
- I. **Mammoth.**

J. **SEMCO Incorporated.**

K. **Trane.**

L. **YORK International Corporation.**

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55.67. Section 237433—Packaged, Outdoor, Heating and Cooling Makeup Air-Conditioners

A. **AAON, Inc.**

B. **Des Champs Laboratories, Incorporated.**

C. **Reznor-Thomas & Betts Corporation, Mechanical Products Division.**

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55.68. Section 238113—Packaged Terminal Air-Conditioners

A. **Carrier Corporation, a United Technologies company.**

B. **ClimateMaster, Inc.**

C. **Friedrich Air Conditioning Co.**

D. **General Electric Company, GE Consumer & Industrial—Appliances.**

E. **McQuay International.**

F. **Mitsubishi.**

G. **Suburban Manufacturing Company, a subsidiary of AIRXCEL, Inc.**

H. **Trane.**

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55.69. Section 238119—Self-Contained Air-Conditioners

A. **Self-Contained Air-Conditioners (Larger than 15 Tons)**

1. Carrier Air Conditioning, a division of Carrier Corporation.

2. Engineered Air.

3. McQuay International.

4. Trane.

B. Water-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)

1. Carrier Air Conditioning, a division of Carrier Corp.
2. Engineered Air.
3. McQuay International.
4. Trane.

C. Remote Air-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)

1. Carrier Air Conditioning, a division of Carrier Corp.
2. Engineered Air.
3. McQuay International.
4. Trane.

D. Integral Air-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)

1. McQuay International.
2. Trane.

E. Integral Air-Cooled, Wall-Mount Self-Contained Air-Conditioners (15 Tons and Smaller)

1. Bard Manufacturing Co.
2. Stulz Air Technology Systems, Inc.

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55.70. Section 238123—Computer-Room Air-Conditioners

A. Floor-Mounted Units

1. APC
2. Compu-Aire, Inc.
3. Data Aire, Inc.
4. Koldwave, Inc., a Mestek company.
5. Liebert Corporation.
6. Stulz-ATS.

B. Ceiling-Mounted Units

1. APC
2. Compu-Aire, Inc.
3. Data Aire, Inc.
4. Koldwave, Inc., a Mestek company.
5. Liebert Corporation.
6. Stulz-ATS.

C. Console Units

1. APC
2. Compu-Aire, Inc.
3. Data Aire, Inc.
4. Koldwave, Inc., a Mestek company.
5. Liebert Corporation.
6. Stulz-ATS.

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55.71. Section 238126—Split-System Air-Conditioners

- A. Carrier Air Conditioning, a division of Carrier Corporation.**
- B. Comfortmaker.**
- C. Friedrich Air Conditioning Company.**
- D. Koldwave, Inc.**
- E. Lennox Industries, Inc.**
- F. Mitsubishi Electric Sales Canada, Inc.**
- G. Mitsubishi Electronics America, Inc., HVAC Division.**
- H. Mitsubishi Heavy Industries America, Inc., Air-Conditioning & Refrigeration Division, Inc.**

I. **Sanyo Fisher (U.S.A.) Corp.**

J. **Trane.**

K. **York International Corp.**

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Holdings

55.72. Section 238146—Water-Source Unitary Heat Pumps

A. Concealed Water-Source Heat Pumps

1. Carrier Corporation.
2. ClimateMaster, Inc.
3. Hydro-Temp Corporation, Inc.
4. Mammoth, Inc.
5. McQuay International.
6. Trane.

B. Vertical-Stack Water-Source Heat Pumps

1. ClimateMaster, Inc.
2. Trane.

C. Rooftop Water-Source Heat Pumps

1. Carrier Corporation.
2. ClimateMaster, Inc.
3. Hydro-Temp Corporation, Inc.
4. Mammoth, Inc.
5. McQuay International.
6. Trane.

D. Exposed, Console Water-Source Heat Pumps

1. Carrier Corporation.
2. ClimateMaster, Inc.
3. Hydro-Temp Corporation, Inc.

4. Mammoth, Inc.
5. McQuay International.
6. Trane.

E. Unit Ventilator Water-Source Heat Pumps

1. Trane.

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55.73. Section 238213—Valance Heating and Cooling Units

A. Electric Radiant Heaters

1. Berko Electric Heating, a division of Marley Engineered Products.
2. Chromalox, Inc., a division of Emerson Electric Company.
3. Markel Products, a division of TPI Corporation.
4. Omega Engineering, Inc.
5. QMark Electric Heating, a division of Marley Engineered Products.

B. Prefabricated Electric Radiant Heating Panels

1. Aztec.
2. Berko Electric Heating, a division of Marley Engineered Products.
3. Markel Products, a division of TPI Corporation.
4. QMark Electric Heating, a division of Marley Engineered Products.

C. Hydronic Heating and Cooling Panels

1. AIRTEX Radiant Systems, a division of Engineered Air Ltd.
2. Rosemex Products.
3. Sun-El Corporation.

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55.74. Section 238216—Air Coils

A. Water Coils

1. Aerofin Corporation.
2. Carrier Corporation.

3. Dunham-Bush, Inc.
4. Heatcraft Refrigeration Products LLC, Heat Transfer Division.
5. Trane.

B. Steam Coils

1. Aerofin Corporation.
2. Carrier Corporation.
3. Dunham-Bush, Inc.
4. Heatcraft Refrigeration Products LLC, Heat Transfer Division.
5. Trane.

C. Refrigerant Coils

1. Aerofin Corporation.
2. Carrier Corporation.
3. Dunham-Bush, Inc.
4. Heatcraft Refrigeration Products LLC, Heat Transfer Division.
5. Trane.

D. Electric Coils

1. Brasch Manufacturing Co., Inc.
2. Chromalox, Inc., Wiegand Industrial Division; Emerson Electric Company.
3. Dunham-Bush, Inc.
4. INDEECO.
5. Trane.

E. Integral Face and Bypass Coils—Water and Steam

1. Aerofin Corporation.
2. Wing, L J; Mestek Technology, Inc.

- A. **Airtherm, a Mestek Company.**
- B. **Carrier Corporation.**
- C. **Engineered Air Ltd.**
- D. **Environmental Technologies, Inc.**
- E. **International Environmental Corporation.**
- F. **McQuay International.**
- G. **Trane.**
- H. **YORK International Corporation.**

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55.76. Section 238223—Unit Ventilators

- A. **Carrier Corporation.**
- B. **Engineered Air Ltd.**
- C. **McQuay International.**
- D. **Nesbitt Aire, Inc.; PEF Industries, Inc.**
- E. **Trane.**

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55.77. Section 238233—Convectors

A. Electric Baseboard Radiators

1. Berko Electric Heating, a division of Marley Engineered Products.
2. Chromalox, a division of Emerson Electric Company.
3. Indeeco.
4. Markel Products, a division of Marley Engineered Products.
5. Marley Electric Heating, a division of Marley Engineered Products.
6. Qmark Electric Heating, a division of Marley Engineered Products.

B. Hot-Water or Steam Baseboard Radiators

1. Dunham Bush.

2. Rittling, a division of Hydro-Air Components.
3. Rosemex.
4. Slant/Fin.
5. Sterling.
6. Ted Reed.
7. Trane.
8. Vulcan.

C. Electric Finned-Tube Radiators

1. Berko Electric Heating, a division of Marley Engineered Products.
2. Chromalox, a division of Emerson Electric Company.
3. Indeeco.
4. Markel Products, a division of Marley Engineered Products.
5. Marley Electric Heating, a division of Marley Engineered Products.
6. Qmark Electric Heating, a division of Marley Engineered Products.

D. Hot-Water or Steam Finned-Tube Radiators

1. Dunham Bush.
2. Rittling, a division of Hydro-Air Components.
3. Rosemex.
4. Slant/Fin.
5. Sterling.
6. Ted Reed.
7. Trane.
8. Vulcan.

E. Electric Convectors

1. Berko Electric Heating, a division of Marley Engineered Products.

2. Chromalox, a division of Emerson Electric Company.
3. Indeeco.
4. Markel Products, a division of Marley Engineered Products.
5. Marley Electric Heating, a division of Marley Engineered Products.
6. Qmark Electric Heating, a division of Marley Engineered Products.

F. Hot-Water or Steam Convectors

1. Dunham Bush.
2. Rittling, a division of Hydro-Air Components.
3. Rosemex.
4. Slant/Fin.
5. Sterling.
6. Ted Reed.
7. Trane.
8. Vulcan.

G. Flat-Pipe Steel Radiators

1. Embassy Industries, Inc.
2. Panel Radiator, Inc., a division of Hydro-Air Components.
3. Runtal North America, Inc.

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55.78. Section 238239—Unit Heaters

A. Electric Cabinet Unit Heaters

1. Brasch.
2. Berko Electric Heating, a division of Marley Engineered Products.
3. Chromalox, Inc., a division of Emerson Electric Company.
4. Indeeco.
5. Markel Products, a division of TPI Corporation.

6. Marley Electric Heating, a division of Marley Engineered Products.
7. QMark Electric Heating, a division of Marley Engineered Products.
8. Trane.
9. Vulcan.

B. Hot Water or Steam Cabinet Unit Heaters

1. Carrier Corporation.
2. Dunham-Bush, Inc.
3. Engineered Air Ltd.
4. International Environmental Corporation.
5. McQuay International.
6. Modine.
7. Ted-Reed.
8. Trane.
9. Vulcan.

C. Electric Propeller Unit Heaters

1. Brasch.
2. Berko Electric Heating, a division of Marley Engineered Products.
3. Chromalox, Inc., a division of Emerson Electric Company.
4. Indeeco.
5. Markel Products, a division of TPI Corporation.
6. Marley Electric Heating, a division of Marley Engineered Products.
7. QMark Electric Heating, a division of Marley Engineered Products.
8. Trane.

D. Hot Water or Steam Propeller Unit Heaters

1. Carrier Corporation.

2. Dunham Bush.
3. Engineered Air Ltd.
4. McQuay International.
5. Modine.
6. Reznor.
7. Ted_Reed
8. Trane.

E. Wall and Ceiling Heaters

1. Berko Electric Heating, a division of Marley Engineered Products.
2. Chromalox, Inc., a division of Emerson Electric Company.
3. Indeeco.
4. Markel Products, a division of TPI Corporation.
5. Marley Electric Heating, a division of Marley Engineered Products.
6. QMark Electric Heating, a division of Marley Engineered Products.
7. Trane.

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55.79. Section 238313—Radiant-Heating Electric Cables

A. Mineral-Insulated, Series-Resistance Heating Cables

1. Chromalox, Inc., Wiegard Industrial Division; Emerson Electric Company.
2. Delta-Therm Corporation.
3. Easy Heat, Inc.
4. Pyrotenax, a division of Tyco Thermal Controls.
5. Raychem, a division of Tyco Thermal Controls.
6. Watts Radiant, Inc.

B. Plastic-Insulated, Series-Resistance Heating Cables

1. Delta-Therm Corporation.

2. Easy Heat, Inc.
3. Pyrotenax, a division of Tyco Thermal Controls.
4. Raychem, a division of Tyco Thermal Controls.
5. Watts Radiant, Inc.

C. Self-Regulating, Parallel-Resistance Heating Cables

1. Chromalox, Inc., Wiegard Industrial Division; Emerson Electric Company.
2. Delta-Therm Corporation.
3. Easy Heat, Inc.
4. Pyrotenax, a division of Tyco Thermal Controls.
5. Raychem, a division of Tyco Thermal Controls.

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55.80. Section 238316—Radiant-Heating Hydronic Piping

A. Pex Pipe and Fittings

1. IPEX, Inc.
2. REHAU.
3. Slant/Fin Corp.
4. Stadler-Viega.
5. Uponor Wirsbo Co.
6. Vanguard Piping Systems, Inc.
7. Warmboard, Inc.
8. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.
9. Zurn Plumbing Products Group.

B. Pex/Al/Pex Pipe and Fittings

1. IPEX Inc.
2. Stadler-Viega.
3. Uponor Wirsbo Co.

4. EPDM Pipe and Fittings.

5. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

C. Controls

1. Danfoss, Inc.

2. IPEX, Inc.

3. REHAU.

4. Slant/Fin Corp.

5. Stadler-Viega.Tekmar Control Systems, Ltd.

6. Uponor Wirsbo Co.

7. Vanguard Piping Systems, Inc.

8. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

9. Zurn Plumbing Products Group.

D. Snow Melt Systems

1. Snow Technologies.

2. Uponor Wirsbo Co.

3. Vanguard Piping Systems, Inc.

4. Watts Radiant, Inc., a division of Watts Water Technologies, Inc.

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55.81. Section 238323—Radiant-Heating Electric Panels

A. Prefabricated Radiant-Heating Electric Panels

1. Berko Electric Heating, a division of Marley Engineered Products.

2. Markel Products, a division of TPI Corporation.

3. QMark Electric Heating, a division of Marley Engineered Products.

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55.82. Section 238413—Humidifiers

A. Water-Pressure Atomizing Humidifiers

1. Carel USA, LLC.
2. Herrmidifier.
3. Mee Industries, Inc.

B. Compressed-Air Atomizing Humidifiers

1. Carel USA, LLC.
2. Herrmidifier.
3. Mee Industries, Inc.

C. Steam-Injection Humidifiers

1. Armstrong International, Inc.
2. Carel USA, LLC.
3. DRI-STEEM Humidifier Company.
4. Herrmidifier.
5. Hygromatik; Spirax Sarco, Inc.
6. Nortec Industries Inc.
7. Pure Humidifier Company.

D. Self-Contained Humidifiers

1. Armstrong International, Inc.
2. Carel USA, LLC.
3. Herrmidifier.
4. Hygromatik; Spirax Sarco, Inc.
5. Nortec Industries, Inc.

E. Heated-Pan Humidifiers

1. Armstrong International, Inc.
2. DRI-STEEM Humidifier Company.
3. Nortec Industries, Inc.
4. Pure Humidifier Company.

F. Heat-Exchanger Humidifiers

1. Armstrong International, Inc.
2. Nortec Industries, Inc.
3. Pure Humidifier Company.

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55.83. Section 238416—Dehumidifiers

A. Desiccant Dehumidification Units

1. Air Technology Systems, Inc.
2. Governair Corporation.
3. Kathabar, Inc.
4. Munters, Cargocaire Division.

B. Refrigeration Dehumidification Units

1. DEC International, Inc.; Therma-Stor Products.
2. DECTRON, Inc.
3. Dehumidifier Corporation of America, Inc.
4. Desert Aire.
5. DryAire Systems Corp.
6. Governair Corporation.
7. Nautica Dehumidifiers, Inc.
8. Nesbitt, a Mestek Company.

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55.84. Section 262419—Motor-Control Centers

- A. ABB Power Distribution, Inc.; ABB Control, Inc., Subsidiary.**
- B. Danfoss, Inc.; Danfoss Electronic Drives Div.**
- C. Eaton Corporation; Cutler-Hammer Products.**
- D. General Electric Company; GE Industrial Systems.**

E. Rockwell Automation; Allen-Bradley Co.; Industrial Control Group.

F. Siemens/Furnas Controls.

G. Square D.

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55.85. Section 262816—Enclosed Switches and Circuit Breakers

A. Fusible Switches

1. Eaton Electrical, Inc.; Cutler-Hammer Business Unit.
2. General Electric Company; GE Consumer & Industrial—Electrical Distribution.
3. Siemens Energy & Automation, Inc.
4. Square D, a brand of Schneider Electric.

B. Nonfusible Switches

1. Eaton Electrical, Inc.; Cutler-Hammer Business Unit.
2. General Electric Company.; GE Consumer & Industrial—Electrical Distribution.
3. Siemens Energy & Automation, Inc.
4. Square D, a brand of Schneider Electric.

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55.86. Section 262913—Enclosed Controllers

A. ABB Power Distribution, Inc.; ABB Control, Inc., Subsidiary.

B. Danfoss, Inc.; Danfoss Electronic Drives Div.

C. Eaton Corporation, Cutler-Hammer Products.

D. General Electrical Company; GE Industrial Systems.

E. Rockwell Automation; Allen-Bradley Co.; Industrial Control Group.

F. Siemens/Furnas Controls.

G. Square D.

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55.87. Section 262923—Variable-Frequency Motor Controllers

- A. **ABB Power Distribution, Inc.; ABB Control, Inc., Subsidiary.**
- B. **Baldor Electric Company (Graham).**
- C. **Danfoss, Inc., Danfoss Electronic Drives Div.**
- D. **Eaton Corporation, Cutler-Hammer Products.**
- E. **General Electric Company; GE Industrial Systems.**
- F. **Rockwell Automation; Allen-Bradley Co.; Industrial Control Group.**
- G. **Siemens Energy and Automation, Industrial Products Division.**
- H. **Square D.**
- I. **Toshiba International Corporation.**

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