INCLUDES 2006 INTERNATIONAL BUILDING CODE

ARTHUR A. BELL JR., P.E.

HVAC

EQUATIONS DATA AND RULES OF THUMB

SECOND EDITION

PART 1

Introduction

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 52 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.

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-dependant, 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.

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. 2003 International Code Council Series of Codes (ICC):
   a. 2003 International Building Code (herein referred to as 2003 IBC).
   b. 2003 International Mechanical Code (herein referred to as 2003 IMC).
   c. 2003 International Energy Conservation Code (herein referred to as 2003 IECC).
   d. 2003 International Plumbing Code (herein referred to as 2003 IPC).
   e. 2003 International Fire Code (herein referred to as 2003 IFC).
   f. 2003 International Electric Code (herein referred to as 2003 IEC) (Administrative Provisions—References the National Electric Code—NFPA 70).
   g. 2003 International Fuel Gas Code (herein referred to as 2003 IFGC).
   h. 2003 International Residential Code (herein referred to as 2003 IRC).
   i. 2003 International Existing Building Code.
   j. 2003 International Performance Code.
   k. 2003 International Private Sewage Disposal Code.
   l. 2003 International Property Maintenance Code.
   m. 2003 International Zoning Code.
   n. 2003 International Wildland-Urban Interface Code.
2. 2006 International Code Council Series of Codes (ICC):
   a. 2006 International Building Code (herein referred to as 2006 IBC).
   b. 2006 International Mechanical Code (herein referred to as 2006 IMC).
   c. 2006 International Energy Conservation Code (herein referred to as 2006 IECC).
   d. 2006 International Plumbing Code (herein referred to as 2006 IPC).
   e. 2006 International Fire Code (herein referred to as 2006 IFC).
   f. 2006 International Electric Code (herein referred to as 2006 IEC) (Administrative Provisions—References the National Electric Code—NFPA 70).
   g. 2006 International Fuel Gas Code (herein referred to as 2006 IFGC).
   h. 2006 International Residential Code (herein referred to as 2006 IRC).
   i. 2006 International Existing Building Code.
   j. 2006 International Performance Code.
   k. 2006 International Private Sewage Disposal Code.
   l. 2006 International Property Maintenance Code.
   m. 2006 International Zoning Code.
   n. 2006 International Wildland-Urban Interface Code.
3. American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE):
   a. ASHRAE Standard 15—2004 (herein referred to as ASHRAE 15-2004).
   b. ASHRAE Standard 55—(herein referred to as ASHRAE 55-2004).
   c. ASHRAE Standard 62—2001 (herein referred to as ASHRAE 62-2004).
   d. ASHRAE Standard 62—2004 (herein referred to as ASHRAE 62-2004).
   e. ASHRAE Standard 90.1—2001 (herein referred to as ASHRAE 90.1-2004).
   f. ASHRAE Standard 90.1—2004 (herein referred to as ASHRAE 90.1-2004).
4. National Fire Protection Association Codes(NFPA):
   a. NFPA 90A—2002 Installation of Air-Conditioning and Ventilating Systems.
   b. NFPA 96—2004 Ventilation Control and Fire Protection of Commercial Cooking Operations.

PART 2

Definitions

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 assure 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 assure 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 quantities (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; 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*).

Definitions

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 chases, and in building shafts.

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

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

O. *Above Ground.* The term *above ground* shall mean not installed under ground, 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. *Un-Conditioned andNon-Conditioned.* The terms *un-conditioned* and *non-conditioned* 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 or un-conditioned.**

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**

Definitions

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, Addendums, 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. *Addendums.* Addendums are issued as changes, amendments, or clarifications to the original or previously issued Contract Documents. Addendums 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 as per 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, Labor and Materialman's 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. ***Labor and Materialman's 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, Addendum, 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.**

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*** **and** ***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, Supplier.*** **The terms** ***furnisher*** **and** ***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.**

PART 3

Equations

3.01 Airside System Equations and Derivations

A. Equations

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

$H_S = 1.1 \times CFM \times \Delta T$

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

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

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

$H_T = H_S + H_L$

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

H_S = Sensible Heat (Btu/hr.)
H_L = Latent Heat (Btu/hr.)
H_T = Total Heat (Btu/hr.)
ΔT = Temperature Difference (°F)
$\Delta W_{GR.}$ = Humidity Ratio Difference (Gr.H_2O/lbs.DA)
$\Delta W_{LB.}$ = Humidity Ratio Difference (lbs.H_2O/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/hr.)
c_a = Specific Heat of Air (0.24 Btu/lbs.DA °F)
DA = Dry Air

B. Derivations

1. Standard air conditions:
   a. Temperature: 60°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°F: 1060 Btu/lbs.
2. Sensible heat equation:
   $H_S = m \times c_a \times \Delta T$
   c_P = 0.24 (Btu/~~lbs.DA~~ . °F) × 0.075 ~~lbs.DA~~/ft.^{3} × 60 min./hr.
   = 1.08 Btu min./hr. ft.^{3} °F
   H_S = 1.08 (Btu min./hr. ft.^{3} °F) × CFM (ft.^{3}/min.) × ΔT (°F)
   $H_S = 1.08 \times CFM \times \Delta T$
3. Latent heat equation:
   $H_L = m \times L_V \times \Delta W_{GR}$
   L_V = 1060 Btu/~~lbs.H2O~~ × 0.075 lbs.DA/ft.^{3} × 60 min./hr. × 1.0 ~~lbs.H2O~~/7,000 Gr.H_2O
   = 0.68 Btu lbs.DA min./hr.ft.^{3} Gr.H_2O
   H_L = 0.68 (Btu lbs.DA min./hr.ft.^{3} Gr.H_2O) × CFM (ft.^{3}/min.) × ΔW_{GR} (Gr.H_2O/lbs.DA)
   $H_L = 0.68 \times CFM \times \Delta W_{GR}$
4. Total heat equation:
   $H_T = m \times \Delta h$
   Factor = 0.075 lbs.DA/ft.^{3} × 60 min./hr. = 4.5 lbs.DA min./hr.ft.^{3}
   H_T = 4.5 (lbs.DA min./hr.ft.^{3}) × CFM (ft.^{3}/min.) × Δh (Btu/lbs.DA)
   $H_T = 4.5 \times CFM \times \Delta h$

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/hr.)
GPM = Water Flow Rate (Gallons per Minute)
ΔT = Temperature Difference (°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_2O)

B. 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
   $H = m \times c_w \times \Delta T$
   $c_w = 1.0\ \text{Btu}/\cancel{\text{Lb}\ H_2O}\ °F \times 62.4\ \cancel{\text{lbs.}H_2O/\text{ft}^3} \times 1.0\ \cancel{\text{ft}^3}\ /\ 7.48052\ \text{gal.} \times 60\ \text{min./hr.}$
   $= 500$ Btu min./hr. °F gal.
   $H = 500$ Btu min./hr. °F gal. $\times$ GPM (gal./min.) $\times \Delta T$ (°F)
   $H = 500 \times GPM \times \Delta T$
3. Evaporator equation:
   $GPM_{EVAP} = H/(500 \times \Delta T)$
   Factor $= 12{,}000\ \cancel{\text{Btu/hr.}}/1.0\ \text{tons} \div 500\ \cancel{\text{Btu}}\ \text{min.}/\cancel{\text{hr.}}\ °F\ \text{gal.}$
   = 24°F gal./tons min.
   GPM_{EVAP} = tons (tons) $\times$ 24 (°F gal./tons min.) / ΔT (°F)
   $GPM_{EVAP} = \text{tons} \times 24 / \Delta T$
4. Condenser equation:
   $GPM_{COND} = 1.25 \times GPM_{EVAP} = 1.25 \times \text{tons} \times 24 / \Delta T$
   $GPM_{COND} = \text{tons} \times 30 / \Delta T$

3.03 Air Change Rate Equations

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

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

AC/HR. = Air Change Rate per Hour
CFM = Air Flow Rate (Cubic Feet per Minute)
VOLUME = Space Volume (Cubic Feet)

3.04 English/Metric Airside System Equations Comparison

A. Sensible Heat Equations

$$H_S = 1.08 \frac{Btu\ min.}{Hr\ ft^3\ °F} \times CFM \times \Delta T$$

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

B. Latent Heat Equations

$$H_L = 0.68 \frac{Btu\ min.\ Lb\ DA}{hr.\ ft^3\ Gr\ H_2O} \times CFM \times \Delta W$$

$$H_{LM} = 177{,}734.8 \frac{kJ\ min.\ kg\ DA}{hr.\ m^3 kg\ H_2O} \times CMM \times \Delta W_M$$

C. Total Heat Equations

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

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

$$H_T = H_S + H_L$$

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

H_S = Sensible Heat (Btu/hr.)
H_{SM} = Sensible Heat (kJ/hr.)
H_L = Latent Heat (Btu/hr.)
H_{LM} = Latent Heat (kJ/hr.)
H_T = Total Heat (Btu/hr.)
H_{TM} = Total Heat (kJ/hr.)
ΔT = Temperature Difference (°F)
ΔT_M = Temperature Difference (°C)
ΔW = Humidity Ratio Difference (Gr.H_2O/lbs.DA)
ΔW_M = Humidity Ratio Difference (kg.H_2O/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

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

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

H = Total Heat (Btu/hr.)
H_M = Total Heat (kJ/hr.)
ΔT = Temperature Difference (°F)
ΔT_M = Temperature Difference (°C)
GPM = Water Flow Rate (Gallons per Minute)
LPM = Water Flow Rate (Liters per Minute)

3.06 English/Metric Air Change Rate Equation Comparison

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

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

AC/HR. = Air Change Rate per Hour – English
$AC/HR._M$ = Air Change Rate per Hour – Metric
AC/HR. = $AC/HR._M$
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)

3.07 English/Metric Temperature and Other Conversions

$$°F = 1.8\ °C + 32$$

$$°C = \frac{°F - 32}{1.8}$$

°F = degrees Fahrenheit
°C = degrees Celsius
kJ/hr. = Btu/hr. × 1.055
CMM = CFM × 0.02832
LPM = GPM × 3.785
kJ/kg = Btu/lbs. × 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/hr.
1.0 lb. stm. / hr. = 0.002 GPM
1.0 lb. H_2O / hr. = 1.0 lbs. steam/hr.
kg / cu. meter = lbs. / cu. ft. × 16.017 (Density)
cu. meters / kg = cu. ft. / lbs. × 0.0624 (Specific Volume)
kg H_2O / kg DA = Gr.H_2O / lbs.DA / 7,000 = lbs.H_2O/lbs.DA

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 in Gallons per Minute
CFM = Quantity of Gas or Air in Cubic Feet per Minute
SP.GR. = Specific Gravity
D = Density in lbs./cubic feet
C_a = Specific Heat of Air (0.24 Btu/lb.)
Cw = Specific Heat of Water (1.00 Btu/lb.)
H_{FG} = Latent Heat of Steam in Btu/lbs. at Steam Design Pressure (ASHRAE Fundamentals or Part 45)
ΔT = Final Temperature minus Initial Temperature
EDR = Equivalent Direct Radiation

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

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

$$R = \frac{1}{C} = \frac{1}{K} \times Thickness$$

$$U = \frac{1}{\sum R}$$

ΔT = Temperature Difference (°F)
A = Area (sq.ft.)
U = U-Value (Btu./hr. sq.ft. °F): See Part 35 for Definitions.
R = R-Value (hr. sq.ft. °F/Btu.): See Part 35 for Definitions.

C = Conductance (Btu./hr. sq.ft. °F): See Part 35 for Definitions.
K = Conductivity (Btu. in./hr. 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 = in. W.G.
BHP = Break 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

3.11 Pump L.ws

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

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

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

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

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

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

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

GPM = Gallons/Minute
RPM = Revolutions/Minute
HD = ft. H_2O
BHP = Break 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 in psi
VH = Velocity Head in ft.
V = Velocity in ft./sec.
g = Acceleration due to Gravity (32.16 ft./sec.^{2})

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 or Part 45)

Note: Calculations may also be performed in psig, provided that all values are in psig.

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)

3.14 Psychrometric Equations

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

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

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

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

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

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

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

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

W = Specific Humidity, lbs.H_2O/lbs.DA or Gr.H_2O/lbs.DA
W_{ACTUAL} = Actual Specific Humidity, lbs.H_2O/lbs.DA or Gr.H_2O/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, lb./sq.ft.
P = Total Absolute Pressure of Air/Water Vapor Mixture, lb./sq.ft.
P_{SAT} = Saturation Partial Pressure of Water Vapor at the Dry Bulb Temperature, lb./sq.ft.
RH = Relative Humidity, %
H_S = Sensible Heat, Btu/hr.
H_L = Latent Heat, Btu/hr.
H_T = Total Heat, Btu/hr.
m = Mass Flow Rate, lbs.DA/hr. or lbs.H_2O/hr.
c_P = Specific Heat, Air—0.24 Btu/lbs.DA, Water—1.0 Btu/lbs.H_2O
T_{DB} = Dry Bulb Temperature, °F
T_{WB} = Wet Bulb Temperature, °F
ΔT = Temperature Difference, °F
ΔW = Specific Humidity Difference, lbs.H_2O/lbs.DA or Gr.H_2O/lbs.DA
Δh = Enthalpy Difference, Btu/lbs.DA
L_V = Latent Heat of Vaporization, Btu/lbs.H_2O

3.15 Ductwork Equations

$$TP = SP + VP$$

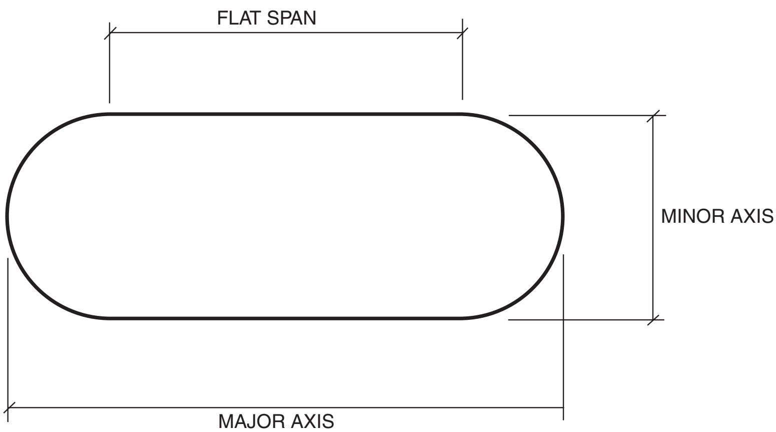
$$VP = \left[\frac{V}{4005}\right]^2 = \frac{(V)^2}{(4005)^2}$$

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

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

TP = Total Pressure
SP = Static Pressure, Friction Losses
VP = Velocity Pressure, Dynamic Losses
V = Velocity, ft./min.
Q = Flow 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.

3.16 Equations for Flat Oval Ductwork



$$FS = MAJOR - MINOR$$

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

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

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

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.)

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./hr.
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

$$FS = \frac{H_{S_{SS}} - H_{S_{CR}}}{H_{L_{CR}}} \times 100$$

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

FS = Flash Steam, Percentage %
$H_{S_{SS}}$ = Sensible Heat at Steam Supply Pressure, Btu/lbs.
$H_{S_{CR}}$ = Sensible Heat at Condensate Return Pressure, Btu/lbs.
$H_{L_{CR}}$ = Latent Heat at Condensate Return Pressure, Btu/lbs.

W = Steam Flow Rate, lbs./hr.
W_{CR} = Condensate Flow based on percentage of Flash Steam created during condensing process, lbs/hr. 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)
$\Delta W_{LB.}$ = Specific Humidity (lbs.H_2O/lbs.DA)
$\Delta W_{GR.}$ = Specific Humidity (Gr.H_2O/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_2O/cu.ft.)
$POUNDS_{REQ'D}$ = Pounds of Moisture Required (lbs.H_2O/cu.ft.)
CFM = Air Flow Rate (cu.ft./min.)
SpV = Specific Volume of Air (cu.ft./lbs.DA)
$W_{GR.}$ = Specific Humidity (Gr.H_2O/lbs.DA)
$W_{LB.}$ = Specific Humidity (lbs.H_2O/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/hr.)
Q = Steam Flow (lbs. steam/hr.)
ΔT = Steam Temperature – Supply Air Temperature (°F)
L = Length of Humidifier Manifold (ft.)

3.22 Expansion Tanks

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

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

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

V_T = Volume of Expansion Tank (Gallons)
V_S = Volume of Water in Piping System (Gallons)
$\Delta T = T_2 - T_1$ (°F)
T_1 = Lower System Temperature (°F)
Heating Water T_1 = 45–50°F Temperature at Fill Condition
Chilled Water T_1 = Supply Water Temperature
Dual Temperature T_1 = Chilled Water 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_2O at T_1 (cu.ft./lbs.H_2O) ASHRAE Fundamentals or Part 45
v_2 = SpV of H_2O at T_2 (cu.ft./lbs.H_2O) ASHRAE Fundamentals or Part 45
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

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

$$EER = \frac{BTU\ OUTPUT}{WATTS\ INPUT}$$

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

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

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

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

$E = GPM_{COND.} \times R \times 0.0008$

$D = GPM_{COND.} \times 0.0002$

$R = EWT - LWT$

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

$KVA = KW + KVAR$

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 = Break Horsepower
MHP = Motor Horsepower

EFF = Efficiency
M/D = Motor Drive

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 (hr. sq.ft. °F/Btu)
U = U-Value (Btu./hr. sq.ft. °F)
IA = Inside Airfilm
OA = Design Outside Air Temperature
DP = Dewpoint

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.

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

$$CFM = 100 \times G^{0.5}$$

CFM = Exhaust Air Flow Rate Required (cu.ft./minute)
G = Mass of Refrigerant of Largest System (pounds)

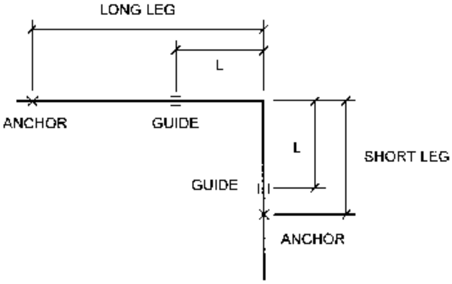
C. Partially Enclosed Equipment Rooms

$$FA = G^{0.5}$$

FA = Ventilation Free Opening Area (sq.ft.)
G = Mass of Refrigerant of Largest System (Pounds)

3.31 Pipe Expansion Equations

A. L-Bends

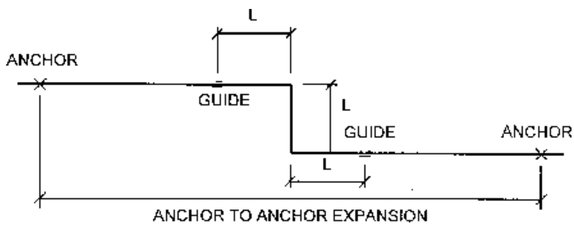


$$L = 6.225 \times \sqrt{\Delta D}$$

$$F = 500\ LB./\ PIPE\ DIA. \times PIPE\ DIA.$$

L = Length of Leg Required to Accommodate Thermal Expansion or Contraction, Feet
Δ = Thermal Expansion or Contraction of Long Leg, 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.

B. Z-Bends

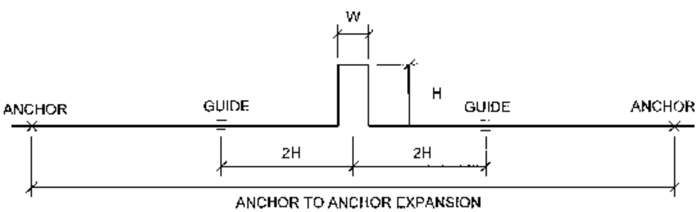


$$L = 4 \times \sqrt{\Delta D}$$

$$F = 200 - 500\ LB./\ PIPE\ DIA. \times PIPE\ DIA.$$

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



$L = 6.225 \times \sqrt{\Delta D}$

$F = 200\ LB.\ /\ PIPE\ DIA. \times PIPE\ DIA.$

$L = 2H + W$

$H = 2W$

$L = 5W$

L = Length of Loop Required to Accommodate Thermal Expansion or Contraction, ft.
Δ = 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.

3.32 Relief Valve Vent Line Maximum Length

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

$$P_1 = 0.25 \times \left[\left(PRESSURE\ SETTING \times 1.1 \right) + 14.7 \right]$$

$$P_2 = \left[\left(PRESSURE\ SETTING \times 1.1 \right) + 14.7 \right]$$

L = Maximum Length of Relief Vent Line in Feet
D = Inside Diameter of Pipe in Inches
C = Minimum Discharge of Air in lbs./min.

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./hr.

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

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./hr.)
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
   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
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

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

3.35 Domestic Water Heater Sizing

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

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

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

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

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

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

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

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

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.

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 degrees 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:

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

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

$$H_{SURFACE\ LOSS} = 5.5\ BTU/HR\ SQ.\ FT.°F \times \Delta T_{WATER/AIR} \times POOL\ AREA$$

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

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

$$T_{INITIAL} = 50\,°F$$

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

H = Heating capacity (Btu/hr.)
ΔT = Temperature difference (°F)

PART 4

Conversion Factors

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

4.02 Weight

1 gal.H_2O	= 8.33 lbs.H_2O
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_2O

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.

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.

4.05 Velocity

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

4.06 Speed of Sound in Air

1128.5 ft./sec. = 769.4 mph

4.07 Pressure

14.7 psi	= 33.95 ft. H_2O = 29.92 in. Hg = 407.2 in. W.G. = 2116.8 lbs./sq.ft.
1 psi	= 2.307 ft. H_2O = 2.036 in. Hg = 16 oz = 27.7 in. WC

1 ft. H_2O = 0.4335 psi = 62.43 lbs./sq.ft.
1 oz = 1.73 in. WC

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_2O

B. Standard Air @ 60°F, 14.7 psi

13.329 cu.ft./lb.	=	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

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/hr.
1 bhp	= 34,500 Btuh (33,472 Btuh) = 34.5 lbs.stm/hr. = 34.5 lbs.H_2O/hr. = 0.069 gpm = 4.14 gph = 140 edr (sq.ft. of equivalent radiation)
1 therm	= 100,000 Btuh
1 mbh	= 1,000 Btuh
1 lb.stm/hr.	= 0.002 gpm
1 gpm	= 500 lbs.stm./hr.
1 edr (equivalent direct radiation)	= 0.000496 gpm = 0.25 lbs.stm.cond./hr.
1,000 edr	= 0.496 gpm
1 edr hot water	= 150 Btu/hr.
1 edr steam	= 240 Btu/hr.
1 edr	= 240 Btu/hr. (up to 1,000 ft. above sea level)
1 edr	= 230 Btu/hr. (1,000 ft.–3,000 ft. above sea level)
1 edr	= 223 Btu/hr. (3,000 ft.–5,000 ft. above sea level)
1 edr	= 216 Btu/hr. (5,000 ft.–7,000 ft. above sea level)
1 edr	= 209 Btu/hr. (7,000 ft.–10,000 ft. above sea level)

4.10 Flow

1 mgd (million gal./day) = 1.547 cu.ft./sec. = 694.4 gpm
1 cu.ft./min. = 62.43 lbs.H_2O/min. = 448.8 gph

4.11 HVAC Metric Conversions

kJ/hr.	= Btu/hr × 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/hr.	
1.0 lb.stm./hr.	= 0.002 gpm	
1.0 lb.H_2O/hr.	= 1.0 lb.steam/hr.	
kg/cu.m	= lbs./cu.ft. × 16.017	(density)
cu.m/kg	= cu.ft./lb. × 0.0624	(specific volume)
kg H_2O/kg DA	= Gr H_2O/lb. DA/7000 = lb. H_2O/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. KWH × 1.06 = KWH for electric boiler
2. KWH × 0.03 = gal. for oil-fired boiler
3. KWH × 0.041 = therms for gas-fired boiler

D. Heat Pump to Hydronic Baseboard

1. KWH × 1.88 = KWH for electric boiler
2. KWH × 0.052 = gal. for oil-fired boiler
3. KWH × 0.073 = therms for gas-fired boiler

E. Electric Baseboard to Warm Air Furnace

1. KWH × 1.19 = KWH for electric furnace
2. KWH × 0.039 = gal. for oil-fired furnace
3. KWH × 0.054 = therms for gas-fired furnace

F. Electric Furnace to Fuel-Fired Furnace

1. KWH × 0.032 = gal. for oil-fired furnace
2. KWH × 0.045 = therms for gas-fired furnace

G. Ceiling Cable to Warm Air Furnace

1. KWH × 1.06 = KWH for electric furnace
2. KWH × 0.034 = gal. for oil-fired furnace
3. KWH × 0.048 = therms for gas-fired furnace

H. Heat Pump to Warm Air Furnace

1. KWH × 1.88 = KWH for electric furnace
2. KWH × 0.061 = gal. for oil-fired furnace
3. KWH × 0.085 = therms for gas-fired furnace

I. Warm Air Systems to Hydronic Baseboard System

1. gal. oil for W.A. × 0.857 = gal. for hydronics
2. therms gas for W.A. × 0.857 = therms for hydronics
3. gal. oil for W.A. × 1.2 = therms for hydronics
4. therms gas for W.A. × 0.612 = gal. for hydronics

PART 5

Cooling Load Rules of Thumb

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/hr.	

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.

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/hr.**	

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/hr.**	

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/hr.	

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/hr.	

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/hr.	

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/hr.	

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/hr.	Cocktail Lounges, Bars, Taverns, Clubhouses
G. Air Change Rate	20–30 AC/hr.	Night Clubs

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	

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.

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/hr.	

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

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	

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	

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	

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/hr.	

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/hr.	

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/hr.	

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/hr.	

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/hr.	

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/hr.	

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/hr.	

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	

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/hr.

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/hr.

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/hr.

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/hr. minimum

G. Total heat includes ventilation. Room sensible heat does not include ventilation.

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 un-conditioned 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.

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	N	S	E	W	NE	SE	SW	NW
25	0.4	0	July	Sept.	July	July	July	Sept.	Sept.	July
25	0.4	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.	July
25	0.4	1:1	July	Oct.	July	July	July	Sept.	Oct.	July
25	0.6	0	July	Sept.	July	July	July	Sept.	Sept.	July
25	0.6	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.	July
25	0.6	1:1	July	Dec.	July	Sept.	July	Sept.	Oct.	July
50	0.4	0	July	Sept.	July	July	July	Sept.	Sept.	July
50	0.4	1:2	July	Oct.	July	Aug.	July	Sept.	Sept.	July
50	0.4	1:1	July	Dec.	July	Sept.	July	Sept.	Oct,	July
50	0.6	0	July	Oct.	July	July	July	Sept.	Sept.	July
50	0.6	1:2	July	Dec.	July	Aug.	July	Sept.	Oct.	July
50	0.6	1:1	July	Dec.	July	Sept.	July	Sept.	Dec.	July

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 exposures 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 the top of the window.
5. The roof will peak in June or July.

PART 6

Heating Load Rules of Thumb

6.01 All Buildings and Spaces

A. 20–60 Btuh/sq.ft.

B. 25–40 Btuh/sq.ft. Average

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

A. 40–120 Btuh/sq.ft.

6.03 Buildings w/Ample Insulation, Few Windows

A. AC tons × 12,000 Btuh/ton × 1.2

6.04 Buildings w/Limited Insulation, Many Windows

A. AC tons × 12,000 Btuh/ton × 1.5

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.

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.

6.07 Heating System Selection Guidelines

A. If heat loss exceeds 450 Btu/hr. 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/hr. 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/hr. 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.

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.

PART 7

Infiltration Rules of Thumb

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).

7.02 Heating Infiltration (15-mph wind)

A. Air Change Rate Method

1. Range 0 to 10 AC/hr.
2. Commercial buildings:
   a. 1.0 AC/hr. one exterior wall
   b. 1.5 AC/hr. two exterior walls
   c. 2.0 AC/hr. three or four exterior walls
3. Vestibules 3.0 AC/hr.

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 building	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

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.

PART 8

Ventilation Rules of Thumb

8.01 Minimum Outdoor Air Requirements 2003 IMC, 2006 IMC, and *ASHRAE Standard 62.1-2001*

MINIMUM VENTILATION RATES

Occupancy Classification	Max. Occupant Load (1) People per 1,000 SF	Max. Occupant Load (1) SF/Person	Outdoor Air CFM/Person (2)
Correctional Facilities			
Cells Without Plumbing Fixtures	20	50	20
Cells With Plumbing Fixtures	20	50	20
Dining Halls	100	10	15
Guard Stations	40	25	15
Dry Cleaners, Laundries			
Coin Operated Dry Cleaner	20	50	15
Coin Operated Laundries	20	50	15
Commercial Dry Cleaner	30	33	30
Commercial Laundry	10	100	25
Storage, Pick-Up	30	33	35
Education			
Auditoriums	150	6	15
Classrooms	50	20	15
Corridors	-	-	0.10 CFM/SF
Laboratories	30	33	20
Libraries	20	50	15
Locker Rooms	-	-	0.50 CFM/SF
Music Rooms	50	20	15
Smoking Lounges	70	14	60
Training Shops	30	33	20
Food and Beverage Service			
Bars, Cocktail Lounges	100	10	30
Cafeteria, Fast Food	100	10	20
Dining Rooms	70	14	20
Kitchens (cooking)	20	50	15 1.5 CFM/SF Min. Exhaust
Hospitals, Nursing, and Convalescent Homes			
Autopsy Rooms	-	-	0.50 CFM/SF
Medical Procedure Rooms	20	50	15
Operating Rooms	20	50	30
Patient Rooms	10	100	25
Physical Therapy	20	50	15
Recovery and ICU	20	50	15
Hotels, Motels, Resorts, and Dormitories			
Assembly Rooms	120	8	15
Bathrooms	-	-	35 CFM/Room
Bedrooms	-	-	30 CFM/Room
Conference Rooms	50	20	20
Dormitory Sleeping Areas	20	50	15
Gambling Casinos	120	8	30
Living Rooms	-	-	30 CFM/Room
Lobbies	30	33	15
Offices			
Conference Rooms	50	20	20
Office Spaces	7	143	20
Reception Areas	60	17	15
Telecommunication Centers and Data Entry	60	17	20
Private Dwellings (Single and Multiple)			
Living Areas	(5)	-	0.35 AC/hr. or 15 CFM/Person whichever is greater

(*Continued*)

MINIMUM VENTILATION RATES (*Continued*)

Occupancy Classification	Max. Occupant Load (1)		Outdoor Air CFM/Person (2)
	People per 1,000 SF	SF/Person	
Kitchens	-	-	100 CFM Intermittent 25 CFM Continuous
Toilet Rooms and Bathrooms	-	-	Mechanical Exhaust 50 CFM Intermittent 20 CFM Continuous
Garages (Separate for Each Dwelling)	-	-	100 CFM/Car
Garages (Common for Multiple Units)	-	-	1.5 CFM/SF See paragraph on Parking Garages
Public Spaces			
Corridors and Utilities	-	-	0.05 CFM/SF
Elevators Elevator Car	-	-	1.00 CFM/SF
Locker Rooms Dressing Rooms	-	-	0.50 CFM/SF
Toilet Rooms Public Restrooms	-	-	75 CFM per 50 CFM per Water Closet or Urinal
Shower Rooms (per shower head)	-	-	Mechanical Exhaust 50 CFM Intermittent 20 CFM Continuous
Smoking Lounges	70	14	60
Retail Stores, Sales Floors, and Show Room Floors			
Basement and Street Levels	- 30	- 33	0.30 CFM/SF
Dressing Rooms	-	-	0.20 CFM/SF
Malls and Arcades	- 20	- 50	0.20 CFM/SF
Shipping and Receiving	- 10	- 100	0.15 CFM/SF
Smoking Lounges	70	14	60
Storage Rooms	- 15	- 66	0.15 CFM/SF
Upper Floors	- 20	- 50	0.20 CFM/SF
Warehouses	- 5	- 200	0.05 CFM/SF
Specialty Shops			
Automotive Service Stations Automotive Motor-Fuel Dispensing Stations (8)	-	-	1.5 CFM/SF See paragraph 8.02 on Parking Garages below
Barber Shops	25	40	15
Beauty Shops	25	40	25
Clothiers, Furniture	-	-	0.30 CFM/SF
Embalming Room (8)	-	-	2.0 CFM/SF
Florists	8	125	15
Hardware, Drugs, Fabrics	8	125	15
Nail Salon (8)	-	-	25 50 CFM Intermittent 20 CFM Continuous per Station
Pet Shops	-	-	1.00 CFM/SF
Reducing Salons	20	50	15
Supermarkets	8	125	15
Sports and Amusement			
Ballrooms and Discos	100	10	25
Bowling Alley (seating areas)	70	14	25
Game Rooms	70	14	25

(*Continued*)

MINIMUM VENTILATION RATES (*Continued*)

Occupancy Classification	Max. Occupant Load (1)		Outdoor Air CFM/Person (2)
	People per 1,000 SF	SF/Person	
Ice Arenas	-	-	0.50 CFM/SF
Playing Floors, Gymnasiums	30	33	20
Spectator Areas	150	6	15
Swimming Pools (pool and deck areas)	-	-	0.50 CFM/SF
Storage			
Repair Garages, Enclosed Parking Garages	-	-	1.5 Cfm SF See paragraph on Parking Garages
Warehouses	- 5	- 200	0.05 CFM/SF
Theaters			
Auditoriums	150	6	15
Lobbies	150	6	20
Stages, Studios	70	14	15
Ticket Booths	60	16	20
Transportation			
Platforms	100	10	15
Vehicles	150	6	15
Waiting Rooms	100	10	15
Workrooms			
Bank Vaults	5	200	15
Darkrooms	- 10	- 100	0.50 CFM/SF
Duplicating, Printing	-	-	0.50 CFM/SF
Meat Processing	10	100	15
Pharmacy	20	50	15
Photo Studios	10	100	15

Notes:

1 Maximum occupant load is based on the net floor area.
2 Outdoor air is expressed in CFM per person unless otherwise indicated. When indicated in CFM/SF, the ventilation rate is based on the floor area being ventilated.
3 Bold and italicized items are 2006 IMC changes.
4 Bold and underlined items are ASHRAE Standard 62-2001 changes.
5 Based on number of bedrooms: First bedroom, two people; each additional bedroom, one person.
6 When the ventilation system serves multiple spaces with different ventilation requirements, the following multiple space equations must be used.

$$Y = X/(1 + X - Z)$$

where:

$Y = V_{ot}/V_{st}$ = Corrected fraction of outdoor air in system supply.
$X = V_{on}/V_{st}$ = Uncorrected fraction of outdoor air in system supply.
$Z = V_{oc}/V_{sc}$ = Fraction of outdoor air in critical space. The critical space is the space with the greatest required fraction of outdoor air in the supply to this space.
V_{ot} = Corrected total outdoor airflow rate.
V_{st} = Total supply flow rate, the sum of all supply for all branches of the system.
V_{on} = Sum of outdoor airflow rates for all the branches on the system.
V_{oc} = Outdoor airflow rate required in critical spaces.
V_{sc} = Supply flow rate in critical space.

7 The multiple space equation usually increases the minimum outdoor airflow required by 30 to 50 percent.
8 This category is not in ASHRAE Standard 62.1-2001.

B. *ASHRAE Standard 62.1-2004*

MINIMUM VENTILATION RATES

Occupancy Category	Outdoor Air Rate (1)		Default Values (2)		
	People CFM/Person	Area CFM/SF	Occupant Density People/1,000 SF	CFM per Person	CFM per SF
Correctional Facilities					
Cell	5.0	0.12	25	10	0.25
Day Room	5.0	0.06	30	7	0.21
Guard Stations	5.0	0.06	15	9	0.14
Booking/Waiting	7.5	0.06	50	9	0.44
Educational Facilities					
Daycare (through age 4)	10.0	0.18	25	17	0.43
Classrooms (ages 5 to 8)	10.0	0.12	25	15	0.37
Classrooms (ages 9 plus)	10.0	0.12	35	13	0.47
Lecture Classroom	7.5	0.06	65	8	0.55
Lecture Hall (fixed seats)	7.5	0.06	150	8	1.19
Art Classroom	10.0	0.18	20	19	0.38
Science Laboratories	10.0	0.18	25	17	0.43
Wood/Metal Shop	10.0	0.18	20	19	0.38
Computer Lab	10.0	0.12	25	15	0.37
Media Center	10.0	0.12	25	15	0.37
Music/Theater/Dance	10.0	0.06	35	12	0.41
Multiuse Assembly	7.5	0.06	100	8	0.8
Food and Beverage Service					
Restaurant Dining Rooms	7.5	0.18	70	10	
Cafeteria/Fast Food	7.5	0.18	100	9	0.93
Bars/Cocktail Lounges	7.5	0.18	100	9	0.93
General					
Conference/Meeting	5.0	0.06	50	6	0.31
Corridors	-	0.06	-	-	0.06
Storage Rooms	-	0.12	-	-	0.12
Hotel, Motels, Resorts, Dormitories					
Bedroom/Living Room	5.0	0.06	10	11	0.11
Barracks Sleeping Areas	5.0	0.06	20	8	0.16
Lobbies/Prefunction	7.5	0.06	30	10	0.29
Multipurpose Assembly	5.0	0.06	120	6	0.66
Office Buildings					
Office Space	5.0	0.06	5	17	0.09
Reception Areas	5.0	0.06	30	7	0.21
Telephone/Data Entry	5.0	0.06	60	6	0.36
Main Entry Lobbie	5.0	0.06	10	11	0.11
Miscellaneous Spaces					
Bank Vault/Safe Deposit	5.0	0.06	5	17	0.09
Computer (not printing)	5.0	0.06	4	20	0.08
Pharmacy (prep area)	5.0	0.18	10	23	0.23
Photo Studios	5.0	0.12	10	17	0.17
Shipping/Receiving	-	0.12	-	-	0.12
Transportation Waiting	7.5	0.06	100	8	0.81
Warehouses	-	0.06	-	-	0.06
Public Assembly Spaces					
Auditorium Seating Area	5.0	0.06	150	5	0.81

(*Continued*)

MINIMUM VENTILATION RATES (*Continued*)

Occupancy Category	Outdoor Air Rate (1)		Default Values (2)		
	People CFM/Person	Area CFM/SF	Occupant Density People/1,000 SF	CFM per Person	CFM per SF
Places of Religious Worship	5.0	0.06	120	6	0.66
Courtrooms	5.0	0.06	70	6	0.41
Legislative Chambers	5.0	0.06	50	6	0.31
Libraries	5.0	0.12	10	17	0.17
Lobbies	5.0	0.06	150	5	0.81
Museums (children's)	7.5	0.12	40	11	0.42
Museums/Galleries	7.5	0.06	40	9	0.36
Retail					
Sales (except as below)	7.5	0.12	15	16	0.23
Mall Common Areas	7.5	0.06	40	9	0.36
Barber Shop	7.5	0.06	25	10	0.27
Beauty and Nail Salons	20.0	0.12	25	25	0.62
Pet Shops (animal areas)	7.5	0.18	10	26	0.26
Supermarkets	7.5	0.06	8	15	0.12
Coin-Operated Laundries	7.5	0.06	20	11	0.21
Sports And Entertainment					
Sports Arena (play areas)	-	0.30	-	-	0.30
Gym, Stadium (play area)	-	0.30	30	-	0.30
Spectator Areas	7.5	0.06	150	8	1.18
Swimming Pool (pool and decks)	-	0.48	-	-	0.48
Disco/Dance Floors	20.0	0.06	100	21	2.06
Health Club/Aerobics Rooms	20.0	0.06	40	22	0.86
Health Club/Weight Rooms	20.0	0.06	10	26	0.26
Bowling Alley (seating)	10.0	0.12	40	13	0.52
Gambling Casinos	7.5	0.18	120	9	1.08
Game Arcades	7.5	0.18	20	17	0.33
Sages, Studios	10.0	0.06	70	11	0.76
Healthcare Facilities					
Patient Rooms	25	-	10	25	-
Medical Procedure Rooms	15	-	20	15	-
Operating Rooms	30	-	20	30	-
Recovery and ICU	15	-	20	15	-
Autopsy Rooms	-	0.50	20	-	0.50
Physical Therapy	15	-	20	15	-

Residential Facilities (Single, Multiple)	
Living Rooms	0.35 AC/hr. 15 CFM/P whichever is greater
Kitchens	100 CFM Intermittent 25 CFM Continuous
Baths, Toilets	50 CFM Intermittent 20 CFM Continuous
Garages—separate for each dwelling unit	100 CFM per Car
Garages—common for several units	1.5 CFM/SF

Notes:

1 Outdoor air rates are based on no-smoking occupancies. Total outdoor air rate for the space is the sum of the people airflow rate and the area airflow rate. Airflow rates based on the net occupiable space.

2 Default occupant densities should be used when occupancies are not known. Default outdoor air values are based on default occupancy density.

3 Outdoor air volumes must be corrected as follows:

V_{OZ} = $R_P P_Z + R_A A_Z$ Outdoor airflow for each zone.
V_{OZCOR} = V_{OZ}/E_Z Final step for Single Zone and 100 percent OA Systems.
V_{OS} = $V_{OZ1COR} + V_{OZ2COR} + \ldots$ Outdoor airflow for a multiple space system—sum of outdoor airflows for each zone.
Z_p = V_{OZCOR}/V_{PZ} Fraction of outside air for each zone—OA corrected divided by SA (worst-case zone used in selection of E_V).
V_{OSCOR} = V_{OS}/E_V Final step for Multiple Zone Systems.
V_{OZ} = Volume of outdoor air uncorrected.
V_{OACOR} = Volume of outdoor air corrected for ventilation effectiveness.
R_P = Outdoor airflow rate for people.
P_Z = People per zone.
R_A = Outdoor airflow rate per area.
A_Z = Area of the zone.
E_Z = Zone air distribution effectiveness factor from following table.
Z_p = Percentage of outside air for each zone—OA divided by SA
V_{PZ} = Supply airflow to the zone.
V_{OS} = Volume of outdoor air for a multiple space system.
V_{OSCOR} = Volume of outdoor air for a multiple space system corrected.

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. Note: 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 opposite side of the room from the exhaust and/or return.	0.8
Makeup supply drawn in near to the exhaust and/or return location.	0.5

System Ventilation Efficiency Table	
Max ZP Zone with Max % OA	E_V
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6
>0.55	See ASHRAE Standard

4. Occupancy schedule by time of day and CO_2 sensors may be used to reduce the outdoor airflow below minimums calculated using the procedure above.

MINIMUM EXHAUST RATES

Occupancy Category	Exhaust Rate		Comments
	CFM/Unit	CFM/SF	
Art Classrooms	-	0.70	
Auto Repair Rooms	-	1.50	Engine exhaust should be provided separately.
Barber Shop	-	0.50	
Beauty Shop and Nail Salons	-	0.60	
Cell with Toilet	-	1.00	
Darkrooms	-	1.00	
Arena	-	0.50	Additional ventilation may be required in arenas where combustion equipment is expected.
Kitchen—commercial	-	0.70	
Kitchenettes	-	0.30	
Locker Rooms	-	0.50	
Locker/Dressing Rooms	-	0.25	
Parking Garages	-	0.75	Exhaust is not required if 50% of the sides are open.
Janitor, Trash, Recycle	-	1.00	
Pet Shops (animal areas)	-	0.90	
Copy, Printing Rooms	-	0.50	
Science Lab Classrooms	-	1.00	
Toilets—Public	50/70	-	Rate is per water closet or urinal. Provide higher rate where periods of heavy use are expected (theaters, schools, sports facilities). Use lower rate where use is intermittent.
Toilets—Private	25/50	-	Single occupancy toilets. Lower rate is for continuous operation; higher rate is for intermittent operation.
Woodwork Shop/Classroom	-	0.50	

A. *ASHRAE Standard 62.1-2004* Return Air, Transfer Air, or Exhaust Air Classifications

1. 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:
   a. Offices.
   b. Reception/waiting areas.
   c. Telephone/data entry.
   d. Lobbies.
   e. Conference/meeting rooms.
   f. Corridors.
   g. Storage rooms.
   h. Break rooms.
   i. Coffee stations.
   j. Equipment rooms.
   k. Mechanical rooms.
   l. Electrical/telephone closets.
   m. Elevator machine rooms.
   n. Laundry rooms within dwelling units.
   o. Sports arena.
   p. Correctional facility day room and guard station.
   q. Educational facilities: classrooms, lecture classrooms, lecture halls, computer lab, media center, music/theater/dance studios, multiuse assembly.
   r. Hotels, motels, resorts, dormitories: bedrooms, living rooms, barracks, sleeping quarters, lobbies, prefunction spaces, multipurpose assembly.

s. Computer rooms.
t. Photo studios.
u. Shipping/receiving rooms.
v. Transportation waiting rooms.
w. Public assembly spaces: auditorium seating area, places of religious worship, courtrooms, legislative chambers, libraries, lobbies, museums/galleries (all types).
x. Mall common areas.
y. Supermarkets.
z. Sports and entertainment: sports arena (play area), spectator areas, disco/dance floors, bowling alleys, gambling casinos, game arcades, stages, studios.

2. 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. This includes:
   a. Kitchens (commercial) and kitchenettes.
   b. Toilet/bath rooms (public and private).
   c. Locker rooms.
   d. Locker/dressing rooms.
   e. Central laundry rooms.
   f. Science laboratories.
   g. University and college laboratories.
   h. Art classrooms.
   i. Retail sales areas.
   j. Barber shops.
   k. Beauty and nail salons.
   l. Prison cells with toilets.
   m. Darkrooms.
   n. Pet shops (animal areas).
   o. Copy printing rooms.
   p. Wood/metal shop classrooms.
   q. Correctional facility booking/waiting areas.
   r. Food and beverage services: restaurant dining rooms, cafeterias, fast food establishments, bars, cocktail lounges.
   s. Bank vaults/safe deposit vaults.
   t. Pharmacy preparation areas.
   u. Warehouses.
   v. Coin-operated laundries.
   w. Gym/stadium (play areas).
   x. Swimming pools and decks.
   y. Health club/aerobics rooms.
   z. Health club/weight rooms.
3. 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:
   a. Commercial kitchen hoods other than grease hoods.
   b. Residential kitchen vented hoods.
   c. Refrigeration machinery rooms.
   d. Boiler rooms.
   e. Soiled laundry storage areas.
   f. Janitor closets.
   g. Trash/recycle rooms.
   h. General chemical/biological laboratories.
   i. Daycare sick rooms.

4. Class 4: Air with highly objectionable fumes or gases or with potentially dangerous particle, 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:
   a. Commercial kitchen grease hoods.
   b. Laboratory hoods.
   c. Paint spray booths.
   d. Diazo printing equipment discharges.
   e. Chemical storage rooms.
   f. Auto repair rooms.
   g. Parking garages.

B. *ASHRAE Standard 62.2-2004*

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

Floor Area Square Feet	Number of Bedrooms				
	0–1	2–3	4–5	6–7	>7
<1,500	30	45	60	75	90
1,501–3,000	45	60	75	90	105
3,001–4,500	60	75	90	105	120
4,501–6,000	75	90	105	120	135
6,001–7,500	90	105	120	135	150
>7,500	105	120	135	150	165

Notes:

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

Q_{OA} $= 0.01 \times A_{FLOOR} + 7.5 \times (N_{BR}\ 1\ 1)$

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/hr.
    2. Bathroom: 20 CFM.

B. 2006 *Guidelines for Design and Construction of Health Care Facilities*—AIA Committee on Architecture for Health and U.S. Department of Health and Human Services

Area Designation	Pressure Relationship	Minimum OA AC/hr.	Minimum Total AC/hr.	All Air Exhaust to Outdoors
Nursing Units				
Patient Rooms	0	2	6	-
Toilet Rooms	Neg	-	10	Yes
Newborn Nursery Suites	0	2	6	-
Protective Environment Rooms (PERs)	Pos	2	12	-
PER Alcove or Anterooms	Pos	-	10	Yes
Isolation Rooms (IRs)	Neg	2	12	Yes
(IR) Alcove or Anterooms	Neg	-	10	Yes
Patient Corridors	0	-	2	-

(*Continued*)

Area Designation	Pressure Relationship	Minimum OA AC/hr.	Minimum Total AC/hr.	All Air Exhaust to Outdoors
Obstetrical Facilities				
Delivery Rooms	Pos	3	15	-
Labor/Delivery/Recovery	-	2	6	-
Labor/Delivery/Recovery/Postpartum	-	2	6	-
Emergency, Surgery, and Critical Care				
Operating/Surgical Cystoscopic Rooms	Pos	3	15	-
Recovery Rooms	0	2	6	-
Critical and Intensive Care	0	2	6	-
Intermediate Care	0	2	6	-
Newborn Intensive Care	0	2	6	-
Treatment Rooms	0	-	6	-
Trauma Rooms	Pos	3	15	-
Bronchoscopy	Neg	2	12	Yes
Triage	Neg	2	12	Yes
ER Waiting Rooms	Neg	2	12	Yes
Procedure Rooms	Pos	3	15	-
Laser Eye Rooms	Pos	3	15	-
X-Ray (Surgical/Critical Care and Catheterization)	Pos	3	15	-
Anesthesia Gas Storage	Neg	-	8	Yes
Support Areas				
Medication Rooms	Pos	-	4	-
Clean Workrooms or Clean Holding	Pos	-	4	-
Soiled Workrooms or Soiled Holding	Neg	-	10	Yes
Diagnostic and Treatment Areas				
Examination Rooms	0	-	6	-
Treatment Rooms	0	-	6	-
Physical Therapy and Hydrotherapy	Neg	-	6	-
Gastrointestinal Endoscopy Rooms	0	2	6	-
Endoscopic Instrument Processing Rooms	Neg	-	10	Yes
Imaging: X-Ray (Diagnostic and Treatment)	0	-	6	-
Imaging: Darkrooms	Neg	-	10	Yes
Imaging: Waiting Rooms	Neg	2	12	Yes
Laboratory: General	0	-	6	-
Laboratory: Biochemistry	Neg	-	6	Yes
Laboratory: Cytology	Neg	-	6	Yes
Laboratory: Glass Washing	Neg	-	10	Yes
Laboratory: Histology	Neg	-	6	Yes
Laboratory: Microbiology	Neg	-	6	Yes
Laboratory: Nuclear Medicine	Neg	-	6	Yes
Laboratory: Pathology	Neg	-	6	Yes
Laboratory: Serology	Neg	-	6	Yes
Laboratory: Sterilizing	Neg	-	10	Yes
Autopsy Rooms	Neg	-	12	Yes
Non-Refrigerated Body-Holding Rooms	Neg	-	10	Yes
Service Areas				
Pharmacies	Pos	-	4	-
Food Preparation Centers	0	-	10	-

(*Continued*)

Area Designation	Pressure Relationship	Minimum OA AC/hr.	Minimum Total AC/hr.	All Air Exhaust to Outdoors
Warewashing	Neg	-	10	Yes
Dietary Day Storage	Neg	-	2	-
Laundry, General	0	-	10	Yes
Soiled Linen (Sorting and Storage)	Neg	-	10	Yes
Clean Linen Storage	Pos	-	2	-
Soiled Linen and Trash Chute Rooms	Neg	-	10	Yes
Bedpan Rooms	Neg	-	10	Yes
Bathrooms	Neg	-	10	-
Housekeeping Rooms	Neg	-	10	Yes
Sterilizing and Supply				
ETO Sterilizer Rooms	Neg	-	10	Yes
Sterilizer Equipment Rooms	Neg	-	10	Yes
Central Medical and Surgical Supply: Soiled or Decontamination Rooms	Neg	-	6	Yes
Central Medical and Surgical Supply: Clean Workrooms	Pos	-	4	-
Central Medical and Surgical Supply: Sterile Storage	Pos	-	4	-

Notes:
1 Pos = Positive Pressure Relationship
2 Neg = Negative Pressure Relationship
3 0 = Neutral Pressure Relationship

8.02 Enclosed Parking Garages

A. 2003 IMC and 2006 IMC

1. Ventilation rates:
   a. Minimum: 0.05 CFM/SF.
   b. Design: 1.5 CFM/SF.
2. Mechanical ventilation systems may reduce the 1.5 CFM/SF ventilation requirement when the system operates automatically upon detection of a concentration of CO of 25 ppm by approved automatic detection devices.

B. Enclosed Parking Garage Design Recommendations

1. Exhaust 1.5 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 1.5 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 CO detection system. Note that the minimum garage ventilation rate is only 4 percent of the design airflow (0.05 CFM/SF divided by 1.5 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.

8.03 Outside Air Intake and Exhaust Locations

A. 2003 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 from any hazardous or noxious contaminant (plumbing vents, chimneys, vents, stacks, alleys, streets, parking lots, loading docks). When within 10 feet, intake must be a minimum of 2 feet below any source of contaminant.
3. Exhausts—shall not create a nuisance or be directed onto walkways.
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. 2006 IMC

1. Requirements are the same as the 2003 IMC, except the distances are indicated to be measured horizontally and as indicated in the following.
2. The exhaust from a bathroom or kitchen in a residential dwelling shall not be considered to be a hazardous or noxious contaminant.

C. NFPA 90A

1. Outside air intakes shall be located to avoid drawing in combustible material or flammable vapor.
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.

D. ASHRAE Standard 62.1-2004—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. Vents, chimneys, flues, and other combustion appliance discharge: 15 feet.
4. Garage entry, automobile loading area, drive-in queue: 15 feet.
5. Truck loading area or dock, bus parking idling area: 25 feet.
6. Driveway, street, or parking area: 5 feet.
7. Street or thoroughfare with high traffic volume: 25 feet.
8. Roof, landscaped grade or other surface directly below intake: 1 foot (or expected average snow depth, whichever is greater).
9. Garbage storage/pickup area, dumpsters: 15 feet.
10. Cooling tower intake or basin: 15 feet.
11. Cooling tower exhaust: 25 feet.

12. Class 1 air: 10 feet (the author's interpretation of Class 1 air).
13. Class 2 air: 15 feet (the author's interpretation of Class 2 air).
14. Class 3 air: 15 feet (see item number 1 preceding the definition of Class 3 air).
15. Class 4 air: 30 feet (see item number 2 preceding the definition of Class 4 air).

E. *2006 Guidelines for Design and Construction of Health CareFacilities*—AIA Committee on Architecture for Health and U.S. Department of Health and Human Services

1. Fresh air intakes shall be located at least 25 feet from 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. Plumbing and vacuum vents that terminate at a level above the top of the air intake may be as close as 10 feet.
3. 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.
4. Relief air is exempt from the 25 foot separation requirement. Relief air is designed 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.
5. Exhaust outlets from areas that may be contaminated shall be above roof level and arranged to minimize recirculation of exhaust air into the building.
6. The bottom air supply, return, and exhaust air distribution devices shall be at least 3 inches above the floor.

8.04 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. CO_2 Levels and IAQ

1. Outdoor background level: 350 PPM CO_2 avg.
2. *ASHRAE Standard 62* recommends: 1000 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.

8.05 Effects of Carbon Monoxide

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

Hours of Exposure	Concentration of Carbon Monoxide in PPM ±		
	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 prescribed by OSHA
400 PPM	1–2 hours	Frontal headaches
	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).

8.06 Toilet Rooms

A. *ASHRAE Standard 62-2001:* 50 CFM/Water Closet and Urinal

B. *2003IMC:* 75 CFM/Water Closet and Urinal

C. 2006 IMC: 75 CFM/Water Closet and Urinal

D. Recommended Design Requirements

1. 2.0 CFM/sq.ft.
2. 10 AC/hr.
3. 100 CFM/water closet and urinal.
4. Toilet room ventilation:
   a. For toilet rooms with high fixture densities (stadiums, auditoriums), the 75 CFM/water closet and urinal dictates.
   b. For toilet rooms with ceiling heights over 12 feet, the 10 AC/hr. 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/hr. recommended airflow requirements.

8.07 Electrical Rooms

A. Recommended Minimum Ventilation Rate

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

8.08 Mechanical Rooms

A. Recommended Minimum Ventilation Rate

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

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 = 34,500 Btuh.

D. Chiller Rooms—*ASHRAE Standard 15-2001*

1. See *ASHRAE Standard 15-2001* 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 refrigerating systems and heat pumps used in institutional, public assembly, residential, commercial, industrial, and mixed-use occupancies, and to parts and components added after adoption of this code.
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	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 occupied space and one type of occupancy (institutional, public assembly, residential, commercial, 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 systems, piping, and associated appurtenances shall not be installed in or on stairways, stair landings, entrances, or exits.
   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 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 (except Group A1) 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.
   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 placed in exits, lobbies, or stairways, except where such refrigerant piping may pass across an exit if there are no joints in the section in the exit.
   f. Refrigerant piping shall not be installed vertically through floors from one story to another except as follow:
      1) Basement to first floor, top floor to mechanical equipment penthouse or roof.
      2) For the purpose of interconnecting separate pieces of equipment. 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.

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, and tight fitting. No other openings shall be permitted in equipment rooms (except doors) that will permit passage of refrigerant to other part of the building.
   d. Refrigeration equipment rooms require a refrigerant detector located in the equipment room 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.
   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 Part 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.
   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-718, or ammonia is used.
   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 air 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 have a separate switch 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*.

8.09 Combustion Air

A. 2003 IMC and 2006 IMC

1. Inside air:
   a. Building cannot be of unusually tight construction.
   b. Room or space with fuel-burning appliance must be an unconfined space.
   c. If air is used from adjacent spaces:
      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) Opening size: The net free area of each opening shall be equal to 1.0 square inch for each 1,000 Btu/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room), 100 square inches minimum.
2. Outdoor air:
   a. 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.
   b. Direct opening size: The net free area of each opening shall be equal to 1.0 square inch for each 4,000 Btu/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
   c. Horizontal duct opening size: The net free area of each opening shall be equal to 1.0 square inch for each 2,000 Btu/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
   d. Vertical opening size: The net free area of each opening shall be equal to 1.0 square inch for each 4,000 Btu/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
3. Forced combustion air supply:
   a. Where combustion air is provided by mechanical means, the system shall deliver a minimum of 1.0 CFM per 2,400 Btu/hr. (0.42 CFM per 1,000 Btu/hr.) of the combined fuel appliance input rating (the sum of all appliances within the room).
   b. Appliances shall be interlocked with the makeup air unit to prevent operation if the makeup air unit is not operating.
4. Direct connection (sealed combustion):
   a. Appliances must be listed and labeled for the direct combustion air connection.
   b. Appliances must be installed in accordance with the manufacturers' installation instructions.
5. Combustion air ducts:
   a. Galvanized steel construction.
   b. Minimum cross-sectional dimension of 3 inches.
   c. Unobstructed termination.
   d. Same cross-sectional area as free area of the openings.
   e. Sever a single appliance enclosure.

f. Separate ducts must be provided for the upper and lower combustion air openings from source to discharge.
g. Ducts, serving the upper combustion air opening, cannot slope downward toward the source of combustion air.

6. 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.

B. 2003 IFGC, 2006 IFGC, and *NFPA 54—2006 National Fuel Gas Code*

1. Inside air:
   a. Minimum required space volume: 50 ft.^{3} per 1,000 Btu/hr. 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/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room), 100 square inches minimum.
   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/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room), 100 square inches minimum.
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/hr. 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/hr. 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/hr. 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/hr. of the combined fuel-burning appliance input rating (the sum of all appliances within the room).
3. 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/hr. 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.
4. Direct connection:
   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.

5. Combustion air ducts:
   a. Galvanized steel construction.
   b. Minimum cross-sectional dimension of 3 inches.
   c. Unobstructed termination.
   d. Same cross-sectional area as the free area of the openings.
   e. Serves a single appliance enclosure.
   f. Separate ducts must be provided for the upper and lower combustion air openings from source to discharge.
   g. Ducts that serve the upper combustion air opening cannot slope downward toward the source of the combustion air.
   h. The bottom of the combustion air opening shall be a minimum of 12 inches above grade.
6. 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.

8.08 Hazardous Locations

A. Hazardous location requirements for electrical and electronic equipment are defined in the *2005 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, or 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 four 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 chemical.
   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 must 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. Nonicendive 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 design 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	X	X	X	X
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	X	X	X
Dust-Ignition-Proof Equipment	N/A	N/A	X	X	X	X
Dust-Tight 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:
1 X = Appropriate to the classification.
2 N/A = Not acceptable to the classification.

A. 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 assure that the 25 percent LFL/LEL is not exceeded.

B. 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 Class 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.

PART 9

Humidification Rules of Thumb

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.

9.02 Proper Vapor Barriers

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.

9.03 Human Comfort

A. 30–60 percent RH

9.04 Electrical Equipment, Computers

A. 35–55 percent RH

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

9.06 Optimum Relative Humidity Ranges for Health

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%

Notes:
1 **Insufficient data above 50 percent RH.**

9.07 Moisture Condensation on Glass

A. The subsequent moisture condensation tables are based on the following:

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

B. 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.

Temp. Room °F	Temp. Outside °F	Single Pane Glass		Double Pane Glass		Triple Pane Glass	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
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

(*Continued*)

Temp. Room °F	Temp. Outside °F	Single Pane Glass		Double Pane Glass		Triple Pane Glass	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
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	5.7	8.0	36.3	32.0	44.7	44.5
	–10	9.4	9.7	38.2	34.5	46.1	46.9
	–5	13.1	11.6	40.1	37.2	47.4	49.3
	0	16.9	13.8	41.9	39.9	48.8	52.0
	5	20.6	16.4	43.8	43.0	50.1	54.6
	10	24.4	19.4	45.7	46.2	51.5	57.5
	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	21.7	48.8	48.6	54.3	59.5
	20	32.3	25.3	50.7	52.1	55.7	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

(*Continued*)

Temp. Room ºF	Temp. Outside ºF	Single Pane Glass		Double Pane Glass		Triple Pane Glass	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
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
	–5	14.4	10.4	43.2	35.4	51.1	47.8
	0	18.1	12.3	45.1	38.1	52.4	50.1
	5	21.9	14.6	46.9	40.8	53.8	52.8
	10	25.6	17.2	48.8	43.8	55.1	55.3
	15	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

(*Continued*)

Temp. Room °F	Temp. Outside °F	Single Pane Glass		Double Pane Glass		Triple Pane Glass	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
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
	5	22.4	14.0	48.2	40.1	55.2	51.9
	10	26.1	16.4	50.1	43.0	56.6	54.6
	15	29.9	19.3	51.9	46.0	58.0	57.5
	20	33.6	22.6	53.8	49.3	59.3	60.2
	25	37.3	26.2	55.7	52.9	60.7	63.3
	30	41.1	30.5	57.5	56.4	62.0	66.2
	35	44.8	35.2	59.4	60.4	63.4	69.6
	40	48.6	40.7	61.3	64.6	64.8	73.1
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	45.3	33.6	60.7	59.2	64.8	68.3
	40	49.1	38.8	62.5	63.1	66.2	71.7
77	–30	–3.0	3.6	37.0	24.4	47.9	35.8
	–25	0.7	4.4	38.8	25.2	49.3	37.8
	–20	4.4	5.3	40.7	27.2	50.6	39.7
	–15	8.2	6.5	42.6	29.3	52.0	41.8
	–10	11.9	7.8	44.5	31.5	53.3	43.8
	–5	15.7	9.3	46.3	33.7	54.7	46.1
	0	19.4	11.1	48.2	36.3	56.1	48.6
	5	23.1	13.0	50.1	38.9	57.4	50.9
	10	26.9	15.4	51.9	41.6	58.8	53.5
	15	30.6	18.0	53.8	44.6	60.1	56.0
	20	34.4	21.1	55.7	47.9	61.5	58.9
	25	38.1	24.5	57.6	51.3	62.9	61.9
	30	41.8	28.4	59.4	54.7	64.2	64.7
	35	45.6	32.8	61.3	58.5	65.6	68.0
	40	49.3	37.8	63.2	62.5	66.9	71.1

(*Continued*)

Temp. Room ºF	Temp. Outside ºF	Single Pane Glass		Double Pane Glass		Triple Pane Glass	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
78	–30	–2.8	3.5	37.6	23.2	48.6	35.6
	–25	0.9	4.3	39.5	25.1	50.0	37.5
	–20	4.7	5.3	41.3	26.9	51.3	39.4
	–15	8.4	6.3	43.2	29.0	52.7	41.5
	–10	12.2	7.6	45.1	31.2	54.1	43.7
	–5	15.9	9.1	47.0	33.5	55.4	45.8
	0	19.7	10.8	48.8	35.9	56.8	48.2
	5	23.4	12.8	50.7	38.5	58.1	50.5
	10	27.1	15.0	52.6	41.3	59.5	53.1
	15	30.9	17.7	54.4	44.2	60.9	55.8
	20	34.6	20.6	56.3	47.3	62.2	58.4
	25	38.4	24.0	58.2	50.7	63.6	61.3
	30	42.1	27.8	60.0	54.0	64.9	64.2
	35	45.8	32.0	61.9	57.8	66.3	67.4
	40	49.6	37.0	63.8	61.8	67.7	70.7
79	–30	–2.5	3.5	38.2	23.0	49.4	35.5
	–25	1.2	4.2	40.1	24.8	50.7	37.3
	–20	4.9	5.1	42.0	26.8	52.1	39.3
	–15	8.7	6.2	43.8	28.7	53.4	41.2
	–10	12.4	7.5	45.7	30.9	54.8	43.4
	–5	16.2	8.9	47.6	33.2	56.2	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	14.7	53.2	40.9	60.2	52.7
	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

PART 10

People/Occupancy Rules of Thumb

10.01 Offices, Commercial

A. General	80–150 sq.ft./person
B. Private	One, Two, or Three People
C. Private	100–150 sq.ft./person
D. Conference, Meeting Rooms	20–50 sq.ft./person

10.02 Banks, Court Houses, Municipal Buildings, Town Halls

A. 50–150 sq.ft./person

10.03 Police Stations, Fire Stations, Post Offices

A. 100–500 sq.ft./person

10.04 Precision Manufacturing

A. 100–300 sq.ft./person

10.05 Computer Rooms

A. 80–150 sq.ft./person

10.06 Restaurants

A. 150–50 sq.ft./person

10.07 Kitchens

A. 50–150 sq.ft./person

10.08 Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

A. 15–50 sq.ft./person

10.09 Hospital Patient Rooms, Nursing Home Patient Rooms

A. 80–150 sq.ft./person

10.10 Hospital General Areas

A. 50–150 sq.ft./person

10.11 Medical/Dental Centers, Clinics, and Offices

A. 50–150 sq.ft./person

10.12 Residential

A. 200–600 sq.ft./person

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

A. 100–400 sq.ft./person

10.14 Motel and Hotel Public Spaces

A. 100–200 sq.ft./person

10.15 Motel and Hotel Guest Rooms, Dormitories

A. 100–200 sq.ft./person

10.16 School Classrooms

A. 20–30 sq.ft./person

10.17 Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

A. 10–50 sq.ft./person

10.18 Libraries, Museums

A. 30–100 sq.ft./person

10.19 Retail, Department Stores

A. 15–75 sq.ft./person

10.20 Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

A. 15–50 sq.ft./person

10.21 Supermarkets

A. 50–100 sq.ft./person

10.22 Malls, Shopping Centers

A. 50–100 sq.ft./person

10.23 Jails

A. 50–300 sq.ft./person

10.24 Auditoriums, Theaters

A. 5–20 sq.ft./person

10.25 Churches

A. 5–20 sq.ft./person

10.26 Bowling Alleys

A. 2–6 people/lane

Note: People/occupancy requirements should be determined from the architect, client, or as required by the building or mechanical codes whenever possible.

10.27 2003 IMC, 2006 IMC, and ASHRAE Standard 62-2001

OCCUPANCY SCHEDULE

Occupancy Classification	Max. Occupant Load (1)	
	People per 1,000 SF	SF/Person
Correctional Facilities		
Cells without Plumbing Fixtures	20	50
Cells with Plumbing Fixtures	20	50
Dining Halls	100	10
Guard Stations	40	25
Dry Cleaners, Laundries		
Coin-Operated Dry Cleaners	20	50
Coin-Operated Laundries	20	50
Commercial Dry Cleaners	30	33
Commercial Laundry Shops	10	100
Storage, Pick-up	30	33
Education		
Auditoriums	150	6
Classrooms	50	20
Corridors	-	-
Laboratories	30	33
Libraries	20	50
Locker Rooms	-	-
Music Rooms	50	20
Smoking Lounges	70	14
Training Shops	30	33
Food and Beverage Service		
Bars, Cocktail Lounges	100	10
Cafeteria, Fast Food	100	10
Dining Rooms	70	14
Kitchens (cooking)	20	50

(*Continued*)

OCCUPANCY SCHEDULE (*Continued*)

Occupancy Classification	Max. Occupant Load (1)	
	People per 1,000 SF	SF/Person
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	20	50
Hotels, Motels, Resorts, and Dormitories		
Assembly Rooms	120	8
Bathrooms	-	-
Bedrooms	-	-
Conference Rooms	50	20
Dormitory Sleeping Areas	20	50
Gambling Casinos	120	8
Living Rooms	-	
Lobbies	30	33
Offices		
Conference Rooms	50	20
Office Spaces	7	143
Reception Areas	60	17
Telecommunication Centers and Data Entry	60	17
Private Dwellings (Single and Multiple)		
Living Areas	(4)	-
Kitchens	-	-
Toilet Rooms and Bathrooms	-	-
Garages (Separate for Each Dwelling)	-	-
Garages (Common for Multiple Units)	-	-
Public Spaces		
Corridors and Utilities	-	-
Elevators, ***Elevator Cars***	-	-
Locker Rooms, **Dressing Rooms**	-	-
Toilet Rooms, **Public Restrooms**	-	-
Shower Rooms (per Shower Head)	-	-
Smoking Lounges	70	14
Retail Stores, Sales Floors, and Show Room Floors		
Basement and Street Levels	- **30**	- **33**
Dressing Rooms	-	-
Malls and Arcades	- **20**	- **50**
Shipping and Receiving	- **10**	- **100**
Smoking Lounges	70	14
Storage Rooms	- **15**	- **66**
Upper Floors	- **20**	- **50**
Warehouses	- **5**	- **200**
Specialty Shops		
Automotive Service Stations, ***Automotive Motor-Fuel Dispensing Stations*** (5)	-	-
Barber Shops	25	40
Beauty Shops	25	40

(*Continued*)

OCCUPANCY SCHEDULE (*CONTINUED*)

Occupancy Classification	Max. Occupant Load (1)	
	People per 1,000 SF	SF/Person
Clothiers, Furniture Stores	-	-
Embalming Room (5)	-	-
Florists	8	125
Hardware, Drugs, Fabrics	8	125
Nail Salons (5)	-	-
Pet Shops	-	-
Reducing Salons	20	50
Supermarkets	8	125
Sports and Amusement		
Ballrooms and Discos	100	10
Bowling Alleys (Seating Areas)	70	14
Game Rooms	70	14
Ice Arenas	-	-
Playing Floors, Gymnasiums	30	33
Spectator Areas	150	6
Swimming Pools (Pool and Deck Areas)	-	-
Storage		
Repair Garages, Enclosed Parking Garages	-	-
Warehouses	- **<u>5</u>**	- **<u>200</u>**
Theaters		
Auditoriums	150	6
Lobbies	150	6
Stages, Studios	70	14
Ticket Booths	60	16
Transportation		
Platforms	100	10
Vehicles	150	6
Waiting Rooms	100	10
Workrooms		
Bank Vaults	5	200
Darkrooms	- **<u>10</u>**	- **<u>100</u>**
Duplicating, Printing Areas	-	-
Meat Processing Areas	10	100
Pharmacies	20	50
Photo Studios	10	100

Notes:

1 **Maximum occupant load is based on the net floor area.**
2 **Bold and italicized items are 2006 IMC changes.**
3 **Bold and underlined items are ASHRAE Standard 62-2001 changes.**
4 **Based on the number of bedrooms: First bedroom, two people; each additional bedroom, one person.**
5 **This category is not in ASHRAE Standard 62-2001.**

10.28 ASHRAE Standard 62-2004

OCCUPANCY SCHEDULE

Occupancy Category	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Correctional Facilities		
Cells	25	40
Day Rooms	30	33
Guard Stations	15	67
Booking/Waiting	50	20
Educational Facilities		
Daycare (through age 4)	25	40
Classrooms (ages 5–8)	25	40
Classrooms (ages 9 plus)	35	28
Lecture Classrooms	65	15
Lecture Halls (Fixed Seats)	150	6
Art Classrooms	20	50
Science Laboratories	25	40
Wood/Metal Shops	20	50
Computer Labs	25	40
Media Centers	25	40
Music/Theater/Dance	35	28
Multiuse Assembly	100	10
Food and Beverage Service		
Restaurant Dining Rooms	70	14
Cafeterias/Fast Food	100	10
Bars/Cocktail Lounges	100	10
General		
Conference/Meeting Rooms	50	20
Corridors	-	-
Storage Rooms	-	-
Hotel, Motels, Resorts, Dormitories		
Bedrooms/Living Rooms	10	100
Barracks Sleeping Areas	20	50
Lobbies/Prefunction	30	22
Multipurpose Assembly Rooms	120	8
Office Buildings		
Office Space	5	200
Reception Areas	30	33
Telephone/Data Entry	60	17
Main Entry Lobbies	10	100
Miscellaneous Spaces		
Bank Vaults/Safe Deposits	5	200
Computers (Not Printing)	4	250
Pharmacies (Prep Area)	10	100
Photo Studios	10	100
Shipping/Receiving	-	-
Transportation Waiting	100	10
Warehouses	-	-
Public Assembly Spaces		
Auditorium Seating Areas	150	6
Places of Religious Worship	120	8

(*Continued*)

OCCUPANCY SCHEDULE (*Continued*)

Occupancy Category	Max. Occupant Load	
	People per 1,000 SF	SF/Person
Courtrooms	70	14
Legislative Chambers	50	20
Libraries	10	100
Lobbies	150	6
Museums (Children's)	40	25
Museums/Galleries	40	25
Retail		
Sales (except for the following)	15	67
Mall Common Areas	40	25
Barber Shops	25	40
Beauty and Nail Salons	25	40
Pet Shops (Animal Areas)	10	100
Supermarkets	8	125
Coin-Operated Laundries	20	50
Sports and Entertainment		
Sports Arena (Play Areas)	-	-
Gym, Stadium (Play Areas)	30	33
Spectator Areas	150	6
Swimming Pool (Pool and Decks)	-	-
Disco/Dance Floors	100	10
Health Club/Aerobics Rooms	40	25
Health Club/Weight Rooms	10	100
Bowling Alley (Seating)	40	25
Gambling Casinos	120	8
Game Arcades	20	50
Sages, Studios	70	14
Healthcare Facilities		
Patient Rooms	10	100
Medical Procedure Rooms	20	50
Operating Rooms	20	50
Recovery and ICU	20	50
Autopsy Rooms	20	50
Physical Therapy	20	50

PART 11

Lighting Rules of Thumb

11.01 Offices, Commercial

A. General	1.1 watts/sq.ft.
B. Private	1.1 watts/sq.ft.
C. Conference, Meeting Rooms	1.3 watts/sq.ft.

11.02 Banks, Court Houses, Municipal Buildings, Town Halls

A. 1.5 watts/sq.ft.

11.03 Police Stations, Fire Stations, Post Offices

A. 1.0 watts/sq.ft.

11.04 Precision Manufacturing

A. 2.1 watts/sq.ft.

11.05 Computer Rooms

A. 1.1 watts/sq.ft.

11.06 Restaurants

A. 1.5 watts/sq.ft.

11.07 Kitchens

A. 1.2 watts/sq.ft.

11.08 Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

A. 1.4 watts/sq.ft.

11.09 Hospital Patient Rooms, Nursing Home Patient Rooms

A. 0.7 watts/sq.ft.

11.10 Hospital General Areas

A. 1.0 watts/sq.ft.

11.11 Medical/Dental Centers, Clinics, and Offices

A. 1.0 watts/sq.ft.

11.12 Residential

A. 1.1 watts/sq.ft.

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

A. 1.1 watts/sq.ft.

11.14 Motel and Hotel Public Spaces

A. 1.1 watts/sq.ft.

11.15 Motel and Hotel Guest Rooms, Dormitories

A. 1.1 watts/sq.ft.

11.16 School Classrooms

A. 1.4 watts/sq.ft.

11.17 Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

A. 1.4 watts/sq.ft.

11.18 Libraries, Museums

A. 1.1 watts/sq.ft.

11.19 Retail, Department Stores

A. 1.5 watts/sq.ft.

11.20 Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

A. 1.5 watts/sq.ft.

11.21 Supermarkets

A. 1.5 watts/sq.ft.

11.22 Malls, Shopping Centers

A. 1.5 watts/sq.ft.

11.23 Jails

A. 1.3 watts/sq.ft.

11.24 Auditoriums, Theaters

A. 1.0 watts/sq.ft. (3)

11.25 Churches

A. 2.4 watts/sq.ft.

11.26 Bowling Alleys

A. 1.4 watts/sq.ft.

Notes:

1 The lighting values for most energy-conscious construction will be the lower values.
2 Actual lighting layouts should be used for calculating lighting loads whenever available.
3 Does not include theatrical lighting.

11.27 Code Lighting Power Level Requirements—Building Area Method

Building Area	Watts/Square Foot			
	2003 IECC	2006 IECC	ASHRAE 90.1-2001	ASHRAE 90.1-2004
Auditorium	1.8	-	-	-
Automotive Facility	0.9	0.9	1.5	0.9
Bank/Financial Institution	1.5	-	-	-
Classroom/Lecture Hall	1.4	-	-	-
Convention, Conference, or Meeting Center	1.3	1.2	1.4	1.2
Corridor, Restroom, Support Area	0.9	-	-	-
Courthouse	1.2	1.2	1.4	1.2
Dining-Bar, Lounge Leisure	0.9	1.3	1.5	1.3
Dining-Cafeteria, Fast Food	-	1.4	1.8	1.4
Dining-Family	-	1.6	1.9	1.6
Dormitory	1.0	1.0	1.5	1.0

(*Continued*)

Building Area	Watts/Square Foot			
	2003 IECC	2006 IECC	ASHRAE 90.1-2001	ASHRAE 90.1-2004
Exercise Center	0.9	1.0	1.4	1.0
Exhibition Hall	1.3	-	-	-
Grocery Store	1.6	-	-	-
Gymnasium Playing Surface	1.4	1.1	1.7	1.1
Hotel Function	1.3	1.0	1.7	1.0
Industrial Work, <20' Ceiling Height	1.2	-	-	-
Industrial Work, ≥20' Ceiling Height	1.7	-	-	-
Kitchen	1.2	-	-	-
Library	1.7	1.3	1.5	1.3
Lobby–Hotel	1.1	-	-	-
Lobby–Other	1.3	-	-	-
Mall, Arcade, or Atrium	0.6	-	-	-
Manufacturing Facility	-	1.3	2.2	1.3
Healthcare, Clinic	1.2	1.0	-	1.0
Medical or Clinical Care Hospital	-	1.2	1.6	1.2
Motel	1.0	1.0	2.0	1.0
Multifamily	0.7	0.7	1.0	0.7
Museum	1.0	1.1	1.6	1.1
Office	1.1	1.0	1.3	1.0
Parking Garage	0.3	0.3	0.3	0.3
Penitentiary	1.0	1.0	1.2	1.0
Police/Fire Station	1.0	1.0	1.3	1.0
Post Office	1.1	1.1	1.6	1.1
Religious Worship	2.4	1.3	2.2	1.3
Restaurant	0.9	-	-	-
Retail Sales, Wholesale Showroom	1.7	1.5	1.9	1.5
School, University	1.2	1.2	1.5	1.2
Sports Arena	-	1.1	1.5	1.1
Storage, Industrial and Commercial	0.8	-	-	-
Theater-Motion Picture	1.2	1.2	1.6	1.2
Theater-Performance	2.6	1.6	1.5	1.6
Town Hall	1.2	1.1	1.4	1.1
Transportation	1.0	1.0	1.2	1.0
Warehouse	-	0.8	1.2	0.8
Workshop	-	1.4	1.7	1.4
Other	1.0	-	-	-

11.28 Code Lighting Power Level Requirements—Space-by-Space Method

Common Space Type	Watts/Sq. Ft.	
	ASHRAE Std 90.1-2001	ASHRAE Std90.1-2004
Atrium-First Three Floors	1.3	0.6
Atrium-Each Additional Floor	0.2	0.2
Auditorium/Seating Area	-	0.9
For Gymnasium	0.5	0.4
For Exercise Center	0.5	0.3
For Convention Center	0.5	0.7
For Penitentiary	1.9	0.7
For Religious Buildings	3.2	1.7
For Sports Arena	0.5	0.4
For Performing Arts Theater	1.8	2.6
For Motion Picture Theater	1.3	1.2
For Transportation	1.0	0.5
Automotive-Service Repair	1.4	0.7
Bank/Office-Banking Activity Area	2.4	1.5
Classroom/Lecture/Training	1.6	1.4
For Penitentiary	1.4	1.3
Conference/Meeting/Multipurpose	1.5	1.3
Convention Center-Exhibit Space	3.3	1.3
Corridor/Transition	0.7	0.5
For Hospital	1.6	1.0
For Manufacturing Facility	0.5	0.5
Courthouse/Police Station/Penitentiary	-	-
Courtrooms	2.1	1.9
Confinement Cells	1.1	0.9
Judges Chambers	1.1	1.3
Dining Areas	1.4	0.9
For Penitentiary	1.4	1.3
For Hotel	1.0	1.3
For Motel	1.2	1.2
For Bar/Lounge/Leisure Dining	1.2	1.4
For Family Dining	2.2	2.1
Dormitory-Living Quarters	1.9	1.1
Dressing/Locker/Fitting Rooms	0.8	0.6
Electrical Rooms	1.3	1.5
Fire Stations	-	-
Fire Station Engine Rooms	0.9	0.8
Sleeping Quarters	1.1	0.3
Food Preparation	2.2	1.2
Gymnasium/Exercise Centers	-	-
Playing Area	1.9	1.4
Exercise Area	1.1	0.9

(Continued)

Common Space Type		Watts/Sq. Ft.	
		ASHRAE Std 90.1-2001	ASHRAE Std90.1-2004
Hospitals		-	-
	Emergency	2.8	2.7
	Exam/Treatment	1.6	1.5
	Laundry-Washing	0.7	0.6
	Medical Supply	3.0	1.4
	Nursery	1.0	0.6
	Nurses Station	1.8	1.0
	Operating Room	7.6	2.2
	Patient Room	1.2	0.7
	Pharmacy	2.3	1.2
	Physical Therapy	1.9	0.9
	Radiology	0.4	0.4
	Recovery	2.6	0.8
Hotel/Motel Guest Rooms		2.5	1.1
Laboratory		1.8	1.4
Library		-	-
	Card File and Cataloging	1.4	1.1
	Stacks	1.9	1.7
	Reading Area	1.8	1.2
Lobby		1.8	1.3
	For Hotel	1.7	1.1
	For Performing Arts Theater	1.2	3.3
	For Motion Picture Theater	0.8	1.1
Lounge/Recreation		1.4	1.2
	For Hospital	1.4	0.8
Manufacturing		-	-
	Low Bay < 25' Floor-to-Ceiling Height	2.1	1.2
	High Bay ≥ 25' Floor-to-Ceiling Height	3.0	1.7
	Detailed Manufacturing	6.2	2.1
	Equipment Room	0.8	1.2
	Control Room	0.5	0.5
Mechanical Rooms		1.3	1.5
Museum		-	-
	General Exhibition	1.6	1.0
	Restoration	2.5	1.7
Office		-	-
	Enclosed, Private Offices	1.5	1.1
	Open Office Plan	1.3	1.1
Parking Garage-Garage Area		-	0.2
	Parking Area Pedestrian	0.2	-
	Parking Area Attendant	0.1	-
Post Office-Sorting Area		1.7	1.2
Religious Buildings		-	-
	Worship Pulpit, Choir	5.2	2.4
	Fellowship Hall	2.3	0.9

(*Continued*)

Common Space Type		Watts/Sq. Ft.	
		ASHRAE Std 90.1-2001	ASHRAE Std90.1-2004
Restrooms		1.0	0.9
Retail		-	-
	Sales Area	2.1	1.7
	Mall Concourse	1.8	1.7
Sports Arena		-	-
	Ring Sports Arena	3.8	2.7
	Court Sports Arena	4.3	2.3
	Indoor Playing Field Area	1.9	1.4
Stairs		0.9	0.6
Storage–Active		1.1	0.8
	For Hospital	2.9	0.9
Storage–Inactive		0.3	0.3
	For Hospital	0.3	0.8
Transportation		-	-
	Airport–Concourse	0.7	0.6
	Air/Train/Bus-Baggage Area	1.3	1.0
	Terminal Ticket Counter	1.8	1.5
Warehouse		-	-
	Fine Material Storage	1.6	1.4
	Medium/Bulky Material Storage	1.1	0.9
Workshop		2.5	1.9

PART 12

Appliance/Equipment Rules of Thumb

12.01 Offices and Commercial Spaces

A. Total Appliance/Equipment Heat Gain 0.5–8.0 watts/sq.ft.

B. Computer equipment loads for office spaces range between 0.5 watts/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).

12.02 Computer Rooms, Data Centers, and Internet Host Sites

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

12.03 Telecommunication Rooms

A. 50.0–120.0 watts/sq.ft.

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 watt
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 amp	400 watts
10. Medium voltage starters size 400 amp	1,300 watts
11. Medium voltage starters size 700 amp	1,700 watts

F. Variable Frequency Drives

1. 2 to 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° 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° 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).

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

B. Motors and driven equipment are shown in the following table.

Motor Horsepower	The Location of Motor and Driven Equipment with Respect to a Conditioned Space or Airstream		
	Motor In, Driven Equipment In Btu/hr.	Motor Out, Driven Equipment In Btu/hr.	Motor In, Driven Equipment Out Btu/hr.
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
1-1/2	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
7-1/2	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.

PART 13

Cooling Load Factors

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.*

C. Floor/Zone Block Loads

1. People 0.90 × Sum of Peak Room/Space People Loads.
2. Lights 0.95 × Sum of Peak Room/Space Lighting Loads.
3. Equipment 0.90 × Sum of Peak Room/Space Equipment Loads.
4. Floor/Zone Total Loads 0.90 × Sum of Peak Room/Space Total Loads.

D. Building Block Loads

1. People 0.75 × Sum of Peak Room/Space People Loads.
2. Lighting 0.95 3 Sum of Peak Room/Space Lighting Loads.
3. Equipment 0.75 3 Sum of Peak Room/Space Equipment Loads.
4. Building Total Load 0.85 × Sum of Peak Room/Space Total Loads.

13.02 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.

13.03 Cooling Load Factors

A. Lighting Load Factors

1. Existing lighting fixtures
   a. Fluorescent lights 1.25 × Bulb Watts.
   b. Incandescent lights 1.00 × Bulb Watts.
   c. HID lighting 1.25 × Bulb Watts.
2. New lighting fixtures
   a. Fluorescent lights 0.85–1.15 × Bulb Watts.
   b. Incandescent lights 1.00 × Bulb Watts.
   c. HID lighting 0.85–1.15 × Bulb Watts.

*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.

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 × Lighting Load.
2. Heat of lights to RAP 0.24 × Lighting Load.
3. Heat of roof to space with RAP 0.30 × Roof Load.
4. Heat of roof to RAP 0.70 × Roof Load.

C. Ducted Exhaust or Return Air (DERA) Factors

1. Heat of lights to space with DERA 1.00 × Lighting Load.
2. Heat of roof to space with DERA 1.00 × Roof Load.

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

1. CLF × Other Loads.

PART 14

Heating Load Factors

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

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.

14.03 Heating System Selection Guidelines

A. If heat loss exceeds 450 Btu/hr. 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/hr. 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/hr. 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.

PART 15

Design Conditions and Energy Conservation

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).
   a. Abbreviations:
      1) db = dry bulb temperature.
      2) wb = wet bulb temperature.
      3) dp = dew point 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.

2005 ASHRAE Handbook - Fundamentals (IP) © 2005 ASHRAE, Inc.

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 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	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	9.8	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%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	8	9a	9b	9c	9d	9e	9f	10a	10b	10c	10d	10e	10f	11a	11b
7	18.9	89.1	72.5	86.2	70.9	83.6	69.3	74.9	85.0	73.3	82.5	71.9	80.3	10.3	240

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
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							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	14b	14c	15	16a	16b	16c	16d	17a	17b	17c	17d	17e	17f	17g	17h
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
	18a	18b	18c	18d	18e	18f	18g	18h	18i	18j	18k	18l
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	75.8	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	57.8

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

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

FIGURE 15.1

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		Heating	
	Temperature °F Dry Bulb	Humidity %RH	Temperature °F Dry Bulb	Humidity %RH
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	-
Storage	78	50	70	-
Garages—Open	-	-	-	-
Garages—Enclosed	-	-	50 (9)	-
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	45 ± 5
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	-
Retail Stores and Specialty Shops				
Malls and Arcades	75	50	70	-
Department Stores, Supermarkets, Showroom Floors, Clothiers, Furniture	75	50	70	-
Dressing Rooms	75	50	70	-
Shipping and Receiving	-	-	60	-

(Continued)

INDOOR DESIGN CONDITIONS (*Continued*)

Facility Type/Spaces (1)	Cooling		Heating	
	Temperature °F Dry Bulb	Humidity %RH	Temperature °F Dry Bulb	Humidity %RH
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	40 ± 5
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	-
Gymnasiums, Playing Floors	75	50	65	-
Swimming Pools, Natatoriums	75	50	70	-
Spectator Areas	75	50	70	-
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	45 ± 5
Computer Rooms, Data Centers, Internet Host Sites, Server Rooms, Demarc Rooms	70 ± 2	45 ± 5	70 ± 2	45 ± 5
High Tech	68 ± 2	45 ± 5	68 ± 2	45 ± 5
High Tech (low humidity)	68 ± 2	35 ± 5	68 ± 2	35 ± 5
Animal Research Rooms	68–84 ± 2	40–70 ± 5	68–84 ± 2	40–70 ± 5
Museums, Galleries, Rare Document Libraries, Archives	72 ± 2	40 ± 5	72 ± 2	40 ± 5
Hospital Nursing Units (2)				
Patient Rooms	75	50	70	-
Toilet Rooms	75	50	70	-
Newborn Nursery Suite	75	50	72	30
Protective Environment Room (PER)	75	50	70	-
PER Alcove or Anterooms	75	50	70	-
Isolation Room (IR)	75	50	70	-
(IR) Alcove or Anterooms	75	50	70	-
Patient Corridor	75	50	70	-

(*Continued*)

INDOOR DESIGN CONDITIONS (*Continued*)

Facility Type/Spaces (1)	Cooling		Heating	
	Temperature °F Dry Bulb	Humidity %RH	Temperature °F Dry Bulb	Humidity %RH
Obstetrical Facilities (2)				
Delivery Rooms	72	50	72	30
Labor/Delivery/Recovery	75	50	70	-
Labor/Delivery/Recovery/Postpartum	75	50	70	-
Emergency, Surgery, and Critical Care (2)				
Operating/Surgical/Cystoscopic Rooms	72 72 ± 2	50 45% ± 5	72 72 ± 2	30 45 ± 5
Cardiac Operating Rooms (3)	72 50	50 50	72 50	30 30
Recovery Rooms	75	50	72	30
Critical and Intensive Care	75 75 ± 2	50 45% ± 5	72 72 ± 2	30 45 ± 5
Intermediate Care	75	50	72	30
Newborn Intensive Care	75 75 ± 2	50 45% ± 5	72 72 ± 2	30 45 ± 5
Treatment Rooms	75	50	70	-
Trauma Rooms	75	50	72	30
Bronchoscopy	72	50	72	30
Triage	75	50	70	-
ER Waiting Rooms	75	50	70	-
Procedure Rooms	75	50	72	30
Laser Eye Rooms	75	50	72	30
X-Ray (Surgical/Critical Care and Catheterization)	75	50	72	30
Anesthesia Gas Storage	75	50	72	-
Hospital Facility Support Areas (2)				
Medication Rooms	75	50	72	-
Clean Workrooms or Clean Holding	75	50	72	-
Soiled Workrooms or Soiled Holding	75	50	72	-
Diagnostic and Treatment Areas (2)				
Examination Rooms	75	50	72	-
Treatment Rooms	75	50	72	-
Physical Therapy and Hydrotherapy	75	50	72	-
Gastrointestinal Endoscopy Rooms	72	50	72	30
Endoscopic Instrument Processing Rooms	75	50	72	-
Imaging: X-Ray (Diagnostic and Treatment)	75	50	75	-
Imaging: Darkrooms	75	50	72	-
Imaging: Waiting Rooms	75	50	72	-
Laboratory: General	75	50	75	-
Laboratory: Biochemistry	75	50	75	-
Laboratory: Cytology	75	50	75	-
Laboratory: Glass Washing	75	50	72	-
Laboratory: Histology	75	50	75	-
Laboratory: Microbiology	75	50	75	-
Laboratory: Nuclear Medicine	75	50	75	-
Laboratory: Pathology	75	50	75	-
Laboratory: Serology	75	50	75	-
Laboratory: Sterilizing	75	50	72	-
Autopsy Rooms	75	50	72	-
Nonrefrigerated Body-Holding Rooms	70	50	70	-
Hospital Service Areas (2)				
Pharmacy	70	50	70	-
Food Preparation Center	70	50	70	-
Warewashing	70	50	70	-
Dietary Day Storage	70	50	70	-
Laundry, General	70	50	70	-
Soiled Linen (Sorting and Storage)	70	50	70	-

(*Continued*)

INDOOR DESIGN CONDITIONS (*Continued*)

Facility Type/Spaces (1)		Cooling		Heating	
		Temperature °F Dry Bulb	Humidity %RH	Temperature °F Dry Bulb	Humidity %RH
	Clean Linen Storage	70	50	70	-
	Soiled Linen and Trash Chute Rooms	70	50	70	-
	Bedpan Rooms	70	50	70	-
	Bathrooms	75	50	75	-
	Housekeeping Rooms	70	50	70	-
Sterilizing and Supply (2)					
	ETO Sterilizer Rooms	75	50	75	30
	Sterilizer Equipment Rooms	70	50	70	-
	Central Medical & Surgical Supply: Soiled or Decontamination Rooms	72	50	72	-
	Central Medical and Surgical Supply: Clean Workrooms	75	50	75	30
	Central Medical and Surgical Supply: Sterile Storage	70	50	70	-

Notes:

1 Indoor design conditions are recommendations that may be used when owners of the facility used have no specific criteria. When codes, processes, or other criteria require different design conditions than those listed here, they should be used for design purposes.
2 2006 *Guidelines for Design and Construction of Health Care Facilities*—AIA Committee on Architecture for Health and U.S. Department of Health and Human Services provides ranges for some of the spaces. The temperatures listed in the table fall within the ranges established in the guidelines or they are design temperatures required for human comfort when not provided by the guideline. Some specialty procedures may require special temperatures and relative humidity levels. The hospital staff should be consulted to determine any special requirements.
3 Cardiac OR may require reduced temperatures for operating as low as 50°F.
4 With laboratories, computer facilities, high-tech industrial, special facilities, 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 only.
5 Some performances will require strict temperature and humidity control during the performance. Careful consideration must be given to the types of performances and their requirements when designing these facilities.
6 3D type theaters (IMAX and OMNIMAX) should be maintained at temperatures at or below 72°F because the incidents of motion sickness increase considerable above these temperatures.
7 Warehouse temperature and humidity requirements can vary considerably depending on the materials being stored.
8 Repair garages are generally not air conditioned. If air conditioning is desired, the cooling design temperature recommendation would be 80 to 85°F.
9 Heating parking garages is not recommended because minimum-code-required ventilation rates require heating of the makeup air for the heating to become effective.

15.02 General Energy Conservation Requirements

A. The major energy codes referenced by the 2003 International Building Code (2003 IBC) and the 2003 International Mechanical Code(2003 IMC) are:

1. 2003 International Energy Conservation Code (2003 IECC is based on and references ASHRAE Standard 90.1-2001).
2. ASHRAE Standard 90.1-2001.

B. The major energy codes referenced by the 2006 International Building Code (2006 IBC) and the 2006 International Mechanical Code(2006 IMC) are:

1. 2006 International Energy Conservation Code (2006 IECC is based on and references ASHRAE Standard 90.1-2004).
2. ASHRAE Standard 90.1-2004.

C. ASHRAE Standard 90.1-2001 and 2004 require 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. Emmissivity coatings.
4. Solar Heat Gain Coefficients (SHGCs).
5. Shading Coefficients (SCs).
6. Visible Light Transmittance (VT).
7. Condensation Resistance Ratings (CRs).

D. National Fenestration Rating Council Product Certification Program (NFRC PCP-2006 and NFRC PCP-2007)

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 manufacturer/responsible party 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 manufacturer/responsible party shall obtain for each product line to be authorized for certification a simulation report from an NFRC-accredited simulation laboratory."
   b. Paragraph 4.3.2.1.B reads "The manufacturer/responsible party 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 manufacturer/responsible party 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 manufacturer/responsible party shall obtain for each product line to be authorized for certification a simulation report from an NFRC-accredited simulation laboratory. The Testing Alternative procedure for these ratings is to be used only if the product cannot be simulated."

E. As can be seen in paragraphs 15.02.C and D, 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/(hr. 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.

Design Conditions and Energy Conservation

4. Maximum U-values must be specified and include the affects of the framing system.
   a. For example: Maximum U-values including the frame shall be 0.46 Btu/(hr. 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.

F. 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

<table>
<tr><td colspan="2">Architectural Building Envelope</td><td colspan="2">Mechanical HVAC</td><td>Plumbing Water Heating</td><td colspan="2">Electrical Lighting</td><td>Electrical Power/ Other</td></tr>
<tr><td colspan="2">Mandatory Requirements</td><td colspan="2">Mandatory Requirements</td><td>Mandatory Requirements</td><td colspan="2">Mandatory Requirements</td><td>Mandatory Requirements</td></tr>
<tr><td>Prescriptive Method</td><td>Building Envelope Trade-off Method</td><td>Simple Method</td><td>Prescriptive Method</td><td>Prescriptive Method</td><td>Space-by-Space Method</td><td>Overall Building Method</td><td>Prescriptive Method</td></tr>
</table>

G. 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

<table>
<tr><td>Architectural Building Envelope</td><td>Mechanical HVAC</td><td>Plumbing Water Heating</td><td>Electrical Lighting</td><td>Electrical Power/ Other</td></tr>
<tr><td>Mandatory Requirements</td><td>Mandatory Requirements</td><td>Mandatory Requirements</td><td>Mandatory Requirements</td><td>Mandatory Requirements</td></tr>
<tr><td colspan="5">Energy Cost Budget Method
“The Energy Model”</td></tr>
</table>

H. 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.

I. 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.

J. 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.

K. 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.

15.03 2003 IECC

A. Scope and Intent

1. Minimum prescriptive and performance requirements for building energy conservation.
2. Applicable buildings:
   a. Public assembly.
   b. Education.
   c. Business.
   d. Mercantile.
   e. Institutional.
   f. Storage.
   g. Residential.
   h. Industrial–portions primarily used for human occupancy.
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 to negate safety, health, or environmental requirements of building design and construction.

B. Design Conditions

1. The United States is categorized into 19 climate zones with Climate Zone 1 at the tip of Florida, and Climate Zone 19 in Alaska.
2. Outdoor design conditions–2001 ASHRAE Handbook of Fundamentals:
   a. Winter: 97-1/2% values.
   b. Summer: 2-1/2% values.
3. Residential indoor design conditions:
   a. Heating: 68°F.
   b. Cooling: 78°F.

C. Residential Energy Efficiency–Mandatory Requirements

1. Minimum HAVC equipment efficiencies:
   a. Heat pumps (heating mode)—split systems: 6.8 HSPF.
   b. Heat pumps (heating mode)—packaged: 6.6 HSPF.

   c. Gas/oil furnace (<225,000 Btu./hr.): AFUE 78%.
   d. Gas/oil furnace (<300,000 Btu./hr.): AFUE 80%.
   e. Air conditioners/heat pumps (cooling mode)—split systems: 10.0 SEER.
   f. Air conditioners/heat pumps (cooling mode)—packaged: 9.7 SEER.
2. Duct insulation: See Part 35.
3. Pipe insulation: See Part 35.
4. HVAC controls:
   a. Each heating and cooling system shall have at least one solid-state programmable thermostat.
   b. A 5°F deadband is required between heating and cooling setpoints.

D. Commercial Energy Efficiency Requirements

1. The 2003 IECC references ASHRAE Standard 90.1-2001—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 the 2001 ASHRAE Handbook of Fundamentals 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. Thermostat controls shall be provided for all HVAC systems. Humidistat 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 an automatic means to reduce or shutoff airflow.
      1) Exception: Systems designed for continuous operation.
      2) Exception: Systems with a maximum 3,000 CFM airflow rate.
      3) Exception: Systems with readily accessible manual dampers.
      4) Exception: Where restricted by health and life safety codes.
   h. Ductwork:
      1) Construction and materials: See Part 17.
      2) Insulation: See Part 35.
   i. Piping:
      1) Construction and materials: See Part 18 thru Part 22.
      2) Insulation: See Part 35.
   j. HVAC system balancing is required for both the air systems and the hydronic systems.
   k. Operation and maintenance manuals are required to be turned over to the owner.
3. Simple HVAC Systems—prescriptive approach:
   a. Applies to unitary or packaged equipment serving single zones controlled by a single thermostat.
   b. Each heating and cooling system shall have at least one solid-state programmable thermostat.
   c. Airside economizers shall be provided for cooling systems with a capacity greater than 65,000 Btu/hr. except for climate zones 1, 2, 3B, 5A, or 6B.
   d. Hydronic systems 600,000 Btu/hr. capacity and larger shall meet the complex HVAC system requirements.
4. Complex HVAC Systems—prescriptive approach:
   a. Airside economizers are required on all systems with capacity greater then 65,000 Btu/hr. except as listed in the following:
      1) Waterside economizers are provided and are capable of providing 100 percent of the cooling load at outside air temperatures of 50°F db/45°F wb and below.

2) Systems with a cooling capacity less than 135,000 Btu/hr. in climate zones 3C, 5B, 7, 13B, and 14.

b. Variable air volume fan control. Fans 25 horsepower and larger shall be controlled by either:
   1) A mechanical or electrical variable frequency drive.
   2) The fan motor shall have controls or devices that will result in fan motor demand of not more than 30 percent of their design wattage at 50 percent of design airflow when the static pressure setpoint equals 1/3 of the total design static pressure, based on the manufacturer's certified fan data.
   3) Air distribution systems serving multiple zones shall have the control to reduce primary airflow to one of the following before reheating, recooling, or mixing takes place:
      a) 30 percent of maximum supply airflow to each zone.
      b) 300 CFM or less where the maximum airflow rate is less than 10 percent of the total system airflow.
      c) Minimum ventilation requirements.
      d) Exception: where pressure relationships are required to prevent cross-contamination.
      e) Exception: where process systems require close temperature and/or humidity control.

c. Hydronic systems:
   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 control that allows 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 5A through 19 to prevent heat loss, except for minimum flow to prevent freezing. All water source heat pumps shall be provided with two-position control valves on all heat pump systems with a total pump energy exceeding 10 horsepower to stop the flow when the heat pump has cycled off (variable flow water distribution system).
   4) Hydronic heating and cooling systems 300,000 Btu/hr. 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.
   5) Hydronic heating and cooling systems 300,000 Btu/hr. capacity or greater 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 designed to modulate closed as a function of load.

d. 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.

e. 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 6,000,000 Btu/hr. capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/hr.

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.

Design Conditions and Energy Conservation

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.

15.04 2006 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–*2005 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: Insulation with R-value = 8.0.
   b. Ducts in floor trusses: Insulation with R-value = 6.0.
   c. Exception: ducts completely inside the building envelope do not require insulation.
2. Pipe insulation
   a. Pipe fluid above 105°F: Insulation with R-value = 2.0.
   b. Pipe fluid below 55°F: Insulation with R-value = 2.0.
   c. Domestic hot water: Insulation with R-value = 2.0.

D. Commercial Energy Efficiency Requirements

1. The 2006 IECC references ASHRAE Standard 90.1-2004—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 *2005 ASHRAE Handbook of Fundamentals* 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. Thermostat controls shall be provided for all HVAC systems. Humidistat 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 systems with airflows of 300 CFM and less.
h. Energy recovery systems shall be provided when the following conditions are met:
   1) HVAC systems have and supply a capacity of 5,000 CFM and greater.
   2) HVAC systems have a minimum outside air requirement of 70 percent or greater.
   3) 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).
   4) 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 thru 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. Simple HVAC Systems—prescriptive approach:
   a. Applies to unitary or packaged equipment serving single zones controlled by a single thermostat.
   b. Airside economizers shall be provided as follows:

Climate Zones	Economizer Requirement
1A, 1B, 2A, 3A, 4A, 7, 8	No requirement
2B, 3B, 3C, 4B, 4C, 5B, 5C, 6B	Economizers on all cooling systems ≥54,000 Btu/hr.
5A, 6A	Economizers on all cooling systems ≥135,000 Btu/hr.

   c. Hydronic systems 300,000 Btu/hr. capacity and larger shall meet the complex HVAC system requirements.

4. Complex HVAC Systems—prescriptive approach:
   c. Airside economizers are required except as listed in the following:
      1) Waterside economizers are provided and are capable of providing 100 percent of the cooling load at outside air temperatures of 50°F db/45°F wb and below.
   d. Variable air volume fan control–fans 10 horsepower and larger shall be controlled by either:
      1) A mechanical or electrical variable frequency drive.
      2) The fan motor shall have controls or devices that will result in fan motor demand of not more than 30 percent of their design wattage at 50 percent of design airflow when the static pressure setpoint equals 1/3 of the total design static pressure, based on the manufacturer's certified fan data.
      3) Air distribution systems serving multiple zones shall have the control to reduce primary airflow to one of the following before reheating, recooling, or mixing takes place:
         a) 30 percent of the maximum supply airflow to each zone.
         b) 300 CFM or less where the maximum airflow rate is less than 10 percent of the total system airflow.
         c) Minimum ventilation requirements.

d) Exception: where pressure relationships are required to prevent cross-contamination.
e) Exception: where process systems require close temperature and/or humidity control.

e. Hydronic systems:
   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 through 8 to prevent heat loss, except for minimum flow to prevent freezing. 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 300,000 Btu/hr. 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.
   5) Hydronic heating and cooling systems 300,000 Btu/hr. capacity or greater 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.

f. Heat rejection equipment: 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.

g. 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/hr. capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/hr.

B. 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.

15.05 ASHRAE Standard 90.1–2001

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.
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 the *2001 ASHRAE Handbook of Fundamentals* 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 with a cooling capacity of 65,000 Btu/hr. or more and a fan system power of 3/4 horsepower or more shall have the following controls:
   a. 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 two-hour operation limitation.
      4) Interlock with security system—security system activation shuts down the HVAC system.
   b. Setback controls.
      1) HVAC systems serving facilities where heating design temperature is 40°F and lower: Provide controls with a setback temperature of 55°F or lower.
      2) HVAC systems serving facilities where the cooling design temperature is greater than 100°F: Provide controls with a setup temperature of 90°F or higher.
   c. Optimum start controls (system with 10,000 CFM capacity or greater).
   d. Shutoff dampers controls.
   e. Zone isolation controls.
   f. Exceptions: Hotel and motels guest rooms and HVAC systems intended to operate continuously.
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 in buildings two stories and less in height.
      2) Exception: Gravity dampers are permitted in systems with airflow of 300 CFM and less.

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. For HVAC systems with design outside air capacities greater than 3,000 CFM serving spaces with an occupant density exceeding 100 people per 1,000 square feet shall have a means to automatically reduce outside air when the space is partially occupied or unoccupied.
   1) Occupancy sensors.
   2) CO_2 sensors.
e. Ductwork:
   1) Construction and materials: See Part 17.
   2) Insulation: See Part 35.
f. Piping:
   1) Construction and materials: See Part 18 thru Part 22.
   2) Insulation: See Part 35.
g. 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 provided by packaged or split system equipment.
4. Airside economizer shall be provided.
5. Outside air quantity shall be less than or equal to 3,000 CFM and less than 70 percent of the supply air quantity.
6. System changeover shall be by a manual changeover or by 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 table.

No. of Hours Between 8:00 a.m. and 4:00 p.m. with 55°F < T_{DB} < 69°F	AHSRAE 1% Cooling Design Wet Bulb Temperature Minimum System Size (Btu/hr.)		
	T_{WB} < 69°F	69°F ≤ T_{WB} ≤ 73°F	T_{WB} > 73°F
0–199	Not Req'd	Not Req'd	Not Req'd
200–399	135,000	Not Req'd	Not Req'd
400–599	135,000	Not Req'd	Not Req'd
600–799	65,000	135,000	Not Req'd
800–999	65,000	135,000	135,000
1000–1199	65,000	65,000	135,000
>1199	65,000	65,000	65,000

   a. Exceptions:
      1) Systems smaller than those indicated in the table under the design conditions listed.
      2) Where 25 percent or more of the HVAC system serves a space that requires humidification levels above a 35°F dew point temperature.
      3) Systems that utilize condenser heat recovery.
      4) Residential HVAC systems where the capacity is less than five times the requirements listed in the preceding table.
      5) Systems expected to operate less than 20 hours per week.

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.
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.
   c. Waterside economizers, when required, shall be used for systems with hydronic cooling and humidification systems designed to maintain a humidity at 35°F dew point or higher.
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 building heating energy use during normal operation.
   c. Economizer control methods.

Climate T_{DB} = 1% Cooling Design DB T_{WB} = 1% Cooling Design WB	Allowed Control Types	Prohibited Control Types
Dry Climate $T_{WB} < 69°F$ or $T_{WB} < 75°F$ and $T_{DB} \geq 100°F$	Fixed dry bulb Differential dry bulb Electronic enthalpy Differential enthalpy	Fixed enthalpy
Intermediate Climate $69°F \leq T_{WB} \leq 73°F$ $T_{DB} < 100°F$	Fixed dry bulb Differential dry bulb Fixed enthalpy Electronic enthalpy Differential enthalpy	
Humid Climate $T_{WB} > 73°F$	Fixed dry bulb Fixed enthalpy Electronic 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) 0.4 CFM/sf of zone floor area.
      3) 30 percent of the design peak supply rate.
      4) 300 CFM—for zones that comprise less than 10 percent of the total system airflow.
      5) Zones where special pressure relationships are required to prevent cross-contamination.
      6) Code required minimum circulation rates—hospitals are an example.
      7) Where 75 percent or more of the energy required for reheating is provided by an energy recovery system.
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 a capacity less than or equal to 80,000 Btu/hr., which reduce the cooling capacity to 50 percent before reheating.
   3) Individual cooling systems with a capacity of 40,000 Btu/hr. 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 designed 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 climates with heating degree days in excess of 1,800 to prevent heat loss, except for minimum flow to prevent freezing. All water source heat pumps shall be provided with two-position control valves on all heat pump systems with a total pump energy exceeding 10 horsepower to stop the flow when the heat pump has cycled off (variable flow water distribution system).
   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 or the design flow rate.
      2) Pumps with head requirements exceeding 100 feet and horsepower requirements exceeding 50 horsepower shall have controls to reduce pump energy:
         a) Driven by either a mechanical or electrical variable frequency drive.
         b) The pump motor shall have controls or devices that will result in a pump motor demand of not more than 30 percent of their design wattage at 50 percent of the design water flow.
         c) Exception: Where the minimum flow required is less than the minimum flow required by the equipment manufacturer for proper equipment operation.
         d) Exception: Systems with no more than three control valves.
   e. Hydronic heating and cooling systems 300,000 Btu/hr. 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 the water temperature or condensing temperature/pressure of the heat rejection device.
   g. 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/hr. capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/hr.

8. Fan power limitation—Fan systems exceeding 5 horsepower.
   a. Allowable fan system power:

Supply Air Volume	Allowable Nameplate Motor Horsepower	
	Constant Volume Systems	Variable Volume Systems
< 20,000 CFM	1.2 hp / 1,000 CFM	1.7 hp / 1,000 CFM
≥ 20,000 CFM	1.1 hp / 1,000 CFM	1.5 hp / 1,000 CFM

b. Where filters have pressure drops that exceed 1.0 inches water column when clean, adjustments can be made using the following equation.
c. When systems are provided with energy recovery coils, adjustments can be made using the following equation.
d. The fan horsepower may be adjusted when the temperature difference between the supply air design temperature and the room design temperature exceeds 20°F.
e. Fan system power equation:

$$AFSP = ANMHp \times TR + PC + RFC$$
$$ANMHp = \text{Table Value} \times \text{System CFM}$$
$$TR = (T_{ROOM} - T_{SA})/20$$
$$PC = [CFM_F \times (SP_F - 1.0) / 3718] + [CFM_{HR} \times SP_{HR} / 3718]$$
$$RFC = RF_{HP} \times [1 - (CFM_{RF} / CFM_F)]$$

AFSP = Allowable Fan System Power
ANMHp = Allowable Nameplate Motor Horsepower (from the table)
TR = Temperature Ratio
PC = Pressure Credit
RFC = Relief Fan Credit
T_{ROOM} = Indoor Design Temperature
T_{SA} = Supply Air Design Temperature
CFM_F = Filtered Air Volume
CFM_{HR} = Heat Recovery Air Volume
CFM_{RF} = Relief Fan Air Volume
SP_F = Clean Filter Air Pressure Drop (in. WC)
SP_{HR} = Heat Recovery Coil Air Pressure Drop (in. WC)
RF_{HP} = Relief Fan Nameplate Horsepower

f. Example:
68,000 CFM VAV System
30% Prefilters–Initial PD 0.35"
90% Main Filters–Initial PD 0.75"
99.97 Final Filters (HEPA)—Initial PD 1.00"
Preheat Heat Recovery Coil–0.75″
Reheat Heat Recovery Coil–0.75″
Relief Fan—30 hp, 55,000 CFM

$$ANMHp7 = 1.5 \text{ hp}/1{,}000 \text{ CFM} \times 68{,}000 \text{ CFM} = 102 \text{ hp}$$
$$TR = (78 - 55) / 20 = 1.15$$
$$PC = [68{,}000 \times (\{0.35 + 0.75 + 1.0\} - 1.0)/3718] + [68{,}000 \times (0.75 + 0.75)/3718] = 47.6 \text{ hp}$$
$$RFC = 30 \times [1 - (55{,}000/ 68{,}000)] = 5.7 \text{ hp}$$
$$AFSP = 102 \text{ hp} \times 1.15 + 47.6 \text{ hp} + 5.7 \text{ hp} = 170.5 \ (175 \text{ hp})$$

9. Variable air volume fan control—fans 30 horsepower and larger shall be controlled by either:
   a. Driven by either a mechanical or electrical variable frequency drive.
   b. Fan shall be a vane axial fan with variable pitch blades.
   c. The fan motor shall have controls or devices that will result in fan motor demand of not more than 30 percent of their design wattage at 50 percent of design airflow when the static pressure set point equals 1/3 of the total design static pressure, based on the manufacturer's certified fan data.
   d. Static pressure sensor location: Position where the sensor static pressure is no greater than 1/3 of the total fan static pressure. Where sensor location is after major duct spits, multiple sensors shall be used.
10. Energy recovery systems are required for individual fan systems with a design supply fan capacity of 5,000 CFM or greater and have a minimum outside air requirement of 70 percent or greater of the design supply airflow rate. 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 of 60°F.
   5) Where 60 percent of the outdoor heating energy is provided by site recovered energy or site solar energy.
   6) Where the largest exhaust source is less than 75 percent of the design outdoor airflow.

11. Kitchen hoods:
    a. Individual kitchen hoods in excess of 5,000 CFM shall be provided with makeup air for at least 50 percent of the total exhaust airflow.
    b. Makeup air shall be unheated or heated to a maximum of 60°F and uncooled or cooled without mechanical cooling.
12. Laboratory fume hoods having a total exhaust flow rate greater than 15,000 CFM shall have at least one of the following features:
    a. VAV exhaust hoods with supply air and exhaust air flow 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.
    c. Heat recovery systems to precondition makeup air without using any exceptions.
13. 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 240,000 Btu/hr.: 50 percent of total system capacity.
       2) System capacity > 240,000 Btu/hr.: 25 percent of total system capacity.

B. Performance Approach—Energy Cost Budget Method

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. The budget building design has specific criteria that must be used to determine the base building energy budget.
   a. Building envelope:
      1) Identical conditioned floor area.
      2) Identical exterior dimensions.
      3) Identical orientation.
      4) Opaque walls and roof: Prescriptive U-values.
      5) Fenestration (glass):
         a) Prescriptive U-values.
         b) Walls may be not more than 50 percent glass; proportionally reduce each exposure glass percentage until 50 percent is obtained.
         c) The roof area may not be more than 5 percent skylight.
         d) No shading projections.

b. HVAC systems based on:
   1) Cooling source.
   2) Heating system.
   3) Air conditioning system.
   4) Minimum prescriptive energy efficiency levels.
   5) Economizers shall be provided.
c. Energy recovery systems—If energy recovery is used in the proposed building, an energy recovery system with 50 percent energy recovery must be used in the budget building.
d. Identical ventilation rates.

5. 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.

15.06 ASHRAE Standard 90.1-2004

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.
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 the *2001 ASHRAE Handbook of Fundamentals* 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) Hotel and motels guest rooms.
      2) HVAC systems intended to operate continuously.
      3) HVAC systems with design heating and cooling capacities less than 15,000 Btu/hr. 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 two-hour operation limitation.
4) Interlock with security system—security system activation shuts down the HVAC system.

c. Setback controls:
1) HVAC systems serving facilities where heating design temperature is 40°F and lower: Provide controls with a setback temperature of 55°F or lower.
2) HVAC systems serving facilities where cooling design temperature is greater than 100°F: Provide controls with a setup temperature of 90°F or higher.

d. Optimum start controls (system with 10,000 CFM capacity or greater).

e. Shutoff dampers controls.

f. Zone isolation controls.

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 in buildings two stories and less in height.
2) Exception: Gravity dampers are permitted in systems with an airflow of 300 CFM and 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. For HVAC systems with design outside air capacities greater than 3,000 CFM serving spaces with an occupant density exceeding 100 people per 1,000 square feet shall have a means to automatically reduce outside air when the space is partially occupied or unoccupied.
1) Occupancy sensors.
2) CO_2 sensors.
f. Ductwork:
1) Construction and materials: See Part 17.
2) Insulation: See Part 35.
g. Piping:
1) Construction and materials: See Part 18 thru 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 provided by packaged or split system equipment.
4. Airside economizer shall be provided.
5. Outside air quantity shall be less than or equal to 3,000 CFM and less than 70 percent of the supply air quantity.
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 table.

Climate Zones	Cooling Capacity Requiring Economizer
1A, 1B, 2A, 3A, 4A	No economizer required
2B, 5A, 6A, 7, 8	≥ 135,000 Btu/hr.
3B, 3C, 4B, 4C, 5B, 5C, 6B	≥ 65,000 Btu/hr.

   a. Exceptions:
      1) Systems smaller than those indicated in the table under the design conditions listed.
      2) Where 25 percent or more of the HVAC system serves a space that requires humidification levels above a 35°F dew point temperature.
      3) Systems that utilize condenser heat recovery.
      4) Residential HVAC systems where the capacity is less than five times the requirements listed in the preceding table.
      5) Systems expected to operate less than 20 hours per week.
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.
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.
   c. Waterside economizers, when required, shall be used for systems with hydronic cooling and humidification systems designed to maintain a humidity at 35°F dew point or higher.
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, 5B, 5C, 6B, 7, 8	Fixed dry bulb Differential dry bulb Electronic enthalpy Differential enthalpy Dew point and dry bulb temperature	Fixed enthalpy
1A, 2A, 3A, 4A	Fixed dry bulb Fixed enthalpy Electronic enthalpy Differential enthalpy Dew point and dry bulb temperature	Differential dry bulb
All Other Climate Zones	Fixed dry bulb Differential dry bulb Fixed enthalpy Electronic enthalpy Differential enthalpy Dew point and dry bulb temperature	

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) 0.4 CFM/sf of zone floor area.
      3) 30 percent of the design peak supply rate.
      4) 300 CFM–For zones that comprise less than 10 percent of the total system airflow.
      5) Zones where special pressure relationships are required to prevent cross-contamination.
      6) Code required minimum circulation rates—hospitals are an example.
      7) Where 75 percent or more of the energy required for reheating is provided by an energy recovery system.
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/hr. and reduces cooling capacity to 50 percent before reheating.
      3) Individual cooling systems with capacity of 40,000 Btu/hr. 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 climates with heating degree days in excess of 1800 to prevent heat loss, except for minimum flow to prevent freezing. All water source heat pumps shall be provided with two-position control valves on all heat pump systems with a total pump energy exceeding 10 horsepower to stop the flow when the heat pump has cycled off (variable flow water distribution system).
   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) Pumps with head requirements exceeding 100 feet and horsepower requirements exceeding 50 horsepower shall have controls to reduce pump energy:
         a) Driven by either a mechanical or electrical variable frequency drive.
         b) The pump motor shall have controls or devices 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.
         c) Exception: Where minimum flow required is less than the minimum flow required by the equipment manufacturer for proper equipment operation.
         d) Exception: Systems with no more than three control valves.
   e. Hydronic heating and cooling systems 300,000 Btu/hr. 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/hr. capacity of heat rejection and the design service water heating load exceeds 1,000,000 Btu/hr.

8. Fan power limitation–Fan systems exceeding 5 horsepower.
   a. Allowable fan system power:

Supply Air Volume	Allowable Nameplate Motor Horsepower	
	Constant Volume Systems	Variable Volume Systems
< 20,000 CFM	1.2 hp / 1,000 CFM	1.7 hp / 1,000 CFM
≥ 20,000 CFM	1.1 hp / 1,000 CFM	1.5 hp / 1,000 CFM

   b. Where filters have pressure drops that exceed 1.0 inches water column when clean, adjustments can be made using the following equation.
   c. When systems are provided with energy recovery coils, adjustments can be made using the following equation.
   d. The fan horsepower may be adjusted when the temperature difference between the supply air design temperature and the room design temperature exceeds 20°F.
   e. Fan system power equation:

$$AFSP = ANMHp \times TR + PC + RFC$$
$$ANMHp = \text{Table Value} \times \text{System CFM}$$
$$TR = (T_{ROOM} - T_{SA})/20$$
$$PC = [CFM_F \times (SP_F - 1.0)/3718] + [CFM_{HR} \times SP_{HR} / 3718]$$
$$RFC = RF_{HP} \times [1 - (CFM_{RF} / CFM_F)]$$

AFSP = Allowable Fan System Power
ANMHp = Allowable Nameplate Motor Horsepower (from the table)
TR = Temperature Ratio
PC = Pressure Credit
RFC = Relief Fan Credit
T_{ROOM} = Indoor Design Temperature
T_{SA} = Supply Air Design Temperature
CFM_F = Filtered Air Volume
CFM_{HR} = Heat Recovery Air Volume
CFM_{RF} = Relief Fan Air Volume
SP_F = Clean Filter Air Pressure Drop (in. WC)
SP_{HR} = Heat Recovery Coil Air Pressure Drop (in. WC)
RF_{HP} = Relief Fan Nameplate Horsepower

9. Variable air volume fan control–fans 15 horsepower and larger shall be controlled by either:
   a. A mechanical or electrical variable frequency drive.
   b. Fan shall be a vane axial fan with variable pitch blades.
   c. The fan motor shall have controls or devices that will result in a fan motor demand of not more than 30 percent of their design wattage at 50 percent of the design airflow when the static pressure setpoint equals 1/3 of the total design static pressure, based on the manufacturer's certified fan data.
   d. Static pressure sensor location: Position where the sensor static pressure is no greater than 1/3 of the total fan static pressure. Where the sensor location is after major duct spits, multiple sensors shall be used.
10. Energy recovery systems are required for individual fan systems with a design supply fan capacity of 5,000 CFM or greater and have a minimum outside air requirement of 70 percent or greater of the design supply airflow rate. 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) Where the largest exhaust source is less than 75 percent of the design outdoor airflow.

11. Kitchen hoods:
    a. Individual kitchen hoods in excess of 5,000 CFM shall be provided with makeup air for at least 50 percent of the total exhaust airflow.
    b. Makeup air shall be unheated or heated to a maximum of 60°F and uncooled or cooled without mechanical cooling.
12. Laboratory fume hoods having a total exhaust flow rate greater than 15,000 CFM shall have at least one of the following features:
    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.
    c. Heat recovery systems to precondition makeup air without using any exceptions.
13. 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 240,000 Btu/hr.: 50% of total system capacity.
       2) System capacity > 240,000 Btu/hr.: 25% 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. The budget building design has specific criteria that must be used to determine the base building energy budget.
   a. Building envelope:
      1) Identical conditioned floor area.
      2) Identical exterior dimensions.
      3) Identical orientation.
      4) Opaque walls and roof: Prescriptive U-values.
      5) Fenestration (glass).
         a) Prescriptive U-values.
         b) Walls may not be more than 50 percent glass; proportionally reduce each exposure glass percentage until 50 percent is obtained.
         c) The roof area may not be more than 5 percent skylight.
         d) No shading projections.
   b. HVAC systems based on:
      1) Cooling source.
      2) Heating system.

3) Air conditioning system.
4) Minimum prescriptive energy efficiency levels.
5) Economizers shall be provided.

c. Energy recovery systems—If energy recovery is used in the proposed building, an energy recovery system with 50 percent energy recovery must be used in the budget building.
d. Identical ventilation rates.

5. 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.

G. Performance Rating Method—Informative 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. Requirements are similar to the energy cost budget method, except as defined in the following:
   a. Five computer simulations must be performed:
      1) Proposed building design.
      2) Baseline building design with rotated orientations and averaging the baseline building energy results.
   b. Orientation:
      1) Actual orientation.
      2) 90-degree rotation.
      3) 180-degree rotation.
      4) 270-degree rotation.
   c. Opaque building assemblies shall be modeled using common lightweight assembly types.
   d. Vertical fenestration (glass):
      1) Prescriptive U-values and SHGCs.
      2) The window area of the baseline building design shall be the same as the proposed design, or 40 percent of the above-grade wall area, whichever is less and shall be distributed evenly in horizontal bands evenly across all four orientations of the building.
      3) No shading projections.
      4) All glass will be fixed.
   e. Skylights:
      1) The skylight area of the baseline building design shall be the same as the proposed design, or 5 percent of the roof area, whichever is less. If the skylight area is more than 5 percent of the gross roof area, the baseline building design shall reduce the skylight area of all building roof components by an equal percentage until the 5 percent area is obtained.
      2) Skylight orientation and tilt shall be the same as the proposed building.

15.07 ASHRAE Standard 90.2-2001

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

B. Heating and cooling load calculations shall be performed in accordance with any of the following, and equipment size should be based on these calculations:

1. *2001 ASHRAE Handbook of Fundamentals*.
2. *ASHRAE Cooling and Heating Load Calculation Manual, GRP 158*.
3. Air Conditioning Contractors' of America—*Residential Load Calculation, Manual J*, 7th Edition.
4. Hydraulics Institute–*Heat Loss Calculation Guide No. H-22*, 1st Edition.

C. Outdoor Design Conditions–2001 ASHRAE Handbook of Fundamentals

1. Winter: 97-1/2% values.
2. Summer: 2-1/2% values.

D. Indoor Design Conditions

1. Heating: 70°F.
2. Cooling: 75°F / 50%–60% RH.
3. Winter humidification: 30% maximum.

E. Duct Insulation

1. Ducts are not required to be insulated:
   a. When supply and return ductwork are within the conditioned space.
   b. When ductwork is within basements and unvented crawl spaces having insulated walls.
   c. If it is exhaust ductwork.
2. Ducts shall be insulated in the following locations:
   a. Ducts located outside the building or roof: R-6.
   b. The attic or garage:
      1) CDH74 < 15,000, HDD65 < 3,000: R-4.
      2) CDH74 15,000, HDD65 3,000: R-6.
   c. The basement under an insulated floor or crawl space:
      1) CDH74 < 30,000, HDD65 < 6,000: R-4.
      2) CDH74 30,000, HDD65 6,000: R-6.

F. Pipe Insulation

1. Pipes are not required to be insulated:
   a. When pipes are within conditioned space, except for condensate control or burn protection.
   b. When pipes are located within HVAC equipment.
   c. When piping contains fluid between 55°F and 120°F.
   d. When piping is within basements and unvented crawl spaces having insulated walls.
2. Piping shall be insulated as follows:
   a. For pipe sizes greater than 2", see Part 35 or the ASHRAE Standard 90.2–2004 requirements shown next.

Piping System Types	Fluid Temperature Range °F	Insulation Thickness (Inches)		
		Runouts	Pipe Size	
			1" and Smaller	1-1/4"–2"
Heating Systems—Steam and Hot Water				
Low Pressure/Temperature	201–250	1.0	1.5	1.5
Low Temperature	120–200	0.5	1.0	1.0
Steam Condensate	Any	1.0	1.0	1.5
Cooling Systems—Chilled Water, Refrigerant, or Brine	40–55	0.5	0.5	0.75
	< 40	1.0	1.0	1.5

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

15.08 ASHRAE Standard 90.2-2004

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./hr. ft.^{2} ºF	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						
201–250ºF	0.27–0.30	1.5	1.5	2.0	2.0	2.0
141–200ºF	0.25–0.29	1.0	1.0	1.0	1.5	1.5
105–140ºF	0.22–0.28	0.5	0.5	1.0	1.0	1.0
Heating Systems—Steam						
212–250ºF 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						
40–60ºF	0.22–0.28	0.5	0.5	1.0	1.0	1.0
< 40ºF	0.22–0.28	0.5	1.0	1.0	1.0	1.5

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

PART 16

HVAC System Selection Criteria

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 obtruding 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 owners 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. 2003 International Code Council Series of Codes (ICC):
    a. 2003 International Building Code.
    b. 2003 International Mechanical Code.
    c. 2003 International Energy Conservation Code.
    d. 2003 International Plumbing Code.
    e. 2003 International Fire Code.
    f. 2003 International Electric Code (Administrative Provisions—References the National Electric Code—NFPA 70).
    g. 2003 International Fuel Gas Code.
    h. 2003 International Residential Code.
    i. 2003 International Existing Building Code.
    j. 2003 International Performance Code.
    k. 2003 International Private Sewage Disposal Code.
    l. 2003 International Property Maintenance Code.
    m. 2003 International Zoning Code.
    n. 2003 International Wildland-Urban Interface Code.
9. 2006 International Code Council Series of Codes (ICC):
    a. 2006 International Building Code.
    b. 2006 International Mechanical Code.
    c. 2006 International Energy Conservation Code.
    d. 2006 International Plumbing Code.
    e. 2006 International Fire Code.
    f. 2006 International Electric Code (Administrative Provisions—References the National Electric Code—NFPA 70).
    g. 2006 International Fuel Gas Code.
    h. 2006 International Residential Code.
    i. 2006 International Existing Building Code.
    j. 2006 International Performance Code.
    k. 2006 International Private Sewage Disposal Code.
    l. 2006 International Property Maintenance Code.
    m. 2006 International Zoning Code.
    n. 2006 International Wildland-Urban Interface Code.

16.02 Heating System Selection Guidelines

A. If heat loss exceeds 450 Btu/hr. 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/hr. 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/hr. 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.

PART 17

Air Distribution Systems

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
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	2003 IMC:1,500 FPM min.; 2006 IMC:500 FPM min.; NFPA 96-2004:500 FPM min.
Dishwasher Exhaust Ducts	0.10 (0.15)	1,500	2,200	
Acid, Ammonia, and Solvent Mains	0.50 (0.60)	1,000	3,000	Mains and risers 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

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.**
3 **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—i.e., 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-$^1/_2$ 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-2002:
    a. Service openings shall be located at approximately 20-foot intervals in horizontal ducts and at the base of the 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 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 $^1/_2$" 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 × System Length (ft./100) × 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—i.e., 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.

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

B. *SMACNA-HVAC* Pressure Ratings

1. ±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 90.1-2001 and 2004: A minimum of 25 percent of duct systems designed to operate at static pressures exceeding 3" WC shall be leak tested according to industry-accepted procedures.

F. 2003 IMC and 2006 IMC reference SMACNA HVAC manual for ductwork testing. A minimum of 25 percent of duct systems designed to operate at static pressures exceeding 3" WC shall be leak tested according to industry-accepted procedures.

G. 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.

H. *SMACNA-HVAC* Ductwork Seal Classes

1. Seal Class A: 2–5 percent total system leakage (all transverse joints, longitudinal seams, and duct penetrations).
2. Seal Class B: 3–10 percent total system leakage (all transverse joints and longitudinal seams).
3. Seal Class C: 5–20 percent total system leakage (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	1/2" WC and higher for all ductwork upstream of VAV terminal units

I. ASHRAE Standard 90.1-2001 and ASHRAE Standard 90.1-2004 Ductwork Seal Classes

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

ASHRAE DUCTWORK SEAL CLASSES

Duct Location	Duct Type			
	Supply		Return	Exhaust
	≤ ±2" WC	> ±2" WC		
Outdoors	A	A	A	C
Unconditioned Spaces	B	A	B	C
Conditioned Spaces	C	B	C	B

J. Recommended Ductwork Seal Classes

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

RECOMMENDED DUCTWORK SEAL CLASSES

	SMACNA Pressure Class (in. WC)						
	±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

(*Continued*)

RECOMMENDED DUCTWORK SEAL CLASSES (*Continued*)

	SMACNA Pressure Class (in. WC)						
	±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

K. Ductwork Materials

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

ASTM Galvanized Coating Designations	Minimum Coating Weight oz./sq.ft.		
	Triple Spot Test Average Total Both Sides	Single Spot Test	
		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: Nonwelded 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. Sheet rock: Air shafts (generally provided by architects).
   a. 2003 IMC and 2006 OMC:
      1) Temperature shall not exceed 1258F.
      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-2002: 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 1258F.
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.

L. Flexible Duct

1. 5–8 ft. maximum recommended length.
2. Insulated, uninsulated.
3. NFPA 90A-2002: 14 feet maximum.

M. Ductwork Sheet Metal Gauges and Weights

SMACNA HVAC DUCTWORK SHEET METAL GAUGES

Maximum Duct Dimension	SMACNA Pressure Class													
	±1/2		±1		±2		±3		±4		±6		±10	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
4"–8"	26	-	26	-	26	-	24	26	24	26	24	26	22	24
9"–10"	26	-	26	-	26	-	24	26	22	26	24	24	20	22
11"–12"	26	-	26	-	26	-	24	26	22	26	20	24	18	22
13"–14"	26	-	26	-	24	26	22	24	20	24	20	22	18	20
15"–16"	26	-	26	-	24	26	22	24	20	24	18	22	16	20
17"–18"	26	-	24	26	22	26	20	24	18	24	18	22	16	20
19"–20"	24	26	24	26	20	26	18	24	18	24	16	22	-	18
21"–22"	22	26	22	26	18	26	18	24	18	24	16	22	-	18
23"–24"	22	26	22	26	18	26	18	24	18	22	16	22	-	18
25"–26"	20	26	20	26	18	26	18	24	16	22	-	20	-	18
27"–28"	18	26	18	26	18	24	18	22	16	22	-	20	-	18
29"–30"	18	26	18	26	18	24	18	22	16	22	-	18	-	18
31"–36"	181	26	18	24	16	24	16	20	-	20	-	18	-	16
37"–42"	6	26	16	24	-	22	-	20	-	18	-	16	-	16
43"–48"	16	26	16	22	-	22	-	18	-	18	-	16	-	16
49"–54"	-	26	-	22	-	20	-	18	-	18	-	16	-	16
55"–60"	-	24	-	22	-	20	-	18	-	16	-	16	-	16
61"–72"	-	22	-	18	-	18	-	16	-	16	-	16	-	16
73"–84"	-	22	-	18	-	16	-	16	-	16	-	16	-	16
85"–96"	-	20	-	18	-	16	-	16	-	16	-	16	-	16
97"–108"	-	18	-	16	-	16	-	16	-	16	-	16	-	16
109"–120"	-	16	-	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. ±1/2" Pressure Class: 5 feet reinforcing spacing for 19"–120".
   d. ±1" Pressure Class: 5 feet reinforcing spacing for 17"–108" and 4 feet spacing for 109"–120".
   e. ±2" Pressure Class: 5 feet reinforcing spacing for 13"–84", 4 feet spacing for 85"–108", and 3 feet spacing for 109"–120".
   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

Sheet Metal Gauge	Material Weight lbs./sq.ft.		
	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 thru 17.3.

B. *2003 IMC*

1. Exhaust/makeup air:
   a. Exhaust systems: 1500 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.

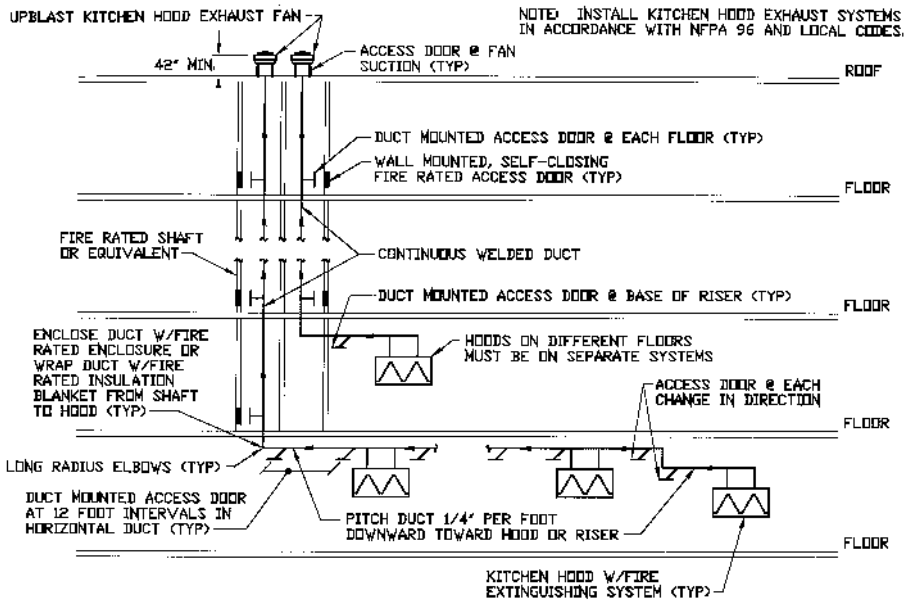


FIGURE 17.1 KITCHEN HOOD EXHAUST SYSTEM—UPBLAST FAN.

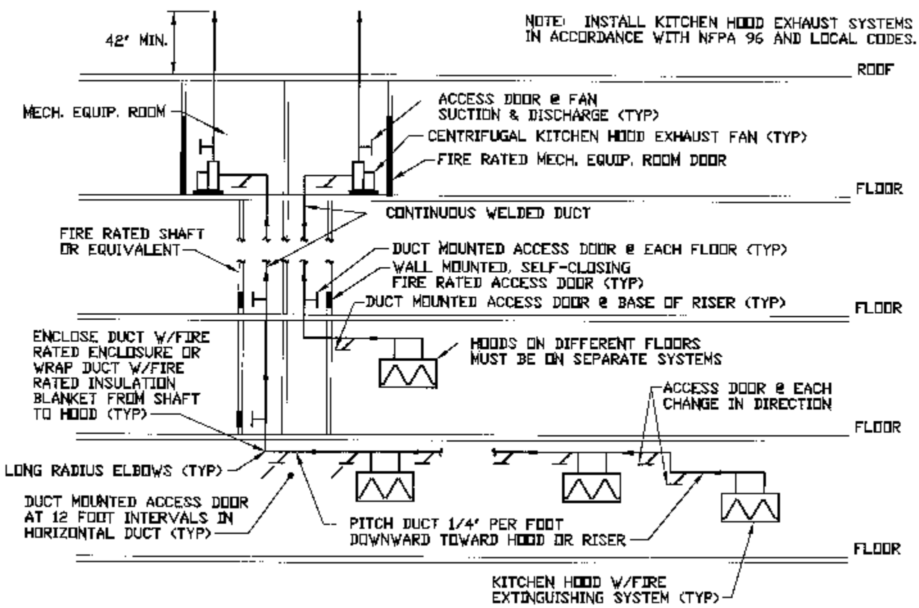


FIGURE 17.2 KITCHEN HOOD EXHAUST SYSTEM—UTILITY SET FAN.

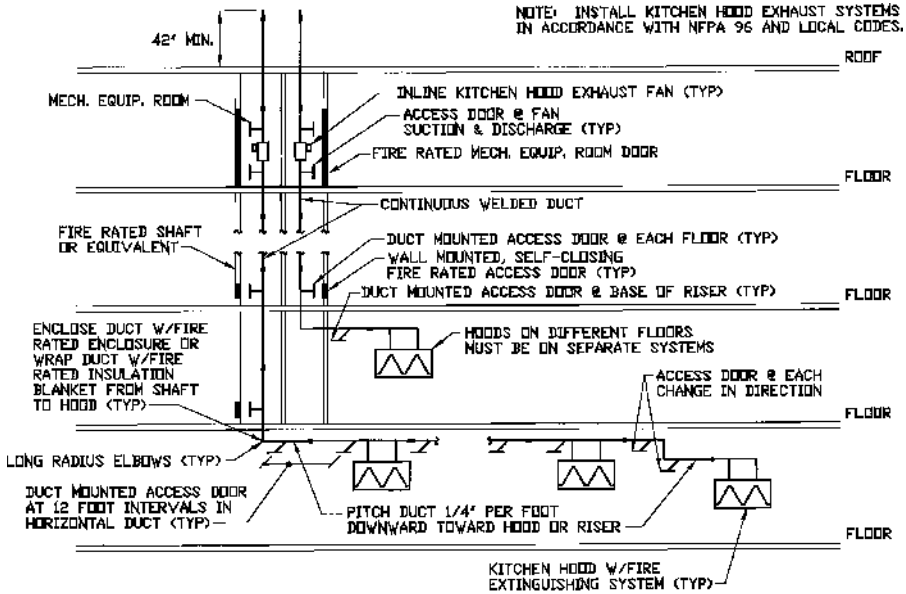


FIGURE 17.3 KITCHEN HOOD EXHAUST SYSTEM—INLINE FAN.

   d. Hoods serving solid fuel cooking appliances must have separate exhaust systems from all the other hoods.
   e. Makeup air systems: ÄT 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) 75 feet or less in length: 1/4" per foot.
      2) 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.
      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: Every 20 feet.
4. Hoods:
   a. Type I hoods: Serve appliances that produce grease or smoke—e.g., griddles, fryers, broilers, ovens, ranges, and wok ranges.
   b. Type II hoods: Serve appliances that produce heat or steam but do not produce grease or smoke—e.g., 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:

Type of Hood	Minimum CFM per Lineal Foot of Hood			
	Type of Cooking Appliances			
	Extra-Heavy Duty	Heavy Duty	Medium Duty	Light Duty
Wall-Mounted Canopy	550	400	300	200
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 cooling, 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.

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. *2006 IMC*: Requirements are the same as the 2003 IMC except as listed in the following.

1. Exhaust/makeup air: 500 ft./min. minimum duct velocity.
2. 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.

D. NFPA 96-2004

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.
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. Each exhaust duct system shall constitute an individual system serving only exhaust hoods in one fire zone on one floor.
g. 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.
h. The bleed air duct shall have a fire damper at least 12" from the master exhaust duct connection, volume balancing damper upstream of the fire damper; the bleed air duct cannot be used for exhaust of grease-laden vapors and labeled as such, and 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. Base of riser.
   b. Each change in direction.
   c. Horizontal: Every 12 feet.
   d. 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 285°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.

E. ASHRAE Standard 154-2003

1. Exhaust/makeup air:
   a. Exhaust systems: 500 ft./minute 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 with respect to dining and other adjacent areas.
      2) Negative with respect to outdoors.
   c. Exhaust discharge shall be designed to prevent reentrainment 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 smoke and/or grease-laden vapor produced by a cooking process, incorporating listed grease-removal devices and fire suppression equipment.
   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—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"	6"	N/A
Single Island Canopy	78"	6"	6"	6"
Double Island Canopy	78"	6"	6"	N/A
Eyebrow	78"	N/A	6"	N/A
Backshelf/Pass-over	24"	6"	10"	N/A

Notes:

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 of Hood	Minimum Exhaust Flow Rate CFM/Lineal Foot of Hood Length			
	Light Duty	Medium Duty	Heavy Duty	Extra-Heavy Duty
Wall-Mounted Canopy	200	300	400	550
Single Island Canopy	400	500	600	700
Double Island Canopy	250	300	400	550
Eyebrow	250	250	Not Permitted	Not Permitted
Backshelf/Pass-over	300	300	400	Not Permitted

Notes:

1 **Light duty: Gas and electric ovens (standard, bake, roasting, revolving, retherm, 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: 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: 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: Appliances using solid fuel such as wood, charcoal, briquettes, and mesquite.**

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.

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 (for example, 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.

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 differentia.l
      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-$^1/_2$ 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, 1-1/2 or 3 hours to match wall construction, Expanding Curtain Type Fire Damper with 1658F. 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, 1-1/2 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, 1-1/2 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, 1-1/2 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. 2003 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 three-hour rated assemblies: 1-1/2 hours
   b. Three hours 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: 286°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 of wall opening with damper.
   d. Smoke dampers may be controlled by area smoke detectors at smoke doors, corridors, or where total coverage smoke detection system is employed.
   e. Smoke damper leakage rating shall not be less than Class II.
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: 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 one-hour fire-resistance rating or less by a ducted HVAC system 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*.

c. 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 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.

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/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: 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 Group B ***and R*** occupancies equipped throughout with an automatic sprinkler system.

3) 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.

4) 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 two-hour fire-resistance rated assemblies.

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. 2006 IMC: 2006 IMC changes are indicated in bold, italicized text in the preceding listings.

E. NFPA 90A-2002

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 three-hour rated assemblies: 1-1/2 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 two-hour rating or more.
    b. 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; otherwise, a shaft enclosure must be provided.
    c. 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 four 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.

17.07 HVAC Smoke Detection Systems Control

A. 2003 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 systems 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 a total-coverage smoke detection 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.

B. 2006 IMC: Requirements are the same as the 2003 IMC.

C. NFPA 90A-2002

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.

D. 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.

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 ever 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.

17.09 Terminal Units

A. For diagrammatic examples of air terminal units, see Fig. 17.4.

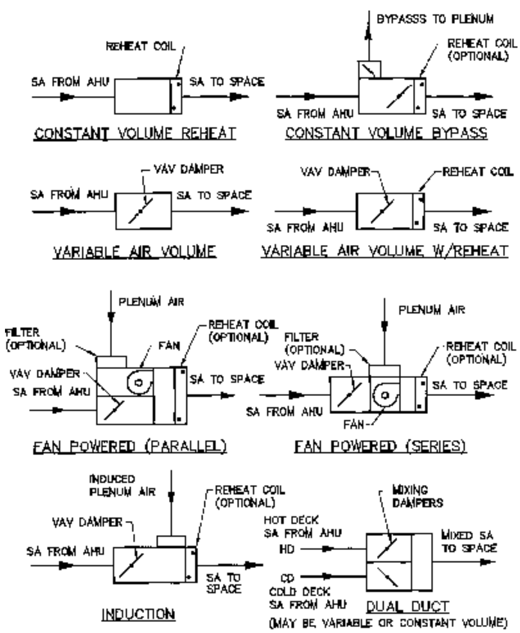


FIGURE 17.4 AIR TERMINAL UNITS.

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.
   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. A series of 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.

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, CT 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 connections 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.**

17.11 Hazardous Exhaust Systems

A. **Hazardous exhaust systems as defined in the 2003 IMC and the 2006 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. Dust and particulate matter.
9. 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. 2006 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 must originate in the same fire area.
   c. Each control branch has a flow regulating device.
   d. Perchloric acid hoods must have a separate exhaust system and cannot be manifolded together.
   e. Radioisotope hoods are properly filtered.
   f. Biological safety cabinets are properly filtered.
   g. A provision is made for continuous operation of the negative statice pressure in the ductwork with standby fans and emergency power operation.

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 with a health hazard of 4.
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 zones.

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 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. In lieu of enclosing the hazardous exhaust duct 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 floor/ceiling assembly must be enclosed in a fire-rated shaft, regardless of whether the system is protected by a fire suppression system.

L. Fire dampers are not permitted in hazardous exhaust systems.

M. 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, cry chemical, carbon dioxide).

1. Except hazardous exhaust systems conveying nonflammable and noncombustible materials at all concentrations.
2. Except in ducts where the cross-sectional duct diameter is less than 10 inches.

N. 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. Minimum hazardous exhaust duct thickness:

Diameter of Duct or Maximum Side Dimension	Minimum Nominal Thickness		
	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

O. Hazardous exhaust ducts shall be supported at intervals not exceeding 10 feet. Supports shall be constructed of noncombustible materials.

17.12 Galvanized Rectangular Ductwork Weights—Pound per Lineal Foot

GALVANIZED RECTANGULAR DUCT WEIGHT

Width + Depth Inches	Sheet Metal Gauge						Surface Area sq.ft./ ln.ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
8	1.51	1.93	2.34	2.76	3.59	4.43	1.33
9	1.70	2.17	2.64	3.11	4.04	4.98	1.50
10	1.89	2.41	2.93	3.45	4.49	5.53	1.67
11	2.08	2.65	3.22	3.80	4.94	6.09	1.83
12	2.27	2.89	3.52	4.14	5.39	6.64	2.00
13	2.45	3.13	3.81	4.49	5.84	7.19	2.17
14	2.64	3.37	4.10	4.83	6.29	7.75	2.34
15	2.83	3.61	4.39	5.18	6.74	8.30	2.50
16	3.02	3.85	4.69	5.52	7.19	8.85	2.67
17	3.21	4.09	4.98	5.87	7.64	9.41	2.83
18	3.40	4.34	5.27	6.21	8.09	9.96	3.00
19	3.59	4.58	5.57	6.56	8.53	10.51	3.17
20	3.78	4.82	5.86	6.90	8.98	11.07	3.34
21	3.96	5.06	6.15	7.25	9.43	11.62	3.50
22	4.15	5.30	6.44	7.59	9.88	12.17	3.67
23	4.34	5.54	6.74	7.94	10.33	12.73	3.83
24	4.53	5.78	7.03	8.28	10.78	13.28	4.00
25	4.72	6.02	7.32	8.63	11.23	13.83	4.17
26	4.91	6.26	7.62	8.97	11.68	14.39	4.34
27	-	6.50	7.91	9.32	12.13	14.94	4.50
28	-	6.74	8.20	9.66	12.58	15.49	4.67
29	-	6.98	8.49	10.01	13.03	16.05	4.83
30	-	7.23	8.79	10.35	13.48	16.60	5.00
31	-	7.47	9.08	10.70	13.92	17.15	5.17
32	-	7.71	9.37	11.04	14.37	17.71	5.34
33	-	7.95	9.67	11.39	14.82	18.26	5.50
34	-	8.20	9.96	11.73	15.27	18.81	5.67
35	-	8.43	10.25	12.08	15.72	19.37	5.83
36	-	8.67	10.55	12.42	16.17	19.92	6.00
37	-	8.91	10.84	12.77	16.62	20.47	6.17

(Continued)

GALVANIZED RECTANGULAR DUCT WEIGHT (*Continued*)

Width + Depth Inches	Sheet Metal Gauge						Surface Area sq.ft./ ln.ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
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
58	-	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
61	-	-	17.87	21.05	27.40	33.75	10.17
62	-	-	18.16	21.39	27.85	34.31	10.34
63	-	-	18.45	21.74	28.30	34.86	10.50
64	-	-	18.75	22.08	28.75	35.41	10.67
65	-	-	19.04	22.43	29.20	35.97	10.83
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
93	-	-	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

(*Continued*)

GALVANIZED RECTANGULAR DUCT WEIGHT (*Continued*)

Width + Depth Inches	Sheet Metal Gauge						Surface Area sq.ft./ ln.ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
98	-	-	28.71	33.81	44.02	54.23	16.34
99	-	-	29.00	34.16	44.47	54.78	16.50
100	-	-	29.29	34.50	44.92	55.33	16.67
101	-	-	29.58	34.85	45.37	55.89	16.83
102	-	-	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
133	-	-	38.96	45.89	59.74	73.59	22.17
134	-	-	39.25	46.23	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

(*Continued*)

GALVANIZED RECTANGULAR DUCT WEIGHT (*Continued*)

Width + Depth Inches	Sheet Metal Gauge						Surface Area sq.ft./ ln.ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
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
168	-	-	49.21	57.96	75.46	92.96	28.00
169	-	-	49.50	58.31	75.91	93.51	28.17
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	-	-	50.67	59.69	77.71	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
203	-	-	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
206	-	-	60.34	71.07	92.53	113.99	34.34
207	-	-	60.63	71.42	92.98	114.54	34.50
208	-	-	60.93	71.76	93.43	115.09	34.67
209	-	-	61.22	72.11	93.88	115.65	34.83
210	-	-	61.51	72.45	94.33	116.20	35.00
211	-	-	61.81	72.80	94.77	116.75	35.17
212	-	-	62.10	73.14	95.22	117.31	35.34
213	-	-	62.39	73.49	95.67	117.86	35.50
214	-	-	62.68	73.83	96.12	118.41	35.67
215	-	-	62.98	74.18	96.57	118.97	35.83
216	-	-	63.27	74.52	97.02	119.52	36.00
217	-	-	63.56	74.87	97.47	120.07	36.17

(*Continued*)

GALVANIZED RECTANGULAR DUCT WEIGHT (*Continued*)

Width + Depth Inches	Sheet Metal Gauge						Surface Area sq.ft./ ln.ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
218	-	-	63.86	75.21	97.92	120.63	36.34
219	-	-	64.15	75.56	98.37	121.18	36.50
220	-	-	64.44	75.90	98.82	121.73	36.67
221	-	-	64.73	76.25	99.27	122.29	36.83
222	-	-	65.03	76.59	99.72	122.84	37.00
223	-	-	65.32	76.94	100.16	123.39	37.17
224	-	-	65.61	77.28	100.61	123.95	37.34
225	-	-	65.91	77.63	101.06	124.50	37.50
226	-	-	66.20	77.97	101.51	125.05	37.67
227	-	-	66.49	78.32	101.96	125.61	37.83
228	-	-	66.79	78.66	102.41	126.16	38.00
229	-	-	67.08	79.01	102.86	126.71	38.17
230	-	-	67.37	79.35	103.31	127.27	38.34
231	-	-	67.66	79.70	103.76	127.82	38.50
232	-	-	67.96	80.04	104.21	128.37	38.67
233	-	-	68.25	80.39	104.66	128.93	38.83
234	-	-	68.54	80.73	105.11	129.48	39.00
235	-	-	68.84	81.08	105.55	130.03	39.17
236	-	-	69.13	81.42	106.00	130.59	39.34
237	-	-	69.42	81.77	106.45	131.14	39.50
238	-	-	69.71	82.11	106.90	131.69	39.67
239	-	-	70.01	82.46	107.35	132.25	39.83
240	-	-	70.30	82.80	107.80	132.80	40.00

Notes:

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 (i.e., a 20 × 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.

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
14	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
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

(*Continued*)

GALVANIZED ROUND DUCT WEIGHT (*Continued*)

Diameter	Gauge						Surface Area sq.ft./ Lin.ft.
	26	24	22	20	18	16	
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
84	---	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	23.56
92	---	34.80	42.33	49.86	64.91	79.96	24.09
94	---	35.56	43.25	50.94	66.32	81.70	24.61
96	---	36.32	44.17	52.02	66.73	83.44	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
5 × 18	9.5	0.57	3.40	24	4.9
5 × 19	10.0	0.63	3.66	24	5.3
5 × 21	10.5	0.68	3.93	24	5.7
6 × 8	6.9	0.26	1.83	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

(*Continued*)

GALVANIZED FLAT OVAL DUCTWORK WEIGHT (*Continued*)

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ ln.ft.	Gauge	Weight lbs./ ln.ft.
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
7 × 20	12.0	0.88	3.93	24	5.7
7 × 21	12.5	0.95	4.19	24	6.1
7 × 23	13.0	1.03	4.45	24	6.4
8 × 10	9.0	0.44	2.36	24	3.4
8 × 11	9.8	0.53	2.62	24	3.8
8 × 13	10.6	0.62	2.88	24	4.2
8 × 14	11.2	0.70	3.14	24	4.5
8 × 16	11.5	0.79	3.40	24	4.9
8 × 17	12.0	0.87	3.67	24	5.3
8 × 18	12.4	0.90	3.80	24	5.5
8 × 19	13.0	0.96	3.93	24	5.7
8 × 21	13.5	1.05	4.18	24	6.1
8 × 22	14.0	1.13	4.45	24	6.4
8 × 24	14.4	1.23	4.71	24	6.8
8 × 27	15.2	1.40	5.23	22	9.2
8 × 30	15.9	1.57	5.76	22	10.2
8 × 33	16.6	1.74	6.28	22	11.0
8 × 35	17.0	1.83	6.54	22	11.5
8 × 36	17.3	1.92	6.80	22	12.0
8 × 39	17.9	2.09	7.33	22	12.9
8 × 43	18.6	2.27	7.85	22	13.8
8 × 46	19.1	2.44	8.37	22	14.7
8 × 49	19.6	2.62	8.89	20	18.4
8 × 50	20.0	2.71	9.16	20	19.0
8 × 52	20.2	2.80	9.42	20	19.5
8 × 58	21.0	3.14	10.47	20	21.7
8 × 65	22.0	3.49	11.52	20	23.8
8 × 71	23.0	3.84	12.57	18	33.9
8 × 77	24.0	4.19	13.61	18	36.7
9 × 12	10.8	0.64	2.88	24	4.2
9 × 14	11.5	0.74	3.14	24	4.6
9 × 15	12.0	0.83	3.40	24	4.9
9 × 17	12.9	0.93	3.67	24	5.3
9 × 18	13.5	1.03	3.93	24	5.7
9 × 20	14.0	1.13	4.19	24	6.1
9 × 22	14.5	1.23	4.45	24	6.4
9 × 23	15.0	1.33	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

(*Continued*)

GALVANIZED FLAT OVAL DUCTWORK WEIGHT (*Continued*)

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ ln.ft.	Gauge	Weight lbs./ ln.ft.
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
11 × 14	13.0	0.90	3.40	24	4.9
11 × 16	13.6	1.02	3.67	24	5.3
11 × 17	14.0	1.14	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
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

(*Continued*)

GALVANIZED FLAT OVAL DUCTWORK WEIGHT (*Continued*)

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ ln.ft.	Gauge	Weight lbs./ ln.ft.
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
16 × 41	26.8	4.19	8.38	22	14.7
16 × 44	27.7	4.53	8.89	22	15.6
16 × 46	28.0	4.71	9.16	22	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
18 × 65	35.3	7.67	12.51	20	25.9
18 × 68	36.0	8.07	13.10	20	27.1
18 × 71	37.0	8.44	13.61	18	36.7
18 × 78	38.0	9.23	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

(*Continued*)

GALVANIZED FLAT OVAL DUCTWORK WEIGHT (*Continued*)

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ ln.ft.	Gauge	Weight lbs./ ln.ft.
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
22 × 53	35.8	7.44	11.00	20	22.8
22 × 57	36.7	7.92	11.52	20	23.8
22 × 60	37.8	8.40	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

(*Continued*)

GALVANIZED FLAT OVAL DUCTWORK WEIGHT (*Continued*)

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
32 × 35	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
32 × 45	39.0	8.38	10.47	22	18.4
32 × 48	40.5	9.08	11.00	22	15.3
32 × 51	42.0	9.77	11.52	20	23.8
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

(*Continued*)

GALVANIZED FLAT OVAL DUCTWORK WEIGHT (*Continued*)

Nominal Flat Oval Size	Equiv. Round	Cross Sectional Area sq.ft.	Surface Area sq.ft./ ln.ft.	Gauge	Weight lbs./ ln.ft.
36 × 67	51.1	14.92	14.66	20	30.3
36 × 71	52.7	15.71	15.18	18	40.9
38 × 41	40.0	8.70	10.47	22	18.4
38 × 44	41.8	9.53	11.00	22	19.3
38 × 47	43.5	10.36	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
± 1/2"	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

17.16 Friction Loss Correction Factors for Ducts

FRICTION LOSS CORRECTION FACTORS FOR DUCTS

Velocity FPM	Material							
	Galv. Steel Stainless Steel	Duct Liner	Aluminum	Carbon Steel	Fiberous Glass (2)	PVC	Concrete or Conc. Block (1)	Drywall
500	1.00	1.25	0.98	0.93	1.25	0.93	1.5–1.9	1.25
600	1.00	1.28	0.98	0.92	1.27	0.92	1.5–1.9	1.27
700	1.00	1.30	0.98	0.92	1.30	0.92	1.5–2.0	1.30
800	1.00	1.31	0.97	0.91	1.31	0.91	1.5–2.0	1.31
900	1.00	1.32	0.97	0.90	1.31	0.90	1.5–2.0	1.31
1000	1.00	1.33	0.97	0.90	1.32	0.90	1.6–2.1	1.32
1200	1.00	1.36	0.97	0.89	1.34	0.89	1.6–2.1	1.34
1400	1.00	1.38	0.96	0.88	1.36	0.88	1.6–2.1	1.36
1600	1.00	1.40	0.96	0.87	1.38	0.87	1.6–2.2	1.38
1800	1.00	1.41	0.96	0.86	1.39	0.86	1.6–2.3	1.39
2000	1.00	1.42	0.96	0.85	1.40	0.85	1.7–2.3	1.40
2500	1.00	1.45	0.95	0.84	1.42	0.84	1.7–2.3	1.42
3000	1.00	1.47	0.95	0.83	1.43	0.83	1.7–2.3	1.43
3500	1.00	1.49	0.95	0.83	1.44	0.83	1.8–2.4	1.44
4000	1.00	1.50	0.94	0.82	1.45	0.82	1.8–2.4	1.45
4500	1.00	1.52	0.94	0.81	1.46	0.81	1.8–2.4	1.46
5000	1.00	1.54	0.94	0.80	1.48	0.80	1.8–2.4	1.48
5500	1.00	1.55	0.93	0.79	1.49	0.79	1.8–2.4	1.49
6000	1.00	1.56	0.93	0.78	1.50	0.78	1.8–2.4	1.50

Notes:
1 First number indicated is for smooth concrete; second number indicated is for rough concrete.
2 Flexible ductwork has a friction loss correction factor of 1.5–2.0 times the value 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.
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

(*Continued*)

VELOCITIES VS. VELOCITY PRESSURES (*Continued*)

Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.	Velocity FPM	Velocity Pressure in. W.G.
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
1,800	0.202	3,800	0.900	5,800	2.097
1,850	0.213	3,850	0.924	5,850	2.134
1,900	0.225	3,900	0.948	5,900	2.170
1,950	0.237	3,950	0.973	5,950	2.207
2,000	0.249	4,000	0.998	6,000	2.244
6,050	2.282	8,050	4.040	10,050	6.297
6,100	2.320	8,100	4.090	10,100	6.360
6,150	2.358	8,150	4.141	10,150	6.423
6,200	2.397	8,200	4.192	10,200	6.486
6,250	2.435	8,250	4.243	10,250	6.550
6,300	2.474	8,300	4.295	10,300	6.614
6,350	2.514	8,350	4.347	10,350	6.678
6,400	2.554	8,400	4.399	10,400	6.743
6,450	2.594	8,450	4.452	10,450	6.808
6,500	2.634	8,500	4.504	10,500	6.873
6,550	2.675	8,550	4.558	10,550	6.939
6,600	2.716	8,600	4.611	10,600	7.005
6,650	2.757	8,650	4.665	10,650	7.071
6,700	2.799	8,700	4.719	10,700	7.138
6,750	2.841	8,750	4.773	10,750	7.205
6,800	2.883	8,800	4.828	10,800	7.272
6,850	2.925	8,850	4.883	10,850	7.339
6,900	2.968	8,900	4.938	10,900	7.407
6,950	3.011	8,950	4.994	10,950	7.475
7,000	3.055	9,000	5.050	11,000	7.544
7,050	3.099	9,050	5.106	11,050	7.612
7,100	3.143	9,100	5.163	11,100	7.681
7,150	3.187	9,150	5.220	11,150	7.751
7,200	3.232	9,200	5.277	11,200	7.820
7,250	3.277	9,250	5.334	11,250	7.890
7,300	3.322	9,300	5.392	11,300	7.961
7,350	3.368	9,350	5.450	11,350	8.031
7,400	3.414	9,400	5.509	11,400	8.102
7,450	3.460	9,450	5.567	11,450	8.173
7,500	3.507	9,500	5.627	11,500	8.245
7,550	3.554	9,550	5.686	11,550	8.317
7,600	3.601	9,600	5.746	11,600	8.389
7,650	3.649	9,650	5.807	11,650	8.461
7,700	3.696	9,700	5.866	11,700	8.534
7,750	3.745	9,750	5.927	11,750	8.607
7,800	3.793	9,800	5.988	11,800	8.681
7,850	3.842	9,850	6.049	11,850	8.755
7,900	3.891	9,900	6.110	11,900	8.829
7,950	3.940	9,950	6.172	11,950	8.903
8,000	3.990	10,000	6.234	12,000	8.978

17.18 Equivalent Round/Rectangular Ducts

EQUIVALENT RECTANGULAR DUCT DIMENSIONS

Duct Dia. in.	Rect. Size in.	Aspect Ratio 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
6	Width	---	6						
	Height	---	5						
7	Width	6	8						
	Height	6	6						
8	Width	7	9	9	11				
	Height	7	7	6	6				
9	Width	8	9	11	11	12	14		
	Height	8	7	7	6	6	6		
10	Width	9	10	12	12	14	14	15	17
	Height	9	8	8	7	7	6	6	6
11	Width	10	11	12	14	14	16	18	17
	Height	10	9	8	8	7	7	7	6
12	Width	11	13	14	14	16	16	18	19
	Height	11	10	9	8	8	7	7	7
13	Width	12	14	15	16	18	18	20	19
	Height	12	11	10	9	9	8	8	7
14	Width	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	Width	27	30	33	35	38	41	43	44
	Height	27	24	22	20	19	18	17	16
30	Width	27	31	35	37	40	43	45	47
	Height	27	25	23	21	20	19	18	17
31	Width	28	31	35	39	40	43	45	50
	Height	28	25	23	22	20	19	18	18
32	Width	29	33	36	39	42	45	48	50
	Height	29	26	24	22	21	20	19	18
33	Width	30	34	38	40	44	47	50	52
	Height	30	27	25	23	22	21	20	19
34	Width	31	35	39	42	44	47	50	52
	Height	31	28	26	24	22	21	20	19

(Continued)

EQUIVALENT RECTANGULAR DUCT DIMENSIONS (*Continued*)

Duct Dia. in.	Rect. Size in.	Aspect Ratio							
		1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
35	Width	32	36	39	42	46	50	53	55
	Height	32	29	26	24	23	22	21	20
20	Width	18	20	23	25	26	27	30	30
	Height	18	16	15	14	13	12	12	11
36	Width	33	36	41	44	48	50	53	55
	Height	33	29	27	25	24	22	21	20
38	Width	35	39	44	47	50	54	58	61
	Height	35	31	29	27	25	24	23	22
40	Width	37	41	45	49	52	56	60	63
	Height	37	33	30	28	26	25	24	23
42	Width	38	43	48	51	56	59	63	66
	Height	38	34	32	29	28	26	25	24
44	Width	40	45	50	54	58	61	65	69
	Height	40	36	33	31	29	27	26	25
46	Width	42	48	53	56	60	65	68	72
	Height	42	38	35	32	30	29	27	26
48	Width	44	49	54	60	62	68	70	74
	Height	44	39	36	34	31	30	28	27
50	Width	46	51	57	61	66	70	75	77
	Height	46	41	38	35	33	31	30	28
52	Width	48	54	59	63	68	72	78	83
	Height	48	43	39	36	34	32	31	30
54	Width	49	55	62	67	70	77	80	85
	Height	49	44	41	38	35	34	32	31
56	Width	51	58	63	68	74	79	83	88
	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	98	105	112	119	128	135
	Height	79	70	65	60	56	53	51	49
88	Width	80	90	99	107	116	124	130	138
	Height	80	72	66	61	58	55	52	50
90	Width	82	93	102	110	118	126	133	140
	Height	82	74	68	63	59	56	53	51

(*Continued*)

EQUIVALENT RECTANGULAR DUCT DIMENSIONS (*Continued*)

Duct Dia. in.	Rect. Size in.	Aspect Ratio							
		1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
92	Width Height	84 84	94 75	104 69	112 64	120 60	128 57	138 55	143 52
94	Width Height	86 86	96 77	107 71	116 66	124 62	131 58	140 56	146 53
96	Width Height	88 88	99 79	108 72	117 67	126 63	135 60	143 57	151 55
98	Width Height	90 90	100 80	111 74	119 68	128 64	137 61	145 58	154 56
100	Width Height	91 91	103 82	113 75	123 70	132 66	140 62	148 59	157 57
102	Width Height	93 93	105 84	116 77	124 71	134 67	142 63	153 61	160 58
104	Width Height	95 95	106 85	117 78	128 73	136 68	146 65	155 62	162 59

EQUIVALENT RECTANGULAR DUCT DIMENSIONS

Duct Dia. in.	Rect. Size in.	Aspect Ratio						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
6	Width Height							
7	Width Height							
8	Width Height							
9	Width Height							
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

(*Continued*)

EQUIVALENT RECTANGULAR DUCT DIMENSIONS (*Continued*)

Duct Dia. in.	Rect. Size in.	Aspect Ratio						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
25	Width Height	42 14	46 13	48 12	55 11	60 10	70 10	72 9
26	Width Height	42 14	46 13	52 13	55 11	66 11	70 10	72 9
27	Width Height	45 15	49 14	52 13	60 12	66 11	70 10	80 10
28	Width Height	45 15	49 14	56 14	60 12	66 11	77 11	80 10
29	Width Height	48 16	53 15	56 14	65 13	72 12	77 11	88 11
30	Width Height	48 16	53 15	60 15	65 13	72 12	77 11	88 11
31	Width Height	51 17	56 16	60 15	70 14	78 13	84 12	88 11
32	Width Height	54 18	56 16	60 15	70 14	78 13	84 12	96 12
33	Width Height	54 18	60 17	64 16	75 15	78 13	91 13	96 12
34	Width Height	57 19	60 17	64 16	75 15	84 14	91 13	96 12
35	Width Height	57 19	63 18	68 17	75 15	84 14	91 13	104 13
36	Width Height	60 20	63 18	68 17	80 16	90 15	98 14	104 13
38	Width Height	63 21	67 19	72 18	85 17	96 16	105 15	112 14
40	Width Height	66 22	70 20	76 19	90 18	96 16	105 15	120 15
42	Width Height	69 23	74 21	80 20	90 18	102 17	112 16	120 15
44	Width Height	72 24	81 23	84 21	95 19	108 18	119 17	128 16
46	Width Height	75 25	84 24	88 22	100 20	114 19	126 18	136 17
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	

EQUIVALENT RECTANGULAR DUCT DIMENSIONS

Duct Dia. in.	Rect. Size in.	Aspect Ratio						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
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			
78	Width Height	129 43	140 40	152 38				
80	Width Height	132 44	144 41	156 39				
82	Width Height	135 45	147 42	160 40				
84	Width Height	138 46	151 43	164 41				
86	Width Height	141 47	154 44	168 42				
88	Width Height	144 48	158 45					
90	Width Height	147 49	161 46					
92	Width Height	150 50	165 47					
94	Width Height	153 51	168 48					
96	Width Height	159 53						
98	Width Height	162 54						
100	Width Height	165 55						
102	Width Height	168 56						
104	Width Height							

Notes:

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	11
3.0	3.3											
3.5	3.5	3.8										
4.0	3.8	4.1	4.4									
4.5	4.0	4.3	4.6	4.9								
5.0	4.2	4.6	4.9	5.2	5.5							
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	12.0
12	6.2	6.8	7.3	7.8	8.3	8.7	9.1	9.9	10.7	11.3	12.0	12.6
13	**6.4**	7.0	7.6	8.1	8.6	9.0	9.5	10.3	11.1	11.8	12.4	13.1
14	**6.6**	7.2	7.8	8.4	8.9	9.3	9.8	10.8	11.4	12.2	12.9	13.5
15	6.8	7.5	8.0	8.6	9.1	9.6	10.1	11.0	11.8	12.6	13.3	14.0
16	7.0	7.7	8.3	8.8	9.4	9.9	10.4	11.3	12.2	13.0	13.7	14.4
17	7.2	7.9	**8.5**	9.1	9.6	10.2	10.7	11.6	12.5	13.4	14.1	14.9
18	7.3	8.0	**8.7**	9.3	9.9	10.4	11.0	11.9	12.9	13.7	14.5	15.3
19	7.5	8.2	**8.9**	9.5	10.1	10.7	11.2	12.2	13.2	14.1	14.9	15.7
20	7.7	8.4	9.1	9.7	10.3	10.9	11.5	12.6	13.5	14.4	15.2	16.0
22	8.0	8.7	9.5	10.1	**10.8**	11.4	12.0	13.0	14.1	15.0	15.9	16.8
24	8.3	9.1	9.8	10.5	11.2	**11.8**	12.4	13.5	14.6	15.6	16.5	17.4
26	8.5	9.4	10.1	10.9	11.5	**12.2**	**12.8**	14.0	15.1	16.2	17.1	18.1
28	8.8	9.6	10.4	11.2	11.9	**12.6**	**13.2**	14.5	15.6	16.7	17.7	18.7
30	9.0	9.9	10.7	11.5	12.2	13.0	13.6	14.9	16.1	17.2	18.3	19.3
32		10.2	11.0	11.8	12.6	13.3	14.0	15.3	16.5	17.7	18.8	19.8
34		10.4	11.3	12.2	12.9	13.6	14.4	15.7	**17.0**	18.2	19.3	20.4
36		10.7	11.5	12.4	13.2	14.0	14.7	16.1	**17.4**	18.6	19.8	20.9
38			11.8	12.7	13.5	14.3	15.0	16.5	**17.8**	**19.0**	20.2	21.4
40			12.0	13.1	13.8	14.7	15.3	16.8	18.2	19.5	20.7	21.8
42				13.2	14.0	14.9	15.6	17.1	18.5	19.9	**21.1**	22.3
44				13.4	14.3	15.1	15.9	17.5	18.9	20.3	**31.5**	22.7
46				13.7	14.6	15.4	16.2	17.8	19.3	20.6	**21.9**	**23.2**
48					14.8	15.7	16.5	18.1	19.6	21.0	**22.3**	**23.6**
50					15.1	15.9	16.8	18.4	19.9	21.4	22.7	24.0
52						16.2	17.1	18.7	20.2	21.7	23.1	24.4
54						16.4	17.3	19.0	20.6	22.0	23.5	24.8
56						16.7	17.6	19.3	20.9	22.4	23.8	25.2
58							17.8	19.5	21.2	22.7	24.2	25.5
60							18.1	19.8	21.5	23.0	24.5	25.9
62								20.1	21.7	23.3	24.8	26.3
64								20.3	22.0	23.6	25.1	26.6
66								20.6	22.3	23.9	25.5	26.9
68								20.8	22.6	24.2	25.8	27.3
70								21.1	22.8	24.5	26.1	27.6
72									23.1	24.8	26.4	27.9
74									23.3	25.1	26.7	28.2
76									23.6	25.3	27.0	28.5
78									23.8	25.6	27.3	28.8
80									24.1	25.8	27.5	29.1
82										26.1	27.8	29.4
84										26.4	28.1	29.7
86										26.6	28.3	30.0
88										26.8	28.6	30.3
90										27.1	28.9	30.6
92											29.1	30.8
94											29.4	31.1
96											29.6	31.4
98											29.9	31.7
100											30.1	31.9

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	12	13	14	15	16	17	18	19	20	22	24	26
3.0												
3.5												
4.0												
4.5												
5.0												
5.5												
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	27.3	28.4
28	19.6	20.5	21.3	22.1	22.9	23.7	24.4	25.1	25.8	27.1	28.3	29.5
30	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.6	28.0	29.3	30.5
32	20.8	21.8	22.7	23.5	24.4	25.2	26.0	26.7	27.5	28.9	30.2	31.5
34	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	31.0	32.4
36	21.9	22.9	23.9	24.8	25.7	26.6	27.4	28.2	29.0	30.5	32.0	33.3
38	22.4	23.5	24.5	25.4	26.4	27.2	28.1	28.9	29.8	31.3	32.8	34.2
40	22.9	24.0	25.0	26.0	27.0	27.9	28.8	29.6	30.5	32.1	33.6	35.1
42	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.3	31.2	32.8	34.4	35.9
44	23.9	25.0	26.1	27.1	28.1	29.1	30.0	30.9	31.8	33.5	35.1	36.7
46	24.4	25.5	26.6	27.7	28.7	29.7	30.6	31.6	32.5	34.2	35.9	37.4
48	24.8	26.0	27.1	28.2	29.2	30.2	31.2	32.2	33.1	34.9	36.6	38.2
50	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8	33.7	35.5	37.2	38.9
52	25.7	26.9	28.0	29.2	30.3	31.3	32.3	33.3	34.3	36.2	37.9	39.6
54	26.1	**27.3**	28.5	29.7	30.8	31.8	32.9	33.9	34.9	36.8	38.6	40.3
56	26.5	**27.7**	28.9	30.1	31.2	32.3	33.4	34.4	35.4	37.4	39.2	41.0
58	26.9	**28.2**	**29.4**	30.6	31.7	32.8	33.9	35.0	36.0	38.0	39.8	41.6
60	27.3	28.6	29.8	31.0	32.2	33.3	34.4	35.5	36.5	38.5	40.4	42.3
62	27.6	28.9	30.2	31.5	32.6	33.8	34.9	36.0	37.1	39.1	41.0	42.9
64	28.0	29.3	30.6	**31.9**	33.1	34.3	35.4	36.5	37.6	39.6	41.6	43.5
66	28.4	29.7	31.0	**32.3**	**33.5**	34.7	35.9	37.0	38.1	40.2	42.2	44.1
68	28.7	30.1	31.4	**32.7**	**33.9**	35.2	36.3	37.5	38.6	40.7	42.8	44.7
70	29.1	30.4	31.8	33.1	34.4	35.6	36.8	37.9	39.1	41.2	43.3	45.3
72	29.4	30.8	32.2	33.5	34.8	36.0	37.2	38.4	39.5	41.7	43.8	45.8
74	29.7	31.2	32.5	33.9	35.2	36.4	**37.7**	38.8	40.0	42.2	44.4	46.4
76	30.0	31.5	32.9	34.3	35.6	36.8	**38.1**	39.3	40.5	42.7	44.9	47.0
78	30.4	31.8	33.3	34.6	36.0	37.2	**38.5**	**39.7**	40.9	43.2	45.4	47.5
80	30.7	32.2	33.6	35.0	36.3	37.6	38.9	40.2	41.4	43.7	45.9	48.0
82	31.0	32.5	34.0	35.4	36.7	38.0	39.3	40.6	**41.8**	44.1	46.4	48.5
84	31.3	32.8	34.3	35.7	37.1	38.4	39.7	41.0	**42.2**	44.6	46.9	49.0
86	31.6	33.1	34.6	36.1	37.4	38.8	40.1	41.4	**42.6**	45.0	47.3	49.6
88	31.9	33.4	34.9	36.4	37.8	39.2	40.5	41.8	**43.1**	45.5	47.8	50.0
90	32.2	33.8	35.3	36.7	38.2	39.5	40.9	42.2	43.5	45.9	48.3	50.5
92	32.5	34.1	35.6	37.1	38.5	39.9	41.3	42.6	43.9	46.4	48.7	51.0
94	32.8	34.4	35.9	37.4	38.9	40.3	41.7	43.0	44.3	46.8	49.2	51.5
96	33.0	34.7	36.2	37.7	39.2	40.6	42.0	43.3	44.7	47.2	49.6	52.0
98	33.3	35.0	36.5	38.1	39.5	41.0	42.4	43.7	45.1	47.6	**50.1**	52.5
100	33.6	35.2	36.8	38.4	39.8	41.3	42.7	44.1	45.4	48	50.5	52.9

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	28	30	32	34	36	38	40	42	44	46	48	50
3.0												
3.5												
4.0												
4.5												
5.0												
5.5												
6												
7												
8												
9												
10												
11												
12												
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	53.6	54.7
52	41.2	42.8	44.3	45.7	47.1	48.4	49.7	51.0	52.2	53.4	54.6	55.7
54	41.9	43.5	45.1	46.5	48.0	49.3	50.7	52.0	53.2	54.4	55.6	56.8
56	42.7	44.3	45.8	47.3	48.8	50.2	51.6	52.9	54.2	55.4	56.6	57.8
58	43.3	45.0	46.6	48.1	49.6	51.0	52.4	53.8	55.1	56.4	57.6	58.8
60	44.0	45.7	47.3	48.9	50.4	51.9	53.3	54.7	60.0	57.3	58.6	59.8
62	44.7	46.4	48.0	49.6	51.2	52.7	54.1	55.5	56.9	58.2	59.5	60.8
64	45.3	47.1	48.7	50.4	51.9	53.5	54.9	56.4	57.8	59.1	60.4	61.7
66	46.0	47.7	49.4	51.1	52.7	54.2	55.7	57.2	58.6	60.0	61.3	62.6
68	46.6	48.4	50.1	51.8	53.4	55.0	56.5	58.0	59.4	60.8	62.2	63.6
70	47.2	49.0	50.8	52.5	54.1	55.7	57.3	58.8	60.3	61.7	63.1	64.4
72	47.8	49.6	51.4	53.2	54.8	56.5	58.0	59.6	61.1	62.5	63.9	65.3
74	48.4	50.3	52.1	53.8	55.5	57.2	58.8	60.3	61.9	63.3	64.8	66.2
76	48.9	50.9	52.7	54.5	56.2	57.9	59.5	61.1	62.6	64.1	65.6	67.0
78	49.5	51.4	53.3	55.1	56.9	58.6	60.2	61.8	63.4	64.9	66.4	67.9
80	50.1	52.0	53.9	55.8	57.5	59.3	60.9	62.6	64.1	65.7	67.2	68.7
82	50.6	52.6	54.6	56.4	58.2	59.9	61.6	63.3	64.9	66.5	68.0	69.5
84	51.1	53.2	55.1	57.0	58.8	60.6	62.3	64.0	65.6	67.2	68.7	70.3
86	51.7	53.7	55.7	57.6	59.4	61.2	63.0	64.7	66.3	67.9	69.5	71.0
88	52.2	54.3	56.3	58.2	60.1	61.9	63.6	65.4	67.0	68.7	70.2	71.8
90	52.7	54.8	56.8	58.8	60.7	62.5	64.3	66.0	67.7	69.4	71.0	72.6
92	53.2	55.3	57.4	59.3	61.3	63.1	64.9	66.7	68.4	70.1	71.7	73.3
94	53.7	55.9	57.9	59.9	61.9	63.7	65.6	67.3	69.1	70.8	72.4	74.0
96	54.2	56.4	58.4	60.5	62.4	64.3	66.2	68.0	69.7	71.5	73.1	74.8
98	54.7	56.9	59.0	61.1	63.0	64.9	66.8	68.6	70.4	72.2	73.8	75.5
100	55.2	57.4	59.5	61.6	63.6	65.5	67.4	69.2	71	72.8	74.5	76.2

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	52	54	56	58	60	62	64	66	68	70	72	74
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	80.9
76	68.4	69.8	71.1	72.4	73.7	75.0	76.2	77.4	78.6	79.7	80.9	82.0
78	69.3	70.6	72.0	73.3	74.6	75.9	77.1	78.4	79.6	80.7	81.9	83.0
80	70.1	71.6	72.9	74.2	75.4	76.9	78.1	79.4	80.6	81.8	82.9	84.1
82	70.9	72.3	73.7	75.1	76.4	77.8	79.0	80.3	81.5	82.8	84.0	85.1
84	71.7	72.6	74.6	76.0	77.3	78.7	80.0	81.3	82.5	83.8	85.0	86.1
86	72.5	73.3	75.4	76.8	78.2	79.6	80.9	82.2	83.5	84.7	85.9	87.1
88	73.3	74.0	76.3	77.7	79.1	80.5	81.8	83.1	84.4	85.7	86.9	88.1
90	74.1	75.6	77.1	78.5	79.9	81.3	82.7	84.0	85.3	86.6	87.9	89.1
92	74.9	76.4	77.9	79.3	80.8	82.2	83.5	85.4	86.2	87.5	88.8	90.1
94	75.6	77.2	78.7	80.1	81.6	83.0	84.4	86.0	87.1	88.4	89.7	91.0
96	76.3	77.9	79.4	80.9	82.4	83.8	85.3	86.6	88.0	89.3	90.7	91.9
98	77.1	78.7	80.2	81.7	83.2	84.7	86.1	87.5	88.9	90.2	91.6	92.9
100	77.8	79.4	81	82.5	84	85.5	86.9	88.3	89.7	91.1	92.4	93.8

ROUND/RECTANGULAR DUCT EQUIVALENTS

A\B	76	78	80	82	84	86	88	90	92	94	96	98
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	102.8		
96	93.2	94.5	95.7	96.9	98.1	99.3	100.5	101.6	102.7	103.8	104.9	
98	94.2	95.5	96.7	97.9	99.1	100.3	101.5	102.7	103.8	104.9	106.0	107.1
100	95.1	96.4	97.6	98.9	100.1	101.3	102.5	103.7	104.8	106	107.1	108.2

Notes:

1 Shaded areas and bold numbers exceed the recommended maximum 4:1 aspect ratio.

PART 18

Piping Systems, General

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 Type 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 Type K, L, and M.
3. Types K, L, and M copper may be hard drawn or annealed (soft) temper.
    a. Hard drawn copper pipe has higher allowable stress than annealed copper pipe.
4. 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).
5. Type K is generally used for higher pressure/temperature applications and for direct burial.
6. Type L copper pipe is the most common copper pipe used in HVAC applications.
7. Type M copper pipe should not be used where subject to external damage.
8. 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 multi-unit 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)			Water Volume Gal./Ft.
						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	0.011
	L	0.545	0.040	0.625	0.233	0.250	0.101	0.351	0.012
	M	0.569	0.028	0.625	0.254	0.179	0.110	0.289	0.013
3/4	K	0.745	0.065	0.875	0.436	0.562	0.189	0.751	0.023
	L	0.785	0.045	0.875	0.484	0.399	0.210	0.609	0.025
	M	0.811	0.032	0.875	0.517	0.288	0.224	0.512	0.027
1	K	0.995	0.065	1.125	0.778	0.736	0.337	1.073	0.040
	L	1.025	0.050	1.125	0.825	0.574	0.357	0.932	0.043
	M	1.055	0.035	1.125	0.874	0.407	0.379	0.786	0.045
1-1/4	K	1.245	0.065	1.375	1.217	0.909	0.527	1.437	0.063
	L	1.265	0.055	1.375	1.257	0.775	0.545	1.320	0.065
	M	1.291	0.042	1.375	1.309	0.598	0.567	1.165	0.068
1-1/2	K	1.481	0.072	1.625	1.723	1.194	0.746	1.941	0.089
	L	1.505	0.060	1.625	1.779	1.003	0.771	1.774	0.092
	M	1.527	0.049	1.625	1.831	0.825	0.793	1.618	0.095
2	K	1.959	0.083	2.125	3.014	1.810	1.306	3.116	0.157
	L	1.985	0.070	2.125	3.095	1.536	1.341	2.877	0.161
	M	2.009	0.058	2.125	3.170	1.280	1.373	2.654	0.165
2-1/2	K	2.435	0.095	2.625	4.657	2.567	2.018	4.585	0.242
	L	2.465	0.080	2.625	4.772	2.174	2.068	4.242	0.248
	M	2.495	0.065	2.625	4.889	1.777	2.118	3.895	0.254
3	K	2.907	0.109	3.125	6.637	3.511	2.876	6.387	0.345
	L	2.945	0.090	3.125	6.812	2.917	2.951	5.868	0.354
	M	2.981	0.072	3.125	6.979	2.348	3.024	5.371	0.363
4	K	3.857	0.134	4.125	11.684	5.712	5.062	10.774	0.607
	L	3.905	0.110	4.125	11.977	4.717	5.189	9.906	0.622
	M	3.935	0.095	4.125	12.161	4.089	5.269	9.358	0.632
5	K	4.805	0.160	5.125	18.133	8.484	7.856	16.341	0.942
	L	4.875	0.125	5.125	18.665	6.675	8.087	14.762	0.970
	M	4.907	0.109	5.125	18.911	5.839	8.193	14.033	0.982
6	K	5.741	0.192	6.125	25.886	12.166	11.215	23.381	1.345
	L	5.845	0.140	6.125	26.832	8.949	11.625	20.574	1.394
	M	5.881	0.122	6.125	27.164	7.822	11.769	19.590	1.411
8	K	7.583	0.271	8.125	45.162	22.732	19.566	42.298	2.346
	L	7.725	0.200	8.125	46.869	16.928	20.306	37.234	2.435
	M	7.785	0.170	8.125	47.600	14.443	20.623	35.066	2.473
10	K	9.449	0.338	10.125	70.123	35.330	30.381	65.711	3.643
	L	9.625	0.250	10.125	72.760	26.367	31.523	57.890	3.780
	M	9.701	0.212	10.125	73.913	22.445	32.023	54.468	3.840
12	K	11.315	0.405	12.125	100.554	50.695	43.565	94.259	5.224
	L	11.565	0.280	12.125	105.046	35.422	45.511	80.933	5.457
	M	11.617	0.254	12.125	105.993	32.203	45.921	78.124	5.506

PROPERTIES OF STEEL PIPE

Pipe Size In.	Schedule		Inside Dia. In.	Wall Thick In.	Outside Dia. In.	Area Sq.In.	Weight (1) Pipe Lbs./Ft.	Weight (1) Water Lbs./Ft.	Weight (1) Total Lbs./Ft.	Water Volume Gal./Ft.
1/2	10	---	0.674	0.083	0.840	0.357	0.671	0.155	0.826	0.019
	40	STD	0.622	0.109	0.840	0.304	0.851	0.132	0.983	0.016
	80	XS	0.546	0.147	0.840	0.234	1.088	0.101	1.189	0.012
	160	---	0.466	0.187	0.840	0.171	1.304	0.074	1.378	0.009
	---	XXS	0.252	0.294	0.840	0.050	1.714	0.022	1.736	0.003
3/4	10	---	0.884	0.083	1.050	0.614	0.857	0.266	1.123	0.032
	40	STD	0.824	0.113	1.050	0.533	1.131	0.231	1.362	0.028
	80	XS	0.742	0.154	1.050	0.432	1.474	0.187	1.661	0.022
	160	---	0.614	0.218	1.050	0.296	1.937	0.128	2.065	0.015
	---	XXS	0.434	0.308	1.050	0.148	2.441	0.064	2.505	0.008
1	10	---	1.097	0.109	1.315	0.945	1.404	0.409	1.813	0.049
	40	STD	1.049	0.133	1.315	0.864	1.679	0.374	2.053	0.045
	80	XS	0.957	0.179	1.315	0.719	2.172	0.312	2.483	0.037
	160	---	0.815	0.250	1.315	0.522	2.844	0.226	3.070	0.027
	---	XXS	0.599	0.358	1.315	0.282	3.659	0.122	3.781	0.015
1-1/4	10	---	1.442	0.109	1.660	1.633	1.806	0.708	2.513	0.085
	40	STD	1.380	0.140	1.660	1.496	2.273	0.648	2.921	0.078
	80	XS	1.278	0.191	1.660	1.283	2.997	0.556	3.552	0.067
	160	---	1.160	0.250	1.660	1.057	3.765	0.458	4.223	0.055
	---	XXS	0.896	0.382	1.660	0.631	5.214	0.273	5.487	0.033
1-1/2	10	---	1.682	0.109	1.900	2.222	2.085	0.963	3.048	0.115
	40	STD	1.610	0.145	1.900	2.036	2.718	0.882	3.600	0.106
	80	XS	1.500	0.200	1.900	1.767	3.631	0.766	4.397	0.092
	160	---	1.338	0.281	1.900	1.406	4.859	0.609	5.468	0.073
	---	XXS	1.100	0.400	1.900	0.950	6.408	0.412	6.820	0.049
2	10	---	2.157	0.109	2.375	3.654	2.638	1.583	4.221	0.190
	40	STD	2.067	0.154	2.375	3.356	3.653	1.454	5.107	0.174
	80	XS	1.939	0.218	2.375	2.953	5.022	1.279	6.301	0.153
	160	---	1.689	0.343	2.375	2.241	7.444	0.971	8.415	0.116
	---	XXS	1.503	0.436	2.375	1.774	9.029	0.769	9.798	0.092
2-1/2	10	---	2.635	0.120	2.875	5.453	3.531	2.363	5.893	0.283
	40	STD	2.469	0.203	2.875	4.788	5.793	2.074	7.867	0.249
	80	XS	2.323	0.276	2.875	4.238	7.661	1.836	9.497	0.220
	160	---	2.125	0.375	2.875	3.547	10.013	1.537	11.549	0.184
	---	XXS	1.771	0.552	2.875	2.463	13.695	1.067	14.762	0.128
3	10	---	3.260	0.120	3.500	8.347	4.332	3.616	7.948	0.434
	40	STD	3.068	0.216	3.500	7.393	7.576	3.203	10.779	0.384
	80	XS	2.900	0.300	3.500	6.605	10.253	2.862	13.115	0.343
	160	---	2.626	0.437	3.500	5.416	14.296	2.346	16.642	0.281
	---	XXS	2.300	0.600	3.500	4.155	18.584	1.800	20.384	0.216
4	10	---	4.260	0.120	4.500	14.253	5.614	6.175	11.789	0.740
	40	STD	4.026	0.237	4.500	12.730	10.791	5.515	16.306	0.661
	80	XS	3.826	0.337	4.500	11.497	14.984	4.981	19.965	0.597
	160	---	3.438	0.531	4.500	9.283	22.509	4.022	26.531	0.482
	---	XXS	3.152	0.674	4.500	7.803	27.541	3.381	30.922	0.405
5	10	---	5.295	0.134	5.563	22.020	7.770	9.540	17.310	1.144
	40	STD	5.047	0.258	5.563	20.006	14.618	8.667	23.285	1.039
	80	XS	4.813	0.375	5.563	18.194	20.778	7.882	28.661	0.945
	160	---	4.313	0.625	5.563	14.610	32.962	6.330	39.291	0.759
	---	XXS	4.063	0.750	5.563	12.965	38.553	5.617	44.170	0.674
6	10	---	6.357	0.134	6.625	31.739	9.290	13.751	23.040	1.649
	40	STD	6.065	0.280	6.625	28.890	18.974	12.517	31.491	1.501
	80	XS	5.761	0.432	6.625	26.067	28.574	11.293	39.867	1.354
	160	---	5.189	0.718	6.625	21.147	45.297	9.162	54.459	1.099
	---	XXS	4.897	0.864	6.625	18.834	53.161	8.160	61.321	0.978
8	10	---	8.329	0.148	8.625	54.485	13.399	23.605	37.005	2.830
	20	---	8.125	0.250	8.625	51.849	22.362	22.463	44.825	2.693
	30	---	8.071	0.277	8.625	51.162	24.697	22.166	46.862	2.658
	40	STD	7.981	0.322	8.625	50.027	28.554	21.674	50.228	2.599
	80	XS	7.625	0.500	8.625	45.664	43.388	19.784	63.172	2.372
	---	XXS	6.875	0.875	8.625	37.122	72.425	16.083	88.508	1.928
	160	---	6.813	0.906	8.625	36.456	74.691	15.794	90.485	1.894

(*Continued*)

PROPERTIES OF STEEL PIPE (*Continued*)

Pipe Size In.	Schedule		Inside Dia. In.	Wall Thick In.	Outside Dia. In.	Area Sq.In.	Weight (1)			Water Volume Gal./Ft.
							Pipe Lbs./Ft.	Water Lbs./Ft.	Total Lbs./Ft.	
10	10	---	10.420	0.165	10.750	85.276	18.653	36.945	55.599	4.430
	20	---	10.250	0.250	10.750	82.516	28.036	35.750	63.785	4.287
	30	---	10.136	0.307	10.750	80.691	34.241	34.959	69.200	4.192
	40	STD	10.020	0.365	10.750	78.854	40.484	34.163	74.647	4.096
	60	XS	9.750	0.500	10.750	74.662	54.736	32.347	87.083	3.879
	80	---	9.564	0.593	10.750	71.840	64.328	31.125	95.453	3.732
	140	XXS	8.750	1.000	10.750	60.132	104.132	26.052	130.184	3.124
	160	---	8.500	1.125	10.750	56.745	115.647	24.585	140.231	2.948
12	10	---	12.390	0.180	12.750	120.568	24.165	52.236	76.401	6.263
	20	---	12.250	0.250	12.750	117.859	33.376	51.062	84.438	6.123
	30	---	12.090	0.330	12.750	114.800	43.774	49.737	93.511	5.964
	---	STD	12.000	0.375	12.750	113.097	49.563	48.999	98.562	5.875
	40	---	11.938	0.406	12.750	111.932	53.526	48.494	102.020	5.815
	---	XS	11.750	0.500	12.750	108.434	65.416	46.979	112.395	5.633
	80	---	11.376	0.687	12.750	101.641	88.510	44.036	132.545	5.280
	120	XXS	10.750	1.000	12.750	90.763	125.492	39.323	164.815	4.715
	160	---	10.126	1.312	12.750	80.531	160.274	34.890	195.164	4.183
14	10	---	13.500	0.250	14.000	143.139	36.713	62.014	98.728	7.436
	20	---	13.376	0.312	14.000	140.521	45.611	60.880	106.492	7.300
	30	STD	13.250	0.375	14.000	137.886	54.569	59.739	114.308	7.163
	40	---	13.126	0.437	14.000	135.318	63.302	58.626	121.928	7.029
	---	XS	13.000	0.500	14.000	132.732	72.091	57.506	129.597	6.895
	80	---	12.500	0.750	14.000	122.718	106.134	53.167	159.302	6.375
	160	---	11.188	1.406	14.000	98.309	189.116	42.592	231.708	5.107
16	10	---	15.500	0.250	16.000	188.692	42.053	81.750	123.803	9.802
	20	---	15.376	0.312	16.000	185.685	52.276	80.447	132.723	9.646
	30	STD	15.250	0.375	16.000	182.654	62.579	79.134	141.714	9.489
	40	XS	15.000	0.500	16.000	176.715	82.772	76.561	159.333	9.180
	80	---	14.314	0.843	16.000	160.921	136.465	69.718	206.183	8.360
	160	---	12.814	1.593	16.000	128.961	245.114	55.872	300.986	6.699
18	10	---	17.500	0.250	18.000	240.528	47.393	104.208	151.601	12.495
	20	---	17.376	0.312	18.000	237.132	58.940	102.737	161.677	12.319
	---	STD	17.250	0.375	18.000	233.705	70.589	101.252	171.841	12.141
	30	---	17.126	0.437	18.000	230.357	81.971	99.802	181.772	11.967
	---	XS	17.000	0.500	18.000	226.980	93.452	98.338	191.790	11.791
	40	---	16.876	0.562	18.000	223.681	104.668	96.909	201.577	11.620
	80	---	16.126	0.937	18.000	204.241	170.755	88.487	259.242	10.610
	160	---	14.438	1.781	18.000	163.721	308.509	70.932	379.440	8.505
20	10	---	19.500	0.250	20.000	298.648	52.733	129.388	182.122	15.514
	20	STD	19.250	0.375	20.000	291.039	78.600	126.092	204.691	15.119
	30	XS	19.000	0.500	20.000	283.529	104.132	122.838	226.970	14.729
	40	---	18.814	0.593	20.000	278.005	122.911	120.445	243.356	14.442
	80	---	17.938	1.031	20.000	252.719	208.873	109.490	318.363	13.128
	160	---	16.064	1.968	20.000	202.674	379.008	87.808	466.816	10.529
22	10	---	21.500	0.250	22.000	363.050	58.074	157.290	215.364	18.860
	20	STD	21.250	0.375	22.000	354.656	86.610	153.654	240.263	18.424
	30	XS	21.000	0.500	22.000	346.361	114.812	150.060	264.872	17.993
	80	---	19.750	1.125	22.000	306.354	250.818	132.727	383.545	15.915
	160	---	17.750	2.125	22.000	247.450	451.072	107.207	558.278	12.855
24	10	---	23.500	0.250	24.000	433.736	63.414	187.915	251.328	22.532
	20	STD	23.250	0.375	24.000	424.557	94.620	183.938	278.558	22.055
	---	XS	23.000	0.500	24.000	415.476	125.492	180.003	305.496	21.583
	30	---	22.876	0.562	24.000	411.008	140.681	178.068	318.749	21.351
	40	---	22.626	0.687	24.000	402.073	171.054	174.197	345.251	20.887
	80	---	21.564	1.218	24.000	365.215	296.359	158.228	454.587	18.972
	160	---	19.314	2.343	24.000	292.978	541.938	126.932	668.870	15.220
26	10	---	25.376	0.312	26.000	505.750	85.598	219.115	304.713	26.273
	---	STD	25.250	0.375	26.000	500.740	102.630	216.944	319.574	26.012
	20	XS	25.000	0.500	26.000	490.874	136.173	212.670	348.842	25.500
28	10	---	27.376	0.312	28.000	588.613	92.263	255.015	347.277	30.577
	---	STD	27.250	0.375	28.000	583.207	110.640	252.673	363.313	30.296
	20	XS	27.000	0.500	28.000	572.555	146.853	248.058	394.910	29.743
	30	---	26.750	0.625	28.000	562.001	182.732	243.485	426.217	29.195

(*Continued*)

PROPERTIES OF STEEL PIPE (*Continued*)

Pipe Size In.	Schedule		Inside Dia. In.	Wall Thick In.	Outside Dia. In.	Area Sq.In.	Weight (1) Pipe Lbs./Ft.	Weight (1) Water Lbs./Ft.	Weight (1) Total Lbs./Ft.	Water Volume Gal./Ft.
30	10	—	29.376	0.312	30.000	677.759	98.927	293.637	392.564	35.208
	—	STD	29.250	0.375	30.000	671.957	118.650	291.123	409.774	34.907
	20	XS	29.000	0.500	30.000	660.520	157.533	286.168	443.701	34.313
	30	—	28.750	0.625	30.000	649.181	196.082	281.255	477.337	33.724
	40	—	28.500	0.688	29.876	637.940	214.473	276.385	490.858	33.140
32	10	—	31.376	0.312	32.000	773.188	105.591	334.981	440.573	40.166
	—	STD	31.250	0.375	32.000	766.990	126.660	332.296	458.957	39.844
	20	XS	31.000	0.500	32.000	754.768	168.213	327.001	495.214	39.209
	30	—	30.750	0.625	32.000	742.643	209.432	321.748	531.180	38.579
	40	—	30.624	0.688	32.000	736.569	230.080	319.116	549.196	38.263
34	10	—	33.376	0.312	34.000	874.900	112.256	379.048	491.304	45.449
	—	STD	33.250	0.375	34.000	868.307	134.671	376.191	510.862	45.107
	20	XS	33.000	0.500	34.000	855.299	178.893	370.555	549.449	44.431
	30	—	32.750	0.625	34.000	842.389	222.782	364.962	587.744	43.760
	40	—	32.624	0.688	34.000	835.919	244.776	362.159	606.935	43.424
36	10	—	35.376	0.312	36.000	982.895	118.920	425.836	544.757	51.060
	—	STD	35.250	0.375	36.000	975.906	142.681	422.808	565.489	50.696
	20	XS	35.000	0.500	36.000	962.113	189.574	416.832	606.406	49.980
	30	—	34.750	0.625	36.000	948.417	236.133	410.899	647.031	49.268
	40	—	34.500	0.750	36.000	934.820	282.358	405.008	687.366	48.562
42	—	STD	41.250	0.375	42.000	1336.404	166.711	578.993	745.704	69.424
	20	XS	41.000	0.500	42.000	1320.254	221.614	571.996	793.610	68.585
	30	—	40.750	0.625	42.000	1304.203	276.183	565.042	841.225	67.751
	40	—	40.500	0.750	42.000	1288.249	330.419	558.130	888.549	66.922
48	—	STD	47.250	0.375	48.000	1753.450	190.742	759.677	950.418	91.088
	20	XS	47.000	0.500	48.000	1734.945	253.655	751.659	1005.314	90.127
	30	—	46.750	0.625	48.000	1716.537	316.234	743.684	1059.918	89.171
	40	—	46.500	0.750	48.000	1698.227	378.480	735.751	1114.231	88.220
54	—	STD	53.250	0.375	54.000	2227.046	214.772	964.860	1179.632	115.691
	20	XS	53.000	0.500	54.000	2206.183	285.695	955.822	1241.517	114.607
	30	—	52.750	0.625	54.000	2185.419	356.285	946.826	1303.111	113.528
	40	—	52.500	0.750	54.000	2164.754	426.540	937.873	1364.413	112.455
60	—	STD	59.250	0.375	60.000	2757.189	238.803	1194.543	1433.346	143.231
	20	XS	59.000	0.500	60.000	2733.971	317.736	1184.484	1502.220	142.024
	30	—	58.750	0.625	60.000	2710.851	396.336	1174.467	1570.803	140.823
	40	—	58.500	0.750	60.000	2687.829	474.601	1164.493	1639.095	139.627
72	—	STD	71.250	0.375	72.000	3987.123	286.863	1727.408	2014.272	207.123
	20	XS	71.000	0.500	72.000	3959.192	381.817	1715.307	2097.124	205.672
	30	—	70.750	0.625	72.000	3931.360	476.437	1703.249	2179.686	204.226
	40	—	70.500	0.750	72.000	3903.625	570.723	1691.233	2261.956	202.786
84	—	STD	83.250	0.375	84.000	5443.251	334.924	2358.271	2693.195	282.766
	20	XS	83.000	0.500	84.000	5410.608	445.898	2344.128	2790.027	281.071
	30	—	82.750	0.625	84.000	5378.063	556.539	2330.029	2886.567	279.380
	40	—	82.500	0.750	84.000	5345.616	666.845	2315.971	2982.816	277.694
96	—	STD	95.250	0.375	96.000	7125.574	382.985	3087.132	3470.117	370.160
	20	XS	95.000	0.500	96.000	7088.218	509.980	3070.948	3580.927	368.219
	30	—	94.750	0.625	96.000	7050.961	636.640	3054.806	3691.446	366.284
	40	—	94.500	0.750	96.000	7013.802	762.967	3038.707	3801.674	364.353

PROPERTIES OF STAINLESS STEEL PIPE

Pipe Size In.	Schedule		Inside Dia. In.	Wall Thick In.	Outside Dia. In.	Area Sq.In.	Weight (1) Pipe Lbs./Ft.	Weight (1) Water Lbs./Ft.	Weight (1) Total Lbs./Fts.	Water Volume Gal./Ft.
1/2	5	---	0.710	0.065	0.840	0.396	0.549	0.172	0.720	0.021
	10	---	0.674	0.083	0.840	0.357	0.684	0.155	0.839	0.019
3/4	5	---	0.920	0.065	1.050	0.665	0.697	0.288	0.985	0.035
	10	---	0.884	0.083	1.050	0.614	0.874	0.266	1.140	0.032
1	5	---	1.185	0.065	1.315	1.103	0.885	0.478	1.363	0.057
	10	---	1.097	0.109	1.315	0.945	1.432	0.409	1.842	0.049
1-1/4	5	---	1.530	0.065	1.660	1.839	1.129	0.797	1.926	0.096
	10	---	1.442	0.109	1.660	1.633	1.842	0.708	2.549	0.085

(*Continued*)

PROPERTIES OF STAINLESS STEEL PIPE (*Continued*)

Pipe Size In.	Schedule		Inside Dia. In.	Wall Thick In.	Outside Dia. In.	Area Sq.In.	Weight (1) Pipe Lbs./Ft.	Weight (1) Water Lbs./Ft.	Weight (1) Total Lbs./Fts.	Water Volume Gal./Ft.
1-1/2	5	---	1.770	0.065	1.900	2.461	1.299	1.066	2.365	0.128
	10	---	1.682	0.109	1.900	2.222	2.127	0.963	3.089	0.115
2	5	---	2.245	0.065	2.375	3.958	1.636	1.715	3.351	0.206
	10	---	2.157	0.109	2.375	3.654	2.691	1.583	4.274	0.190
2-1/2	5	---	2.709	0.083	2.875	5.764	2.524	2.497	5.022	0.299
	10	---	2.635	0.120	2.875	5.453	3.601	2.363	5.964	0.283
3	5	---	3.334	0.083	3.500	8.730	3.090	3.782	6.872	0.454
	10	---	3.260	0.120	3.500	8.347	4.419	3.616	8.035	0.434
4	5	---	4.334	0.083	4.500	14.753	3.994	6.392	10.385	0.766
	10	---	4.260	0.120	4.500	14.253	5.726	6.175	11.901	0.740
5	5	---	5.345	0.109	5.563	22.438	6.476	9.721	16.197	1.166
	10	---	5.295	0.134	5.563	22.020	7.925	9.540	17.465	1.144
6	5	---	6.407	0.109	6.625	32.240	7.737	13.968	21.705	1.675
	10	---	6.357	0.134	6.625	31.739	9.475	13.751	23.226	1.649
8	5	---	8.407	0.109	8.625	55.510	10.112	24.050	34.162	2.884
	10	---	8.329	0.148	8.625	54.485	13.667	23.605	37.273	2.830
10	5	---	10.482	0.134	10.750	86.294	15.497	37.386	52.883	4.483
	10	---	10.420	0.165	10.750	85.276	19.026	36.945	55.972	4.430
12	5	---	12.438	0.156	12.750	121.504	21.403	52.641	74.044	6.312
	10	---	12.390	0.180	12.750	120.568	24.648	52.236	76.884	6.263
14	5	---	13.688	0.156	14.000	147.153	23.527	63.754	87.281	7.644
	10	---	13.624	0.188	14.000	145.780	28.287	63.159	91.446	7.573
16	5	---	15.670	0.165	16.000	192.854	28.463	83.553	112.016	10.018
	10	---	15.624	0.188	16.000	191.723	32.384	83.063	115.447	9.960
18	5	---	17.670	0.165	18.000	245.224	32.058	106.243	138.301	12.739
	10	---	17.624	0.188	18.000	243.949	36.480	105.690	142.170	12.673
20	5	---	19.624	0.188	20.000	302.458	40.576	131.039	171.615	15.712
	10	---	19.564	0.218	20.000	300.611	46.979	130.239	177.218	15.616
22	5	---	21.624	0.188	22.000	367.250	44.672	159.110	203.782	19.078
	10	---	21.564	0.218	22.000	365.215	51.729	158.228	209.957	18.972
24	5	---	23.564	0.218	24.000	436.102	56.479	188.940	245.418	22.655
	10	---	23.500	0.250	24.000	433.736	64.682	187.915	252.597	22.532

18.02 Pipe Support and Pipe Spacing

HORIZONTAL PIPE SUPPORT SPACING

Pipe Size	Maximum Horizontal Hanger Spacing Feet						Minimum Rod Size (Inches)
	Steel			Copper			
	Recommend	Water Systems	Vapor Systems	Recommend	Water Systems	Vapor Systems	
1/2	6	7	8	5	5	6	3/8
3/4	6	7	9	5	5	7	3/8
1	6	7	9	6	6	8	3/8
1-1/4	6	7	9	6	7	9	3/8
1-1/2	6	9	12	6	8	10	3/8
2	7	10	13	7	8	11	3/8
2-1/2	10	11	14	8	9	13	1/2
3	10	12	15	10	10	14	1/2
4	10	14	17	10	12	16	5/8
5	10	16	19	10	13	18	5/8
6	10	17	21	10	14	20	3/4
8	12	19	24	10	16	23	7/8
10	12	22	26	10	18	25	7/8
12	12	23	30	10	19	28	7/8
14	12	25	32	--	--	--	1
16	12	27	35	--	--	--	1
18	12	28	37	--	--	--	1-1/4
20	12	30	39	--	--	--	1-1/4

(*Continued*)

HORIZONTAL PIPE SUPPORT SPACING (*Continued*)

Pipe Size	Maximum Horizontal Hanger Spacing Feet						Minimum Rod Size (Inches)
	Steel			Copper			
	Recommend	Water Systems	Vapor Systems	Recommend	Water Systems	Vapor Systems	
22	12	30	39	--	--	--	1-1/2
24	12	32	42	--	--	--	1-1/2
26	12	32	42	--	--	--	1-1/2
28	12	32	42	--	--	--	1-1/2
30	12	33	44	--	--	--	1-1/2
32	12	33	44	--	--	--	1-1/2
34	12	33	44	--	--	--	1-1/2
36	12	33	44	--	--	--	1-1/2
42	12	33	44	--	--	--	1-1/2
48	12	32	42	--	--	--	1-3/4
54	12	33	44	--	--	--	1-3/4
60	12	33	44	--	--	--	2
72	12	33	44	--	--	--	2
84	12	33	44	--	--	--	2-1/2
96	12	33	44	--	--	--	2-1/2

Notes:

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 with steel bar joist construction.**

VERTICAL PIPE SUPPORT SPACING

Pipe Size	Maximum Vertical Support Spacing Feet		Support
	Steel	Copper	
8" and Smaller	Every other floor and base of tall pipe risers	Every floor and base of tall 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	---	---
5	12.0	12.0	12.5	12.5	12.5	13.0	14.0	14.5	15.5	16.0	---
6	12.5	12.5	13.0	13.0	13.0	13.5	14.5	14.5	16.0	16.5	17.0
8	13.5	14.0	14.0	14.5	14.5	15.0	16.0	16.0	17.5	18.0	18.5
10	15.0	15.0	15.5	15.5	15.5	16.0	17.0	17.5	18.5	19.0	19.5
12	16.5	16.5	17.0	17.5	17.0	17.5	18.5	19.0	20.0	20.5	21.0
14	17.5	17.5	18.0	18.0	18.0	18.5	19.5	20.0	21.0	21.5	22.0
16	18.5	19.0	19.0	19.0	19.5	20.0	21.0	21.0	22.5	23.0	23.5
18	19.5	19.5	20.0	20.0	20.0	20.5	21.5	22.0	23.0	23.5	24.0
20	20.5	21.0	21.0	21.0	21.5	22.0	23.0	23.0	24.5	25.0	25.5
22	22.0	22.0	22.0	22.0	22.5	23.0	24.0	24.0	25.5	26.0	26.5
24	23.0	23.5	23.5	23.5	23.5	24.0	25.0	25.5	26.5	27.0	27.5
26	24.0	24.5	24.5	24.5	25.0	25.0	26.0	26.5	28.0	28.0	29.0
28	25.0	25.5	25.5	25.5	26.0	26.5	27.5	27.5	29.0	29.5	30.0
30	26.5	27.0	27.0	27.0	27.0	27.5	28.5	29.0	30.0	30.5	31.0
32	28.0	28.0	28.0	28.0	28.5	29.0	29.5	30.0	31.5	32.0	32.5
34	29.0	29.0	29.0	29.0	29.5	30.0	31.0	31.0	32.5	33.0	33.5
36	30.0	30.5	30.5	30.5	30.5	31.0	32.0	32.5	33.5	34.0	34.5
42	33.5	34.0	34.0	34.0	34.0	34.5	35.5	36.0	37.0	37.5	38.0

(*Continued*)

PIPE SPACING ON RACKS (*Continued*)

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
48	36.5	37.0	37.0	37.5	37.5	38.0	39.0	39.0	40.5	41.0	41.5
54	40.0	40.0	40.5	40.5	41.0	41.5	42.5	42.5	44.0	44.5	45.0
60	43.5	43.5	44.0	44.0	44.0	44.5	45.5	46.0	47.0	47.5	48.0
72	50.0	50.5	50.5	51.0	51.0	51.5	52.5	52.5	54.0	54.5	55.0
84	57.0	57.0	57.5	57.5	57.5	58.0	59.0	59.5	60.5	61.0	61.5
96	63.5	64.0	64.0	64.5	64.5	65.0	66.0	66.0	67.5	68.0	68.5

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches											
Pipe Size	Pipe Size										
	8	10	12	14	16	18	20	22	24	26	28
1/2	---	---	--	--	--	--	--	---	---	---	---
3/4	---	---	--	--	--	--	--	---	---	---	---
1	---	---	--	--	--	--	--	---	---	---	---
1-1/4	---	---	--	--	--	--	--	---	---	---	---
1-1/2	---	---	--	--	--	--	--	---	---	---	---
2	---	---	--	--	--	--	--	---	---	---	---
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	42.5
30	32.5	33.5	35.0	36.0	37.5	38.0	39.5	40.5	41.5	42.5	44.0
32	34.0	35.0	36.5	37.4	39.0	39.5	41.0	42.0	43.0	44.0	45.5
34	35.0	36.0	37.5	38.5	40.0	40.5	42.0	43.0	44.0	45.0	46.5
36	36.0	37.0	38.5	39.5	41.0	41.5	43.0	44.0	45.0	46.5	47.5
42	39.5	40.5	42.0	41.0	44.5	45.0	46.5	47.5	48.5	50.0	51.0
48	42.5	44.0	45.5	46.5	47.5	48.5	49.5	51.0	52.0	53.0	54.0
54	46.0	47.5	49.0	50.0	51.0	52.0	53.0	54.0	55.5	56.5	57.5
60	49.5	50.5	52.0	53.0	54.5	55.0	56.5	57.5	58.5	60.0	61.0
72	56.0	57.5	59.0	60.0	61.0	62.0	63.0	64.5	65.5	66.5	67.5
84	63.0	64.0	65.5	66.5	68.0	68.5	70.0	71.0	72.0	73.5	74.5
96	69.5	71.0	72.5	73.5	74.5	75.5	76.5	78.0	79.0	80.0	81.0

PIPE SPACING ON RACKS

Minimum Centerline-to-Centerline Dimensions, Inches											
Pipe Size	Pipe Size										
	30	32	34	36	42	48	54	60	72	84	96
1/2	---	---	---	---	---	---	---	---	---	---	---
3/4	---	---	---	---	---	---	---	---	---	---	---
1	---	---	---	---	---	---	---	---	---	---	---
1-1/4	---	---	---	---	---	---	---	---	---	---	---
1-1/2	---	---	---	---	---	---	---	---	---	---	---
2	---	---	---	---	---	---	---	---	---	---	---
2-1/2	---	---	---	---	---	---	---	---	---	---	---
3	---	---	---	---	---	---	---	---	---	---	---
4	---	---	---	---	---	---	---	---	---	---	---

(*Continued*)

PIPE SPACING ON RACKS (*Continued*)

Minimum Centerline-to-Centerline Dimensions, Inches											
Pipe Size	Pipe Size										
	30	32	34	36	42	48	54	60	72	84	96
5	---	---	---	---	---	---	---	---	---	---	---
6	---	---	---	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---	---	---	---
10	---	---	---	---	---	---	---	---	---	---	---
12	---	---	---	---	---	---	---	---	---	---	---
14	---	---	---	---	---	---	---	---	---	---	---
16	---	---	---	---	--	---	---	---	---	---	---
18	---	---	---	---	--	---	---	---	---	---	---
20	---	---	---	---	--	---	---	---	---	---	---
22	---	---	---	---	--	---	---	---	---	---	---
24	---	---	---	---	--	---	---	---	---	---	---
26	---	---	---	---	--	---	---	---	---	---	---
28	---	---	---	---	--	---	---	---	---	---	---
30	45.0	---	---	---	--	---	---	---	---	---	---
32	46.5	48.0	---	---	--	---	---	---	---	---	---
34	47.5	49.0	50.0	---	--	---	---	---	---	---	---
36	48.5	50.0	51.0	52.0	--	---	---	---	---	---	---
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	62.0	63.5	64.5	65.5	69.0	72.5	76.0	79.0	---	---	---
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	119.5

Notes:

1 Table based schedule 40 pipe and includes the outside dimensions for flanges, fittings, etc.; insulation over flanges, fittings, etc. The space between fittings are as follows:
Pipe sizes: 2" and smaller: 1-1/2" Insulation
2-1/2" and larger: 2" Insulation
Space between two pipes 3" and smaller: 1"
Space between one pipe 3" and smaller, and one pipe 4" and larger: 1-1/2"
Space between two pipes 4" and larger: 2"

2 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"

3 Tables do not include space for valve handles and stems, expansion joints, expansion loops, and pipe guides.

18.03 Pipe Expansion

A. Expansion Loops (See Chapter 3)

1. L-Bends. Anchor force = 500 Lbs./Dia. Inch.
2. Z-Bends. Anchor force = 200–500 Lbs./Dia. Inch.
3. U-Bends. Anchor force = 200 Lbs./Dia. Inch.
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 Chapter 3.

THERMAL EXPANSION OF METAL PIPE

Saturated Steam Pressure Psig	Temperature °F	Linear Thermal Expansion Inches/100 Feet		
		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
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
---	940	8.77	11.45	11.71
---	960	8.99	11.73	11.98
---	980	9.20	12.00	12.27
---	1000	9.42	12.27	12.54

Notes:

1 Table based on ASTM A53, Grade B, steel pipe.
2 Temperature range applicable through 400°F.
3 Table also applicable to copper tube.
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

Pipe Size	Expansion of Longest Leg							
	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"
20	27'10"	34'2"	39'6"	44'0"	48'3"	55'8"	62'3"	68'3"
22	29'3"	35'9"	41'4"	46'2"	50'8"	58'6"	65'4"	71'8"
24	30'6"	37'6"	43'2"	48'3"	52'10"	61'0"	68'3"	74'9"
26	31'9"	39'0"	45'0"	50'3"	55'0"	63'6"	71'0"	77'9"
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

Pipe Size	Anchor-to-Anchor Expansion							
	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"
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"

(*Continued*)

PIPE EXPANSION Z-BENDS (*Continued*)

Pipe Size	Anchor-to-Anchor Expansion							
	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
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

Pipe Size	Anchor-to-Anchor Expansion							
	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"
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"	13'0"	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

Pipe Size	Anchor-to-Anchor Expansion							
	3"		4"		5"		6"	
	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"
1	2'6"	5'0"	3'0"	6'0"	3'4"	6'8"	3'6"	7'0"

(*Continued*)

PIPE EXPANSION U-BENDS OR LOOPS (*Continued*)

Pipe Size	Anchor-to-Anchor Expansion							
	3"		4"		5"		6"	
	W	H	W	H	W	H	W	H
1-1/4	2'10"	5'8"	3'3"	6'6"	3'8"	7'4"	4'0"	8'0"
1-1/2	3'0"	6'0"	3'6"	7'0"	3'10"	7'8"	4'3"	8'6"
2	3'4"	6'8"	4'0"	8'0"	4'4"	8'8"	4'9"	9'6"
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

Pipe Size	Anchor-to-Anchor Expansion							
	7"		8"		10"		12"	
	W	H	W	H	W	H	W	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"

(*Continued*)

PIPE EXPANSION U-BENDS OR LOOPS (*Continued*)

Pipe Size	Anchor-to-Anchor Expansion							
	7"		8"		10"		12"	
	W	H	W	H	W	H	W	H
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	23'8"	47'4"	29'11"	59'10"	33'5"	66'10"	36'8"	73'4"
84	30'3"	60'6"	32'4"	64'8"	36'1"	72'2"	39'7"	69'2"
96	32'4"	64'8"	34'7"	69'2"	38'8"	77'4"	42'4"	84'8"

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, nonflammable gases, and combustible liquids including fuel oil.
General Limitations	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.	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 –20ºF through 366ºF. 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.	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.
Pipe Size Limitations	No limit	No limit	Carbon steel - 30" nominal pipe size and 0.5" wall (30" xs steel pipe) Copper—12" nominal pipe size Stainless steel—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

(*Continued*)

ASME B31 PIPING CODE COMPARISON (*Continued*)

Item	Power Piping Asme B31.1-1998	Process Piping Asme B31.3-1996	Building Services Piping Asme B31.9-1996
Temperature Limitations	No limit	No limit	Steam and condensate—366ºF Maximum (150 psig) Other gases and vapors—200ºF maximum Nonflammable liquids—250ºF maximum Minimum temperature all services—0ºF
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 BPVC Section I	Boiler external piping is governed by ASME B31.1. All other piping may be governed by this code within the limitations of the code.	Boiler external piping is governed by ASME B31.1. All other piping may be governed by this code within the limitations of the code.	Boiler external piping is governed by ASME B31.1. All other piping may be governed by this code within the limitations of the code.
Class IV Boiler Systems—ASME BPVC Section IV	All piping, including boiler external piping, may be governed by this code within the limitations of the code.	All piping, including boiler external piping, may be governed by this code within the limitations of the code.	All piping, including boiler external piping, may be governed by this code within the limitations of the code.

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.
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

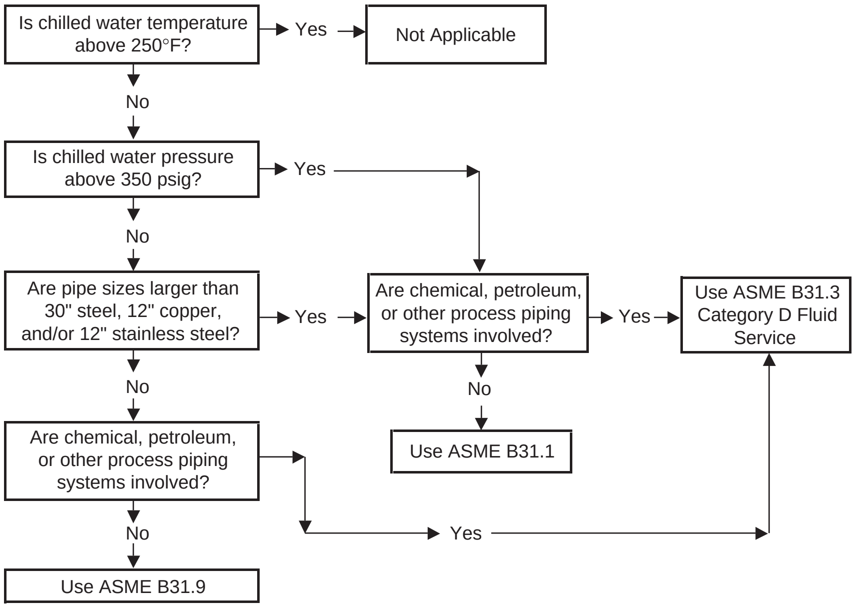
Item	Power Piping Asme B31.1 - 1998	Process Piping Asme B31.3 - 1996	Building Services Piping Asme B31.9 - 1996
Piping Classifications	No classifications required by this code. The code deals with and governs all piping under its jurisdiction the same.		No classifications required by this code. The code deals with and governs all piping under its jurisdiction the same.
Low Temp Chilled Water (0–40ºF)		D	
Chilled Water (40–60ºF)		D	

(*Continued*)

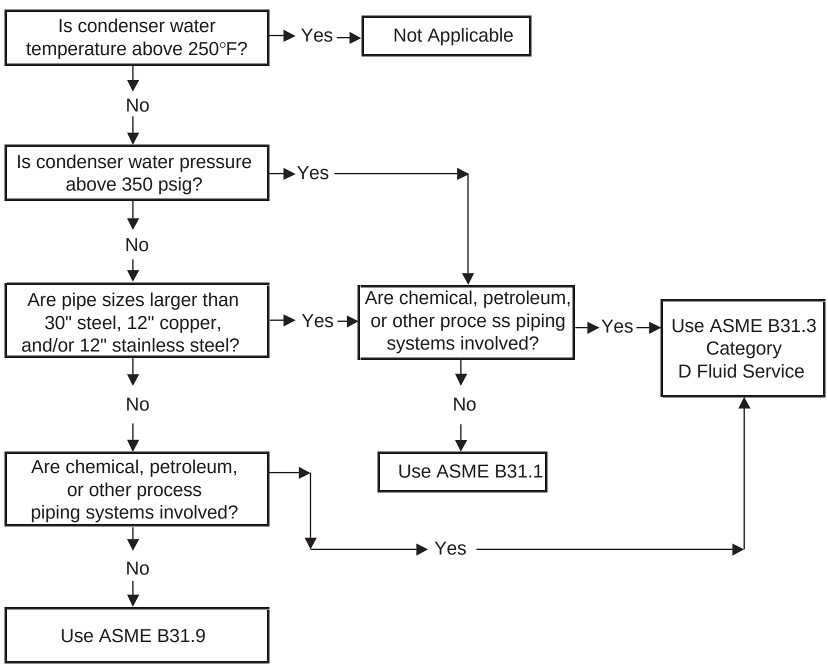
ASME B31 PIPING CODE COMPARISON (*Continued*)

Item	Power Piping Asme B31.1 - 1998	Process Piping Asme B31.3 - 1996	Building Services Piping Asme B31.9 - 1996
Condenser Water (60–110°F)		D	
Low Temp Heating Water (110–250°F)		N	
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 pressure for a minimum of 10 minutes.		All Other Services—1.5 times the design pressure but not to exceed the max. allowable system pressure for a minimum of 10 minutes.
Examination, Inspection, and Testing Requirements	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.	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.	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.
	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.	Category D Fluid Service—Visual Examination	All Services—Visual Examinations.
	Class IV Steam & Hot Water Systems—Visual examination only. All other services—Visual examination only.	Category N Fluid Service—Visual Examination, 5% Random Examination of components, fabrication, welds, and installation. Random radiographic or ultrasonic testing of 5% of circumferential butt welds.	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.	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

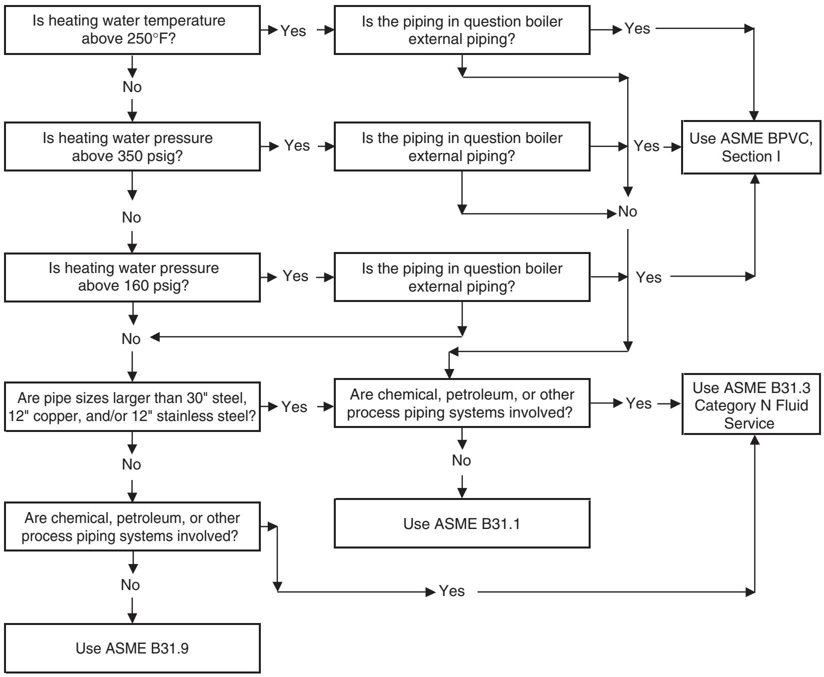
ASME B31 Chilled Water System Decision Diagram Chilled Water Systems (0–60°F)



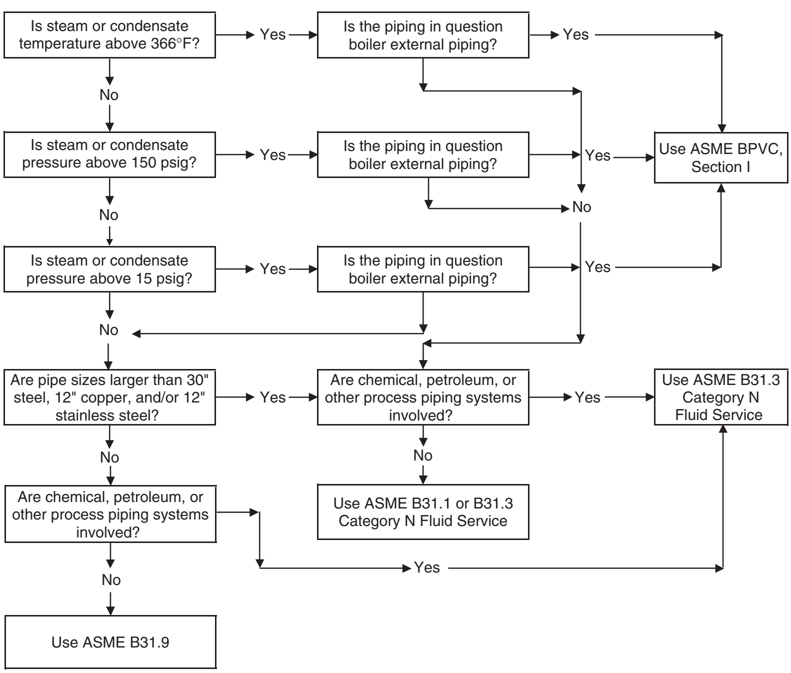
ASME B31 Condenser Water System Decision Diagram Condenser Water Systems (60–110°F)



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)



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

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

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. *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. *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 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 size of the elbow.
15. *Elbow, Short Radius*. An elbow with a centerline turning radius of one times the nominal 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.
    a. *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.
    b. *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.
    c. *Safety Relief Valve*. An automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.
    d. 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 and 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
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-Wast-Vent Fitting
NPS	Nominal Pipe Size
IPS	Iron Pipe Size
NPT	National Standard Pipe Thread Taper

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 smaller: 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. H_2O.
2. 2"–4" (Y type and Basket type):
   a. Pressure drop: 1.0 PSI, 2.31 ft. H_2O.
3. 5" and larger:
   a. Y-type pressure drop 1.5 PSI, 3.46 ft H_2O
   b. Basket-type pressure drop 1.0 PSI, 2.31 ft. H_20

PART 19

Hydronic (Water) Piping Systems

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.

19.02 Friction Loss Estimate

A. 1.5 × System Length (ft.) × Friction Rate (ft./100 ft.)

B. Pipe Friction Estimate: 3.0 to 3.5 ft./100 ft.

19.03 Pipe Testing

A. 1.5 × System Working Pressure

B. 100 psi Minimum

19.04 Hydronic System Pipe Sizing Tables

HYDRONIC PIPING SYSTEMS—TYPE K COPPER PIPE

Pipe Size	Water Flow—GPM							
	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 3/4 1	1.0 2.4 5.2	1.2 3.0 6.4	1.4 3.5 7.4		Pressure with these	drop pipe	governs sizes	
1-1/4 1-1/2 2	9 15 31	12 18 38	13 21 44	 21 38				
2-1/2 3 4	55 87 183	67 107 224	78 123 258	58 83 146	73 103 182	124 219		
5 6 8	324 515 1,064	397 631 1,304	458 729	226 323 563	283 403 704	339 484 845	452 645 1,126	1,408
10 12	1,887 3,015	Velocity with these	governs pipe sizes	874 1,254	1,093 1,567	1,311 1,880	1,749 2,507	2,186 3,134

HYDRONIC PIPING SYSTEMS—TYPE L COPPER PIPE

Pipe Size	Water Flow—GPM							
	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					
3/4	2.8	3.4	4.0					
1	5.7	6.9	8.0		Pressure	drop		
1-1/4	10	12	14		with these	pipe		
1-1/2	16	19	22	22			governs	
2	32	39	45	39			sizes	
2-1/2	57	69	80	59	74			
3	90	111	128	85	106	127		
4	189	231	267	149	187	224		
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

Pipe Size	Water Flow—GPM							
	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					
3/4	3.1	3.7	4.3					
1	6.1	7.5	8.6		Pressure	drop		
1-1/4	10	13	15	16	with these	pipe		
1-1/2	16	20	23	23			governs	
2	33	41	47	40			sizes	
2-1/2	58	72	83	61	76			
3	93	114	132	87	109	131		
4	192	236	272	152	190	227		
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

Pipe Size	Water Flow—GPM							
	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			
3/4	3.2	3.9	4.5		with these			
1	6.0	7.4	8.5			drop		
1-1/4	12	15	18	19		pipe		
1-1/2	19	23	26	25			governs	
2	36	44	51	42	52		sizes	
2-1/2	57	70	80	60	75			
3	100	123	142	92	115	138		
4	204	250	289	159	198	238		
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	1,559

(*Continued*)

HYDRONIC PIPING SYSTEMS—STANDARD STEEL PIPE (*Continued*)

Pipe Size	Water Flow—GPM							
	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
10	2,198			983	1,229	1,475	1,966	2,458
12	3,512			1,410	1,763	2,115	2,820	3,525
14				1,719	2,149	2,579	3,438	4,298
16				2,277	2,847	3,416	4,554	5,693
18				2,914	3,642	4,371	5,827	7,284
20				3,629	4,536	5,443	7,257	9,071
22				4,422	5,527	6,633	8,843	11,054
24				5,293	6,616	7,940	10,586	13,233
26				6,243	7,804	9,364	12,486	15,607
28			with	7,271	9,089	10,907	14,542	18,178
30		governs	sizes	8,378	10,472	12,566	16,755	20,944
32		pipe		9,562	11,953	14,344	19,125	23,906
34	Velocity			10,826	13,532	16,238	21,651	27,064
36	these			12,167	15,209	18,251	24,334	30,418
42				16,662	20,827	24,992	33,323	41,654
48				21,861	27,327	32,792	43,722	54,653
54				27,766	34,707	41,649	55,532	69,414
60				34,375	42,969	51,563	68,751	85,938
72				49,710	62,137	74,564	99,419	124,274
84				67,864	84,830	101,796	135,728	169,660
96				88,838	111,048	133,257	177,677	222,096

HYDRONIC PIPING SYSTEMS—XS STEEL PIPE

Pipe Size	Water Flow—GPM							
	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					
3/4	2.4	3.0	3.4					
1	4.7	5.8	6.7		Pressure	drop		
1-1/4	10	12	14		with these	pipe		
1-1/2	15	19	22	22			governs	
2	30	37	43	37			sizes	
2-1/2	48	59	69	53	66			
3	87	106	123	82	103	124		
4	179	219	253	143	179	215		
5	325	399	460	227	284	340	454	
6	520	637	736	325	406	487	650	
8	1,080	1,322		569	712	854	1,139	1,423
10	2,047			931	1,164	1,396	1,862	2,327
12	3,325			1,352	1,690	2,028	2,704	3,380
14				1,655	2,069	2,482	3,310	4,137
16				2,203	2,754	3,305	4,406	5,508
18				2,830	3,537	4,245	5,660	7,075
20		governs	with	3,535	4,419	5,302	7,070	8,837
22		pipe	sizes	4,318	5,398	6,477	8,637	10,796
24	Velocity			5,180	6,475	7,770	10,360	12,950
26	these			6,120	7,650	9,180	12,240	15,300
28				7,138	8,923	10,708	14,277	17,846
30				8,235	10,294	12,353	16,470	20,588
32				9,410	11,763	14,115	18,820	23,525

(*Continued*)

HYDRONIC PIPING SYSTEMS—XS STEEL PIPE (*Continued*)

Pipe Size	Water Flow—GPM							
	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
34				10,663	13,329	15,995	21,327	26,659
36				11,995	14,994	17,993	23,990	29,988
42				16,460	20,575	24,690	32,921	41,151
48				21,630	27,038	32,446	43,261	54,076
54				27,506	34,382	41,258	55,011	68,764
60				34,086	42,607	51,129	68,172	85,215
72				49,361	61,702	74,042	98,723	123,403
84				67,457	84,321	101,185	134,914	168,642
96				88,373	110,466	132,559	176,745	220,931

HYDRONIC PIPING SYSTEMS—XXS STEEL PIPE

Pipe Size	Water Flow—GPM							
	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	governs	
3/4	0.6	0.7	0.8		with these	pipe	sizes	
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		
6	341	417	482	235	294	352	470	
8	825	1,010		463	579	694	926	1,157
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

Pipe Size	Water Flow—GPM							
	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			
3/4	3.2	3.9	4.5		with these			
1	6.0	7.4	8.5			drop		
1-1/4	12	15	18	19		pipe	governs	
1-1/2	19	23	26	25			sizes	
2	36	44	51	42	52			
2-1/2	57	70	80	60	75			
3	100	123	142	92	115	138		
4	204	250	289	159	198	238		
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	1,559

(*Continued*)

HYDRONIC PIPING SYSTEMS—SCHEDULE 40 STEEL PIPE (*Continued*)

Pipe Size	Water Flow—GPM							
	Friction Rate—ft./100 ft.			Velocity—ft./sec.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
10	2,198			983	1,229	1,475	1,966	2,458
12	3, 65			1,396	1,744	2,093	2,791	3,489
14				1,687	2,109	2,531	3,374	4,218
16				2,203	2,754	3,305	4,406	5,508
18				2,789	3,486	4,183	5,577	6,972
20				3,466	4,333	5,199	6,932	8,665
22				---	---	---	---	---
24				5,013	6,266	7,519	10,026	12,532
26				---	---	---	---	---
28				---	---	---	---	---
30		governs	with	7,954	9,942	11,930	15,907	19,884
32		pipe	sizes	9,183	11,479	13,775	18,366	22,958
34	Velocity			10,422	13,027	15,633	20,844	26,055
36	these			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
60				33,511	41,888	50,266	67,021	83,776
72				48,669	60,836	73,003	97,337	121,671
84				66,647	83,308	99,970	133,293	166,617
96				87,445	109,306	131,167	174,890	218,612

HYDRONIC PIPING SYSTEMS—SCHEDULE 80 STEEL PIPE

Pipe Size	Water Flow—GPM							
	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					
3/4	2.4	3.0	3.4					
1	4.7	5.8	6.7		Pressure	drop		
1-1/4	10	12	14		with these	pipe		
1-1/2	15	19	22	22			governs	
2	30	37	43	37			sizes	
2-1/2	48	59	69	53	66			
3	87	106	123	82	103	124		
4	179	219	253	143	179	215		
5	325	399		227	284	340	454	
6	520	637	460	325	406	487	650	
8	1,080	1,322	736	569	712	854	1,139	1,423
10	1,947			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		governs	with	2,006	2,508	3,009	4,013	5,016
18		pipe	sizes	2,546	3,183	3,820	5,093	6,366
20	Velocity			3,151	3,938	4,726	6,302	7,877
22	these			3,819	4,774	5,729	7,639	9,549
24				4,553	5,692	6,830	9,107	11,383

Hydronic (Water) Piping Systems

HYDRONIC PIPING SYSTEMS—SCHEDULE 160 STEEL PIPE

Pipe Size	Water Flow—GPM							
	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					
3/4	1.5	1.8	2.1					
1	3.1	3.8	4.4		Pressure	drop		
1-1/4	8	10	11		with these	pipe	governs	
1-1/2	11	14	16				sizes	
2	21	26	30	28				
2-1/2	38	47	54	44	55			
3	67	82	95	68	84			
4	135	166	191	116	145	174		
5	244	299	346	182	228	273		
6	396	485	560	264	330	395	527	
8	805	986		455	568	682	909	1,136
10	1,433	1,755		707	884	1,061	1,415	1,769
12	2,259			1,004	1,255	1,506	2,008	2,510
14	2,928			1,226	1,532	1,839	2,451	3,064
16			with	1,608	2,010	2,412	3,216	4,020
18	Velocity	governs	sizes	2,041	2,551	3,062	4,082	5,103
20	these	pipe		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	Water Flow—GPM							
	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	2.2	2.6	3.0					
3/4	4.3	5.2	6.0		Pressure			
1	8.3	10.2	11.7		with these	drop	governs	
1-1/4	16	20	23	23		pipe	sizes	
1-1/2	24	29	34	31				
2	44	54	63	49	62			
2-1/2	73	89	103	72	90			
3	125	153	176	109	136	163		
4	248	303	350	184	230	276		
5	428	524	605	280	350	420	559	
6	686	840	970	402	502	603	804	
8	1,392	1,705		692	865	1,038	1,384	1,730
10	2,471			1,076	1,345	1,614	2,152	2,690
12				1,515	1,894	2,272	3,030	3,787
14				1,835	2,293	2,752	3,669	4,587
16		governs	with	2,404	3,006	3,607	4,809	6,011
18		pipe	sizes	3,057	3,822	4,586	6,115	7,643
20	Velocity			3,771	4,714	5,656	7,542	9,427
22	these			4,579	5,723	6,868	9,157	11,447
24				5,437	6,796	8,156	10,874	13,593

HYDRONIC PIPING SYSTEMS—SCHEDULE 10 STAINLESS STEEL PIPE

Pipe Size	Water Flow—GPM							
	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	1.9	2.3	2.7		Pressure			
3/4	3.8	4.7	5.4		with these			
1	6.8	8.3	9.6			drop		
1-1/4	14	17	20	20		pipe		
1-1/2	21	25	29	28			governs sizes	
2	40	49	56	46	57			
2-1/2	67	83	95	68	85			
3	118	144	166	104	130	156		
4	237	290	335	178	222	267		
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			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		governs pipe	with sizes	2,390	2,988	3,585	4,781	5,976
18				3,041	3,802	4,562	6,083	7,604
20	Velocity these			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.
7. Types K, L, and M copper pipe are available in sizes up through 12 inch.
8. Standard and XS steel pipe are available in sizes through 96 inch.
9. XXS steel pipe is available in sizes through 12 inch.
10. Schedule 40 steel pipe is available in sizes through 96 inch.
11. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.
12. Schedule 5 and 10 stainless steel pipe are available in sizes through 24 inch.
13. Standard and Schedule 40 steel pipe have the same dimensions and flow for 10 inch and smaller.
14. XS and Schedule 80 steel pipe have the same dimensions and flow for 8 inch and smaller.
15. 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).

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.

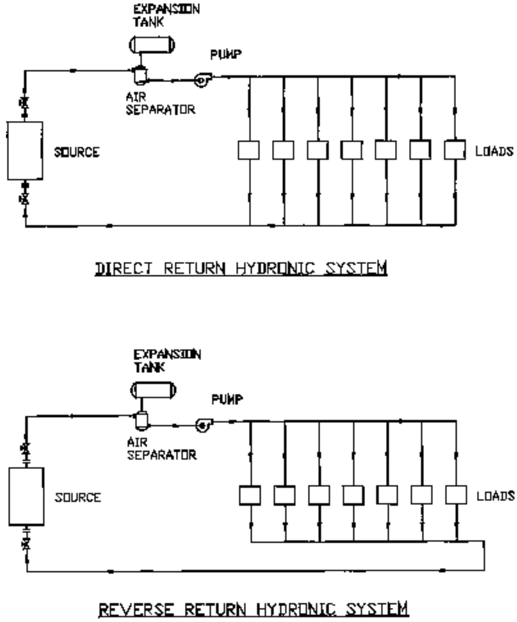


FIGURE 19.1 HYDRONIC SYSTEM RETURN TYPES.

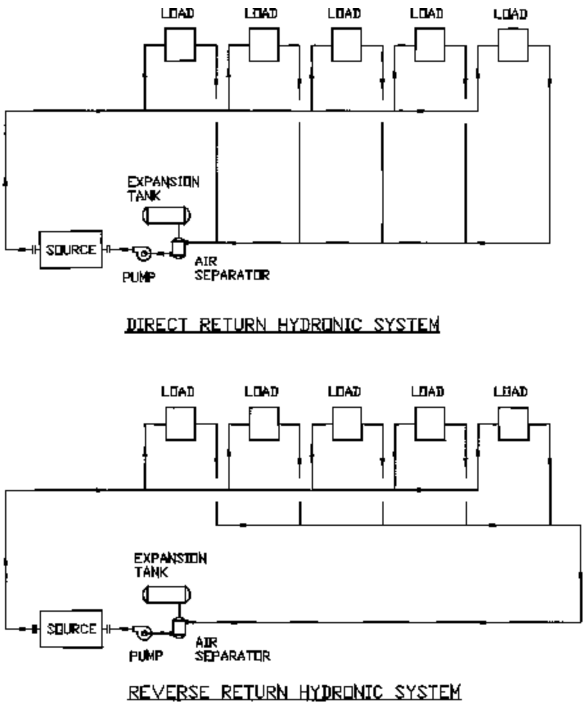
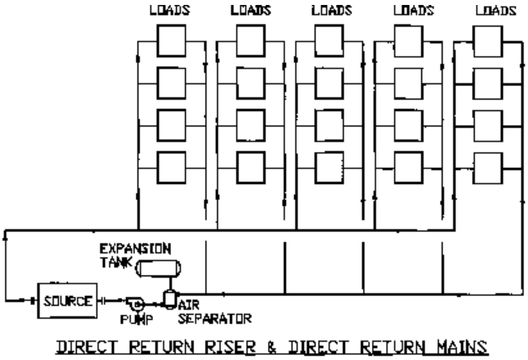


FIGURE 19.2 HYDRONIC SYSTEM RETURN TYPES.



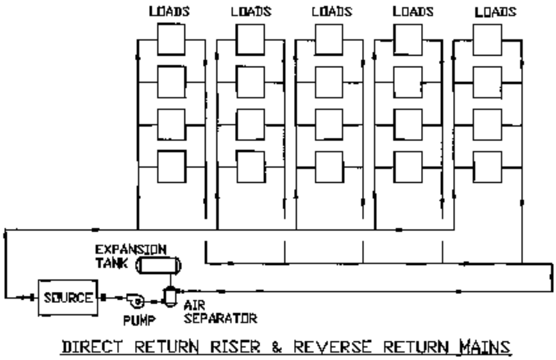
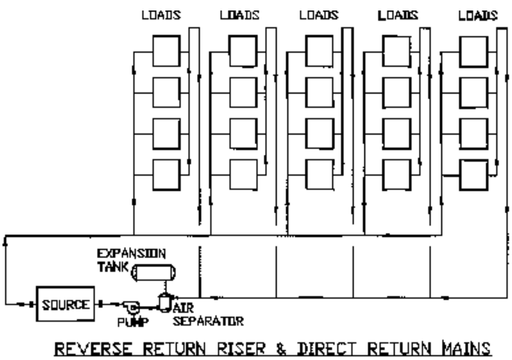


FIGURE 19.3 HYDRONIC SYSTEM RETURN TYPES.



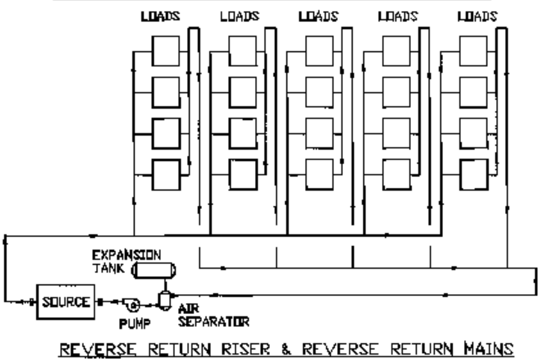


FIGURE 19.4 HYDRONIC SYSTEM RETURN TYPES.

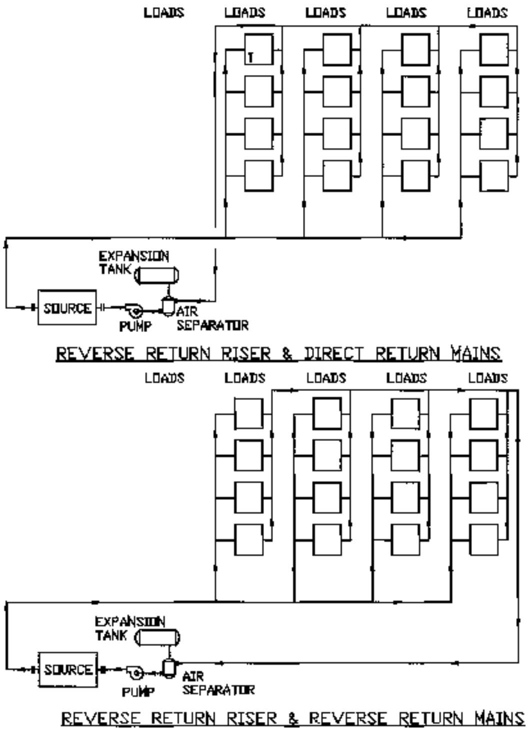


FIGURE 19.5 HYDRONIC SYSTEM RETURN TYPES.

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)

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)

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)

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.

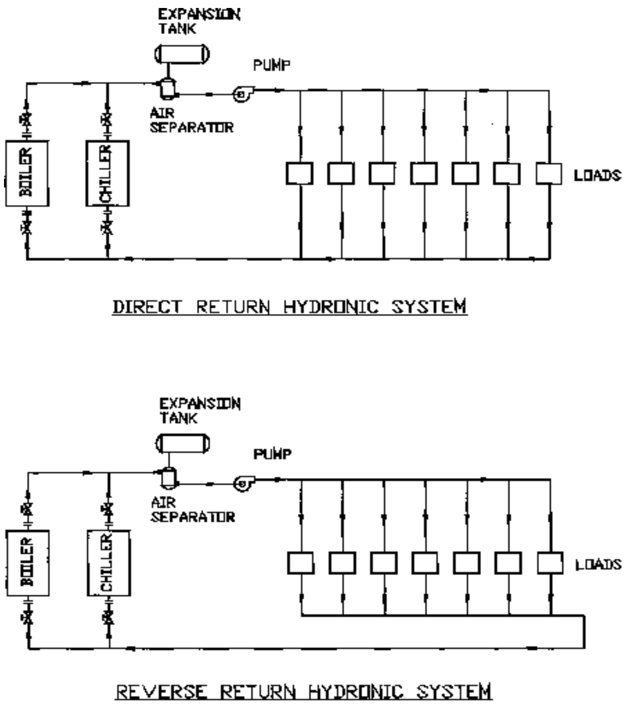


FIGURE 19.6 TWO-PIPE HYDRONIC SYSTEMS.

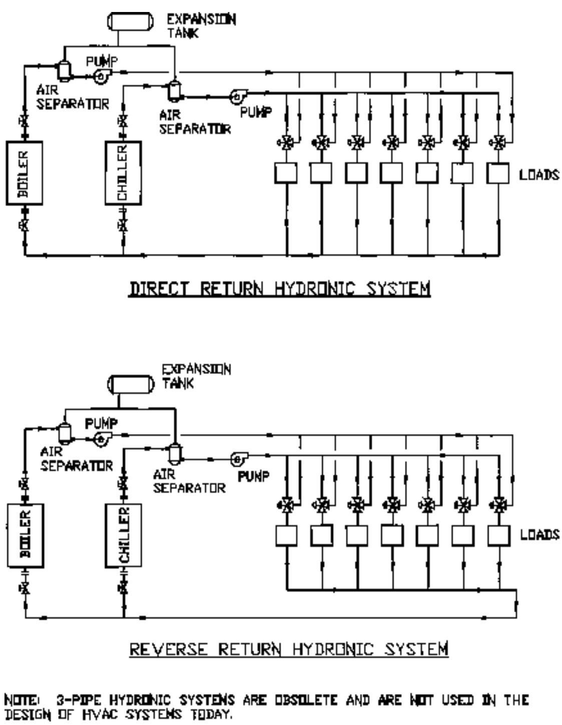


FIGURE 19.7 THREE-PIPE HYDRONIC SYSTEMS.

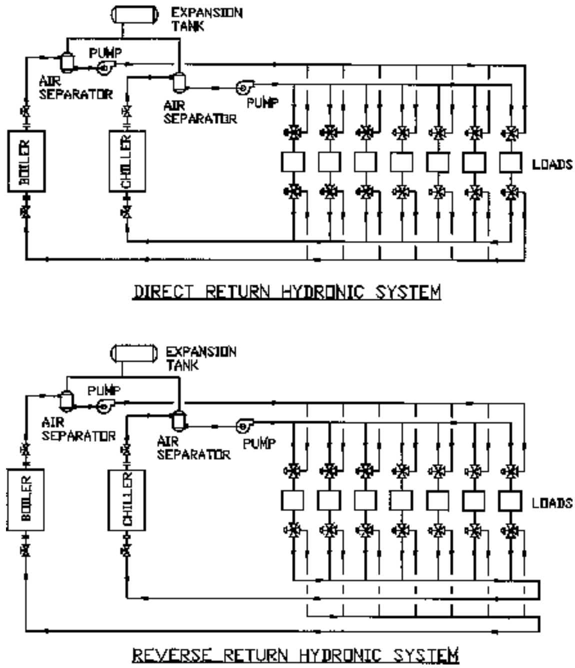


FIGURE 19.8 FOUR-PIPE HYDRONIC SYSTEMS COMMON LOAD SYSTEMS.

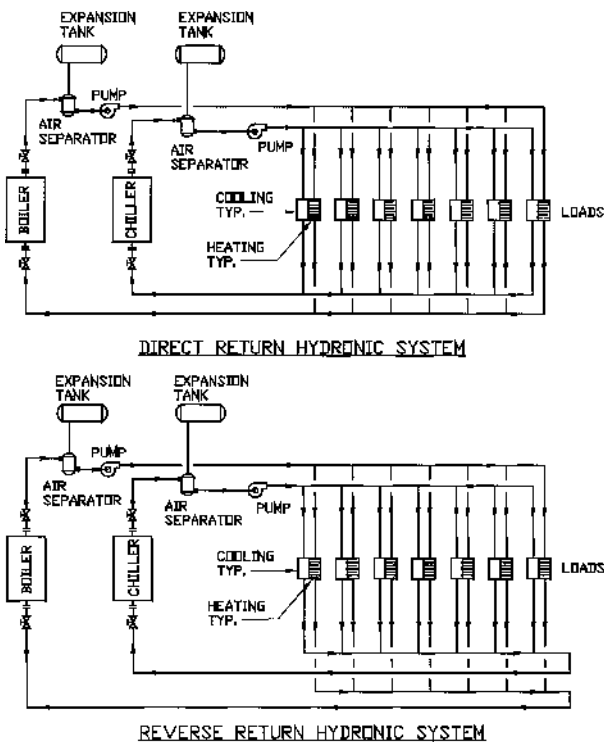


FIGURE 19.9 FOUR-PIPE HYDRONIC SYSTEMS INDEPENDENT LOAD SYSTEMS.

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):
   a. Small systems with a single boiler or chiller.
   b. More than one boiler system if boilers are firetube or firebox boilers.

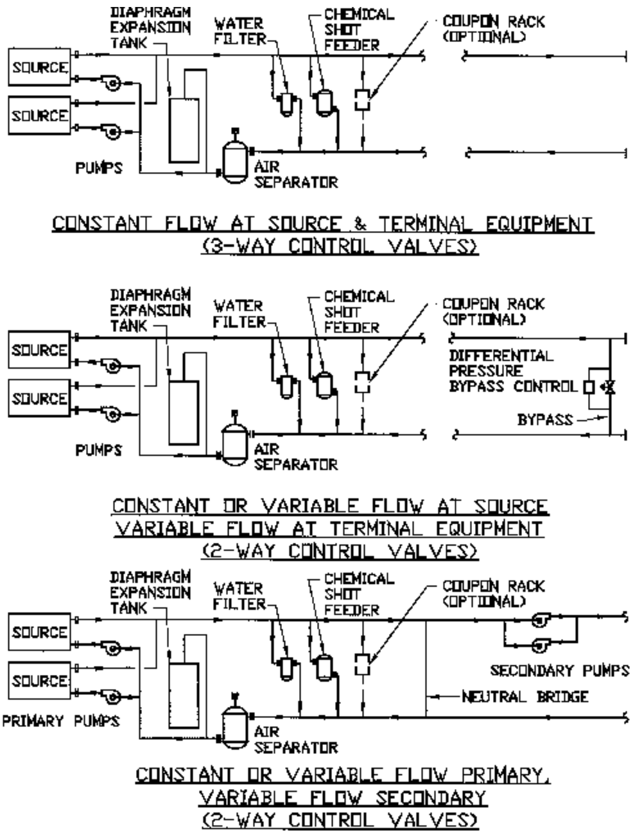


FIGURE 19.10 CONSTANT vs. VARIABLE FLOW SYSTEMS.

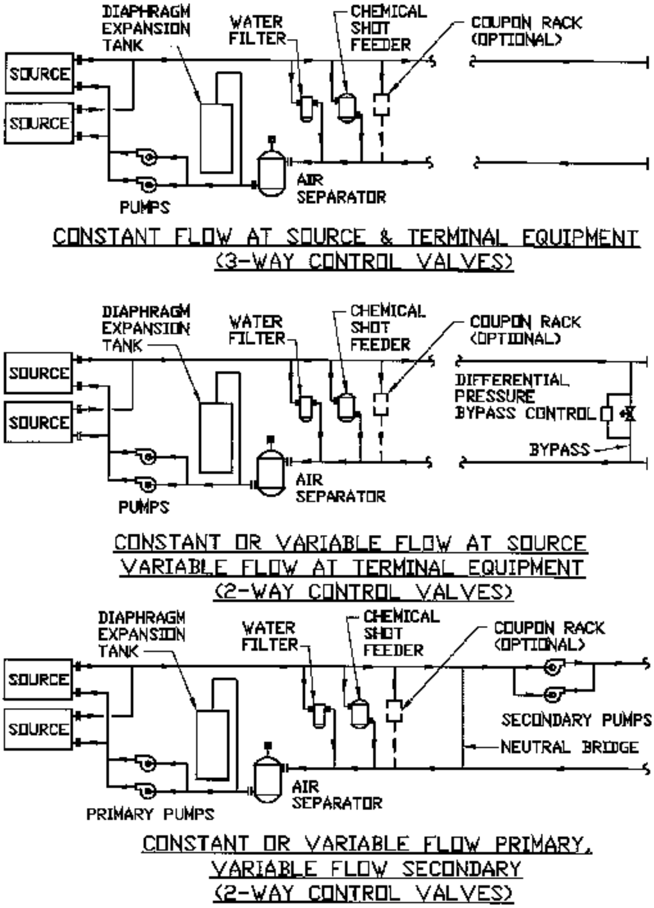


FIGURE 19.11 CONSTANT vs. VARIABLE FLOW SYSTEMS.

   c. Two chiller systems if chillers are connected in series.
   d. Small low-temperature heating water systems with 10–20°F delta T.
   e. 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)

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.

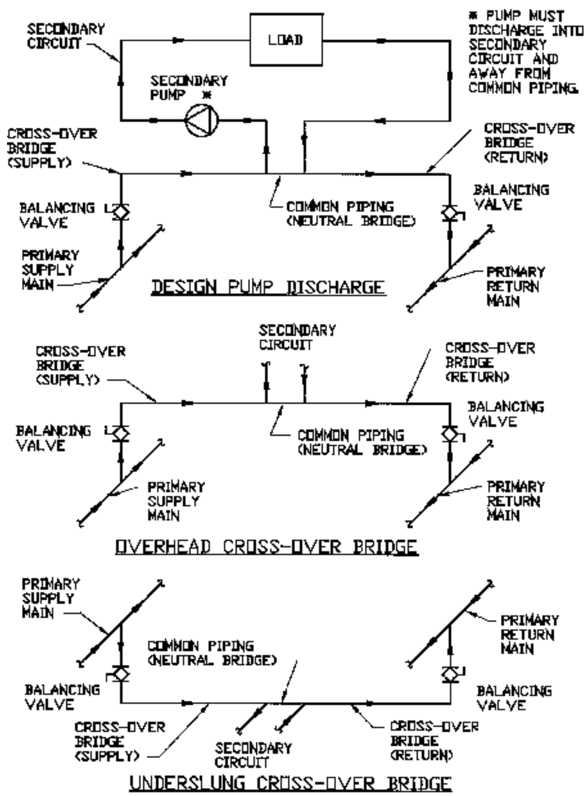


FIGURE 19.12 PRIMARY-SECONDARY TERMINOLOGY.

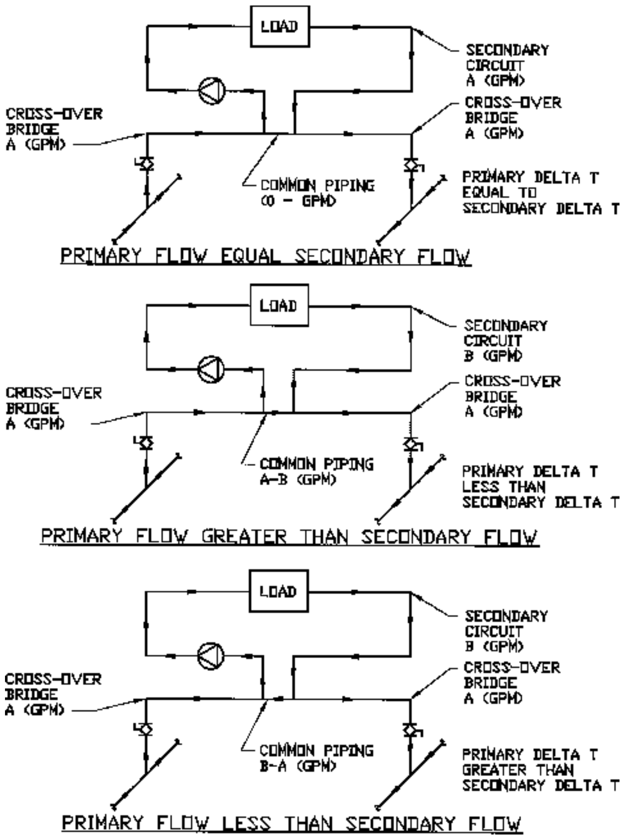


FIGURE 19.13 PRIMARY-SECONDARY FLOW ANALYSIS.

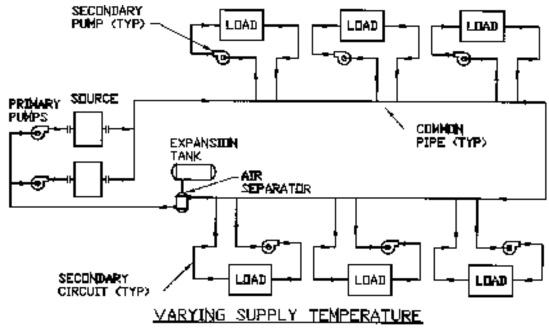
6. A 1-pipe primary system uses one pipe for supply and return. The secondary circuits are in series. Therefore, this system supplies a different supply water temperature to each secondary circuit, and the secondary circuits must be designed for this temperature change.
7. A 2-pipe primary system uses 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.

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.



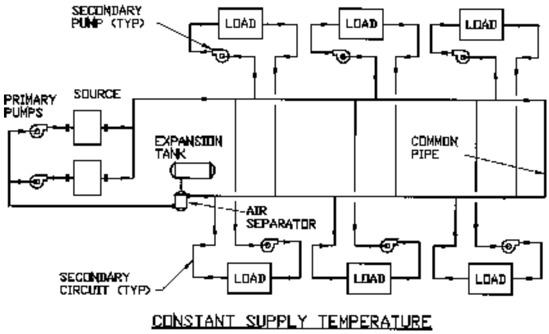
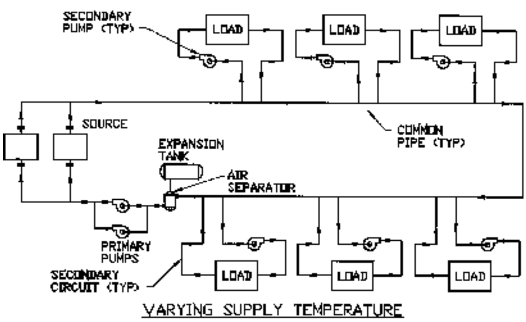


FIGURE 19.14 COUPLED ONE-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.



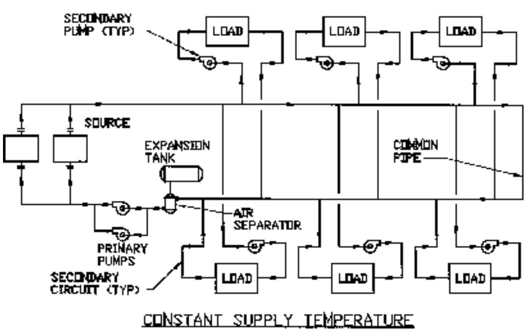


FIGURE 19.15 HEADERED ONE-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

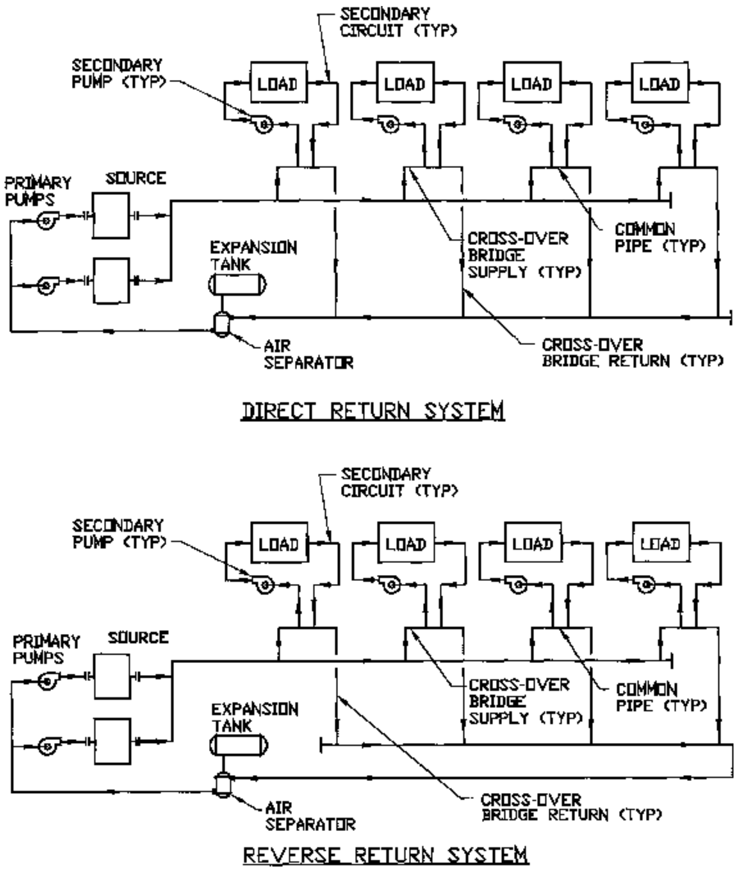


FIGURE 19.16 COUPLED TWO-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

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 Fig. 19.23 and Fig. 19.24).
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, system is easier to design and operate if the equipment is of equal capacity.

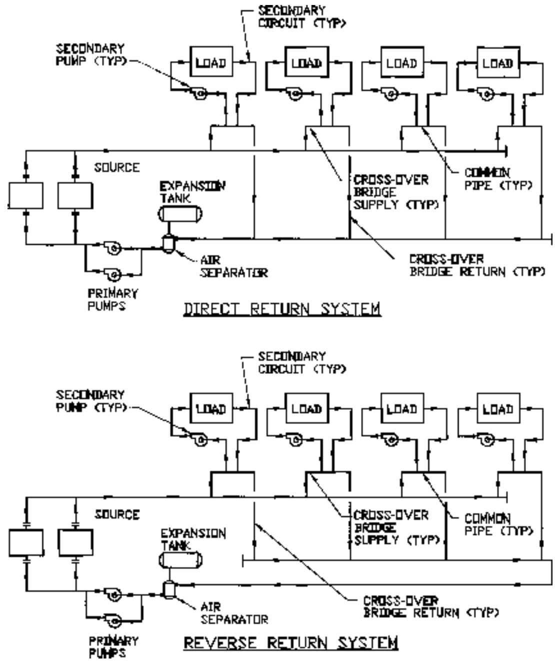


FIGURE 19.17 HEADERED TWO-PIPE PRIMARY-SECONDARY HYDRONIC SYSTEMS.

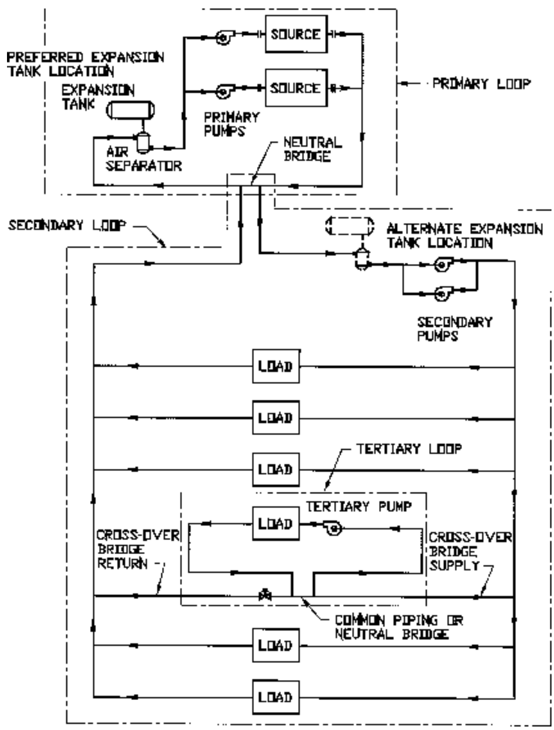


FIGURE 19.18 COUPLED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

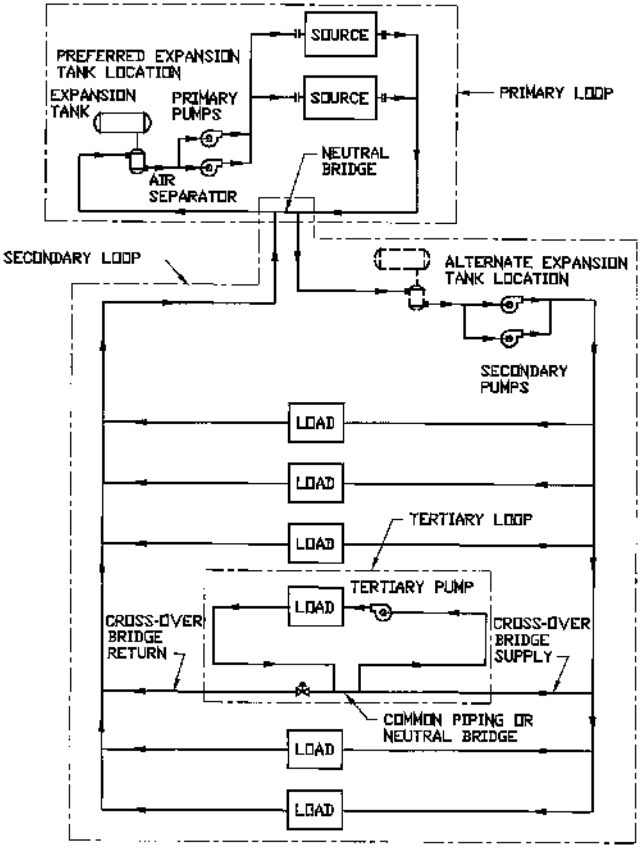


FIGURE 19.19 HEADERED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

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.

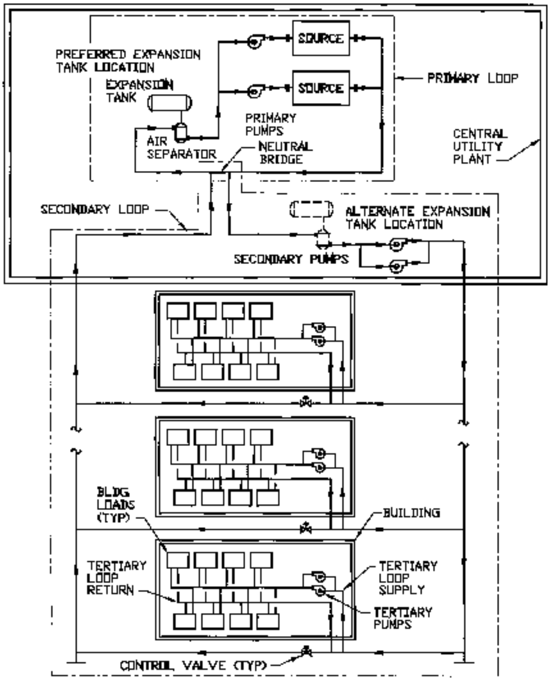


FIGURE 19.20 COUPLED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

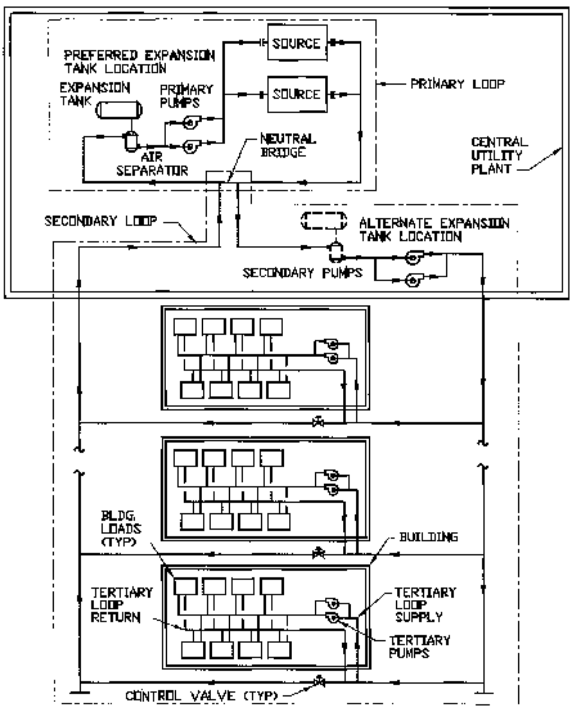


FIGURE 19.21 HEADERED PRIMARY-SECONDARY-TERTIARY HYDRONIC SYSTEMS.

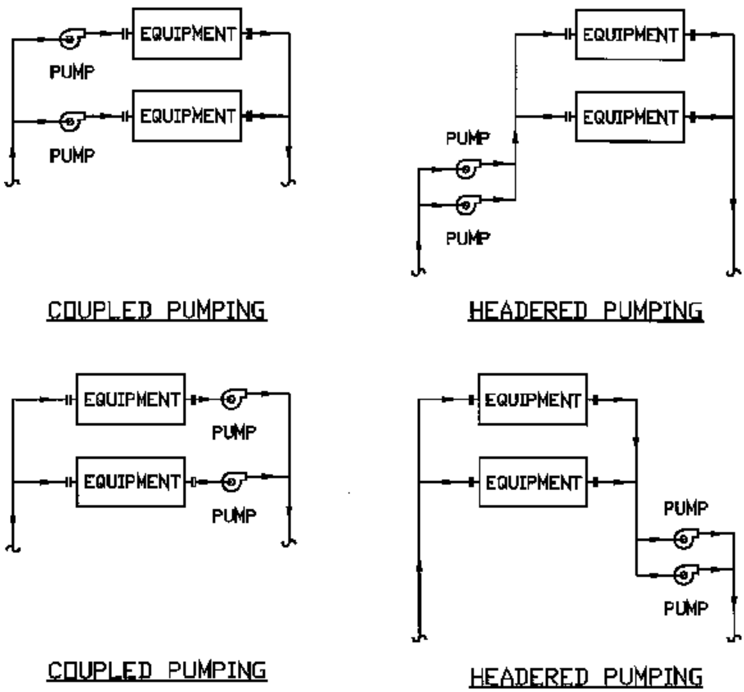


FIGURE 19.22 COUPLED-HEADERED PUMPING ARRANGEMENTS.

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 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.

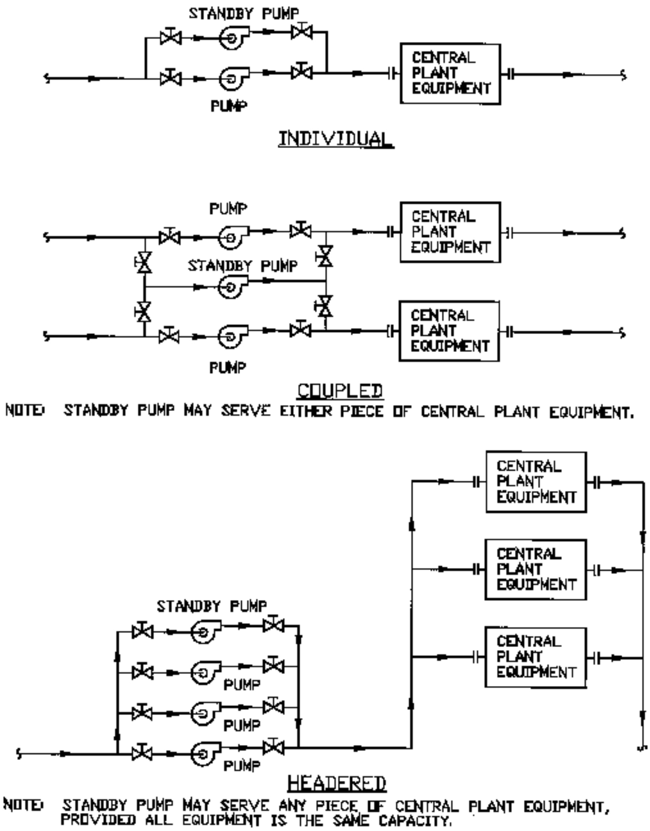


FIGURE 19.23 STANDBY PUMPS.

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 328 F. Higher tube velocity selection

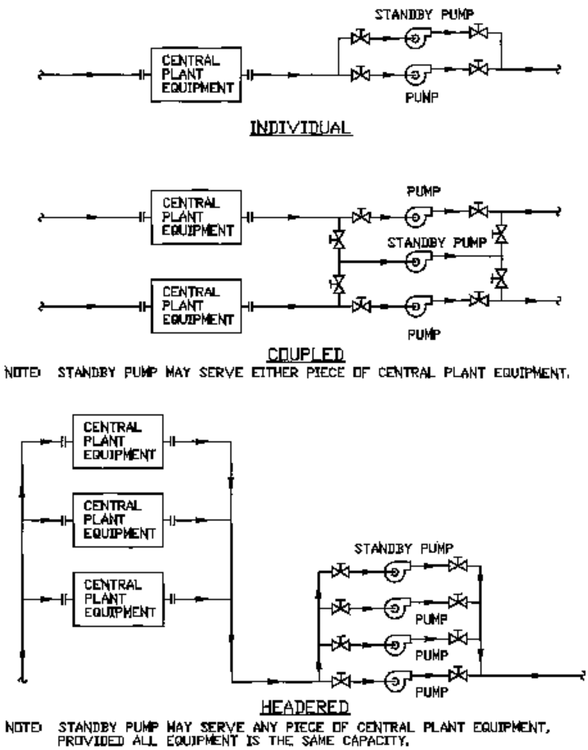


FIGURE 19.24 STANDBY PUMPS.

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):

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).

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.

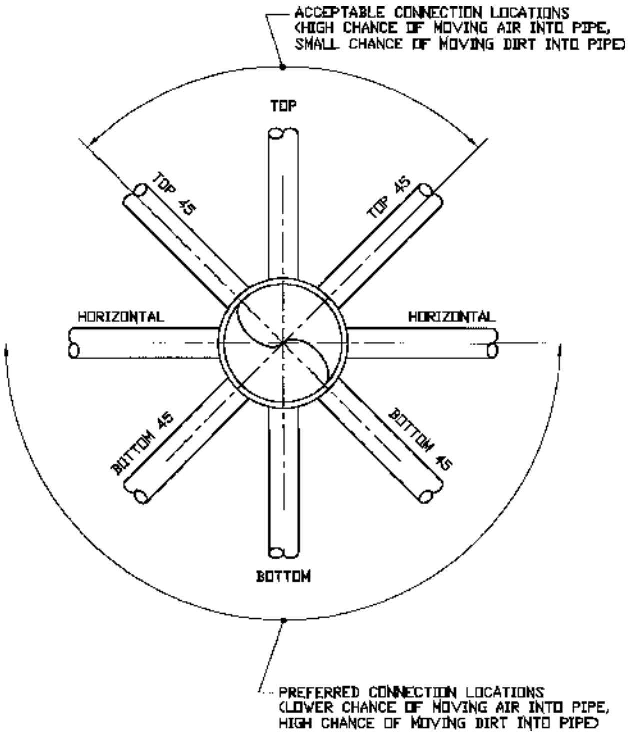


FIGURE 19.25 HYDRONIC PIPING CONNECTIONS.

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 the 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. **Glycol systems do not use malleable iron fittings.**

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 acid; above 7 is alkaline. Closed system water treatment should be 1,600 to 2,000 ppm Borax-Nitrite additive.**

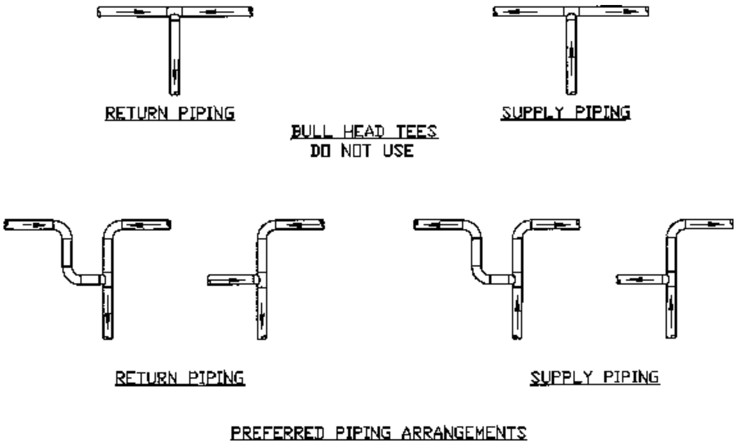


FIGURE 19.26 PIPING DESIGN—BULL HEAD TEES.

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.

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.

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.

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.

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 temperatures or to prevent condensation in the boiler due to low supply water temperatures 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.

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)

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 delta T, 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 delta T 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 antiflash 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 Fig. 19.27 and Fig. 19.28).

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

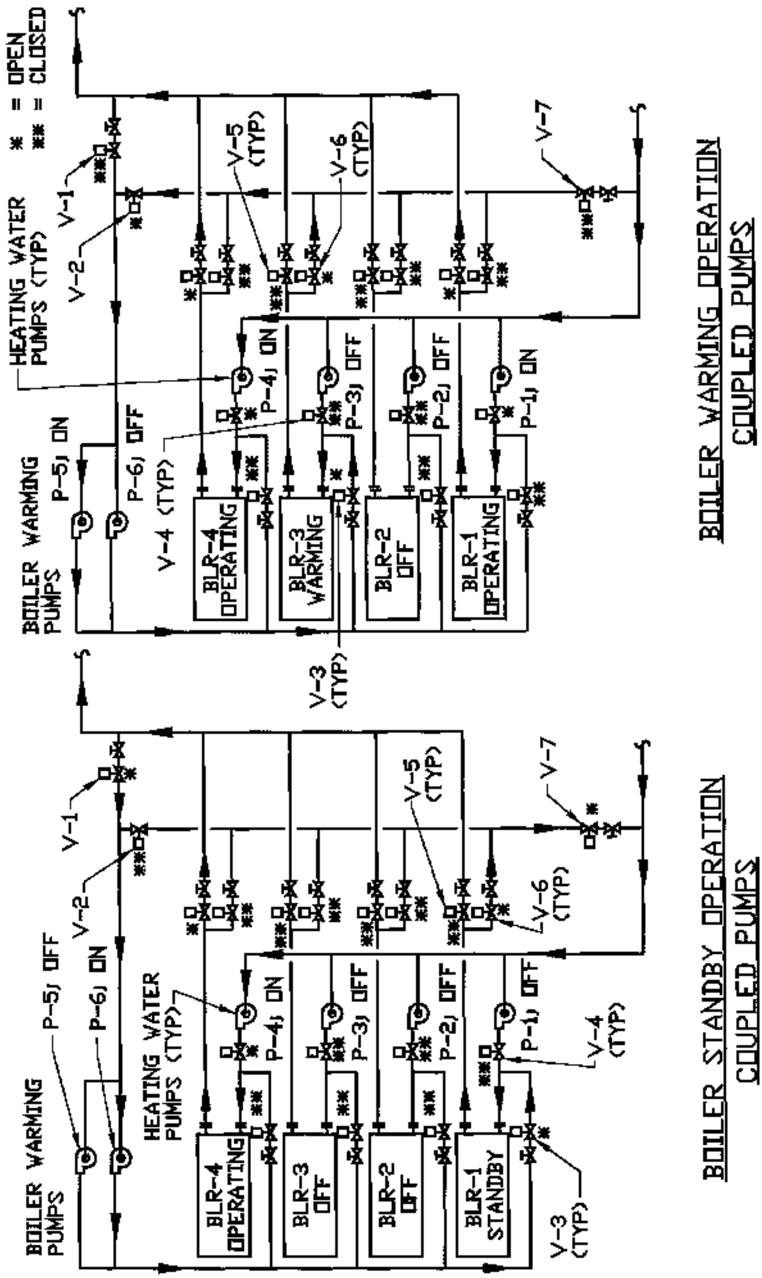


FIGURE 19.27 BOILER STANDBY AND WARMING DIAGRAM—COUPLED PUMPS.

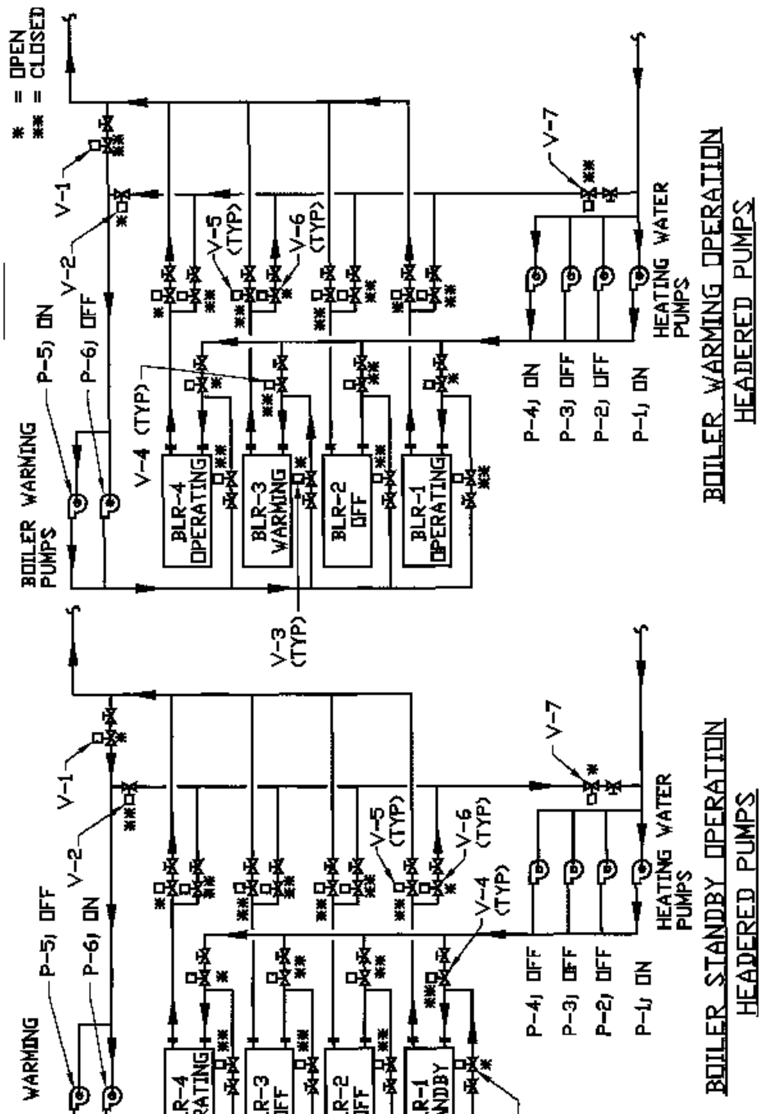


FIGURE 19.28 BOILER STANDBY AND WARMING DIAGRAM—HEADERED PUMPS.

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		
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 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.

19.13 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.

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.

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

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 19.

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

$$c_w = 1.02\ \text{Btu}/\cancel{\text{Lb H}_2\text{O}}\,°\text{F} \times 62.4\ \cancel{\text{Lbs.H}_2\text{O}/\text{ft}^3} \times 1.0\ \cancel{\text{ft}^3}/7.48052\ \text{gal.} \times 60\ \text{min./hr.} \times 0.94\ (\text{SG})$$

$$= 480\ \text{Btu min./hr.°F gal.}$$

$$H_{250°F} = 480\ \text{Btu min./hr. °F gal.} \times \text{GPM (gal./min.)} \times \Delta T\ (°\text{F})$$

$$H_{250°F} = 480 \times \text{GPM} \times \Delta T\ (°\text{F})$$

Water @ 450°F

$$c_w = 1.13\ \text{Btu}/\cancel{\text{Lb H}_2\text{O}}\ °\text{F} \times 62.4\ \cancel{\text{Lbs.H}_2\text{O}/\text{ft}^3} \times 1.0\ \cancel{\text{ft}^3}/7.48052\ \text{Gal.} \times 60\ \text{Min./Hr.} \times 0.83\ (\text{SG})$$

$$= 470\ \text{Btu min./hr. °F gal}$$

$$H_{450°F} = 470\ \text{Btu min./hr. °F gal.} \times \text{GPM (gal./min.)} \times \Delta T\ (°\text{F})$$

$$H_{450°F} = 470 \times \text{GPM} \times \Delta T\ (°\text{F})$$

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								
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
430	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
455	429.1	475	525	578	635	697	762	832

Notes:

1 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.

2 The antiflash margin of 40°F minimum is recommended for nitrogen or mechanically pressurized systems.

19.18 Piping Materials

A. 125 Psi (28 9 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 lb. 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 lb. 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 lb., 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 lb., 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 lb., 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 lb., 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-lb. systems: 45–125 psi.
2. 250-lb. 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-dependant. 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 startup, 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 268 through 270.
    b. Medium-temperature systems. Tables on pages 270 through 273.
    c. High-temperature systems. Tables on pages 273 through 276.

F. Air Separators

1. Air separators shall be full line size.

EXPANSION TANK SIZING—LOW TEMPERATURE SYSTEMS

Maximum System Temperature °F	Tank Size Expressed as a Percentage of System Volume			
	Expansion Tank Type			
	Closed Tank	Open Tank	Diaphragm Tank	
			Tank Volume	Acceptance Volume
100	2.21	1.37	1.32	0.59
110	3.08	1.87	1.83	0.82
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 in the table, multiply tank size only (not Acceptance Volume) by correction factors contained in the following Low Temperature System Correction Factor tables.

CLOSED 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	1.76	1.06	0.83	0.71	0.64	0.59	0.56	0.53	0.51	0.50
10	2.66	1.55	1.18	**1.00**	0.89	0.82	0.76	0.72	0.69	0.67
15	3.73	2.14	1.60	1.34	1.18	1.07	0.99	0.94	0.89	0.86
20	4.99	2.81	2.08	1.72	1.50	1.36	1.25	1.17	1.11	1.06
25	6.43	3.57	2.62	2.15	1.86	1.67	1.53	1.43	1.35	1.29
30	8.05	4.43	3.22	2.62	2.26	2.02	1.84	1.71	1.61	1.53
35	9.85	5.37	3.88	3.14	2.69	2.39	2.18	2.02	1.89	1.80
40	11.83	6.41	4.60	3.70	3.16	2.80	2.54	2.35	2.20	2.07
45	13.99	7.54	5.39	4.31	3.66	3.23	2.93	2.70	2.52	2.37
50	16.34	8.75	6.23	4.96	4.21	3.70	3.34	3.07	2.86	2.69
55	18.86	10.06	7.13	5.66	4.78	4.20	3.78	3.46	3.22	3.02
60	21.57	11.46	8.09	6.41	5.40	4.72	4.24	3.88	3.60	3.37
65	24.46	12.95	9.11	7.20	6.05	5.28	4.73	4.32	4.00	3.75
70	27.53	14.53	10.20	8.03	6.73	5.87	5.25	4.78	4.42	4.13
75	30.77	16.20	11.34	8.91	7.45	6.48	5.79	5.27	4.86	4.54
80	34.21	17.96	12.55	9.84	8.21	7.13	6.36	5.78	5.33	4.96
85	37.82	19.81	13.81	10.81	9.01	7.81	6.95	6.31	5.81	5.41
90	41.61	21.75	15.13	11.83	9.84	8.52	7.57	6.86	6.31	5.87
95	45.59	23.79	16.52	12.89	10.71	9.25	8.22	7.44	6.83	6.35
100	49.74	25.91	17.97	13.99	11.61	10.02	8.89	8.04	7.37	6.84

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.

CLOSED 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	0.48	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	0.62
10	2.66	1.55	1.18	**1.00**	0.89	0.82	0.76	0.72	0.69	0.67
15	3.11	1.78	1.33	1.11	0.98	0.89	0.83	0.78	0.74	0.71
20	3.55	2.00	1.48	1.22	1.07	0.96	0.89	0.84	0.79	0.76
25	4.00	2.22	1.63	1.34	1.16	1.04	0.95	0.89	0.84	0.80
30	4.45	2.45	1.78	1.45	1.25	1.11	1.02	0.95	0.89	0.85
35	4.89	2.67	1.93	1.56	1.34	1.19	1.08	1.00	0.94	0.89
40	5.34	2.89	2.08	1.67	1.43	1.26	1.15	1.06	0.99	0.94
45	5.79	3.12	2.23	1.78	1.52	1.34	1.21	1.12	1.04	0.98
50	6.24	3.34	2.38	1.89	1.61	1.41	1.27	1.17	1.09	1.03
55	6.68	3.57	2.53	2.01	1.69	1.49	1.34	1.23	1.14	1.07
60	7.13	3.79	2.68	2.12	1.78	1.56	1.40	1.28	1.19	1.12
65	7.58	4.01	2.82	2.23	1.87	1.64	1.47	1.34	1.24	1.16
70	8.03	4.24	2.97	2.34	1.96	1.71	1.53	1.39	1.29	1.21
75	8.47	4.46	3.12	2.45	2.05	1.79	1.59	1.45	1.34	1.25
80	8.92	4.68	3.27	2.57	2.14	1.86	1.66	1.51	1.39	1.29
85	9.37	4.91	3.42	2.68	2.23	1.93	1.72	1.56	1.44	1.34
90	9.82	5.13	3.57	2.79	2.32	2.01	1.79	1.62	1.49	1.38
95	10.26	5.36	3.72	2.90	2.41	2.08	1.85	1.67	1.54	1.43
100	10.71	5.58	3.87	3.01	2.50	2.16	1.91	1.73	1.59	1.47

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									
	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
100	1.38	1.30	1.24	1.18	1.13	1.09	1.05	1.02	0.99	0.96

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.

EXPANSION TANK SIZING—MEDIUM 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
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

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	10	20	30	40	50	60	70	80	90	100
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	072	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	0.27
90	1.78	0.97	0.70	0.56	0.48	0.43	0.39	0.36	0.34	0.32
100	2.12	1.14	0.82	0.66	0.56	0.49	0.45	0.41	0.39	0.36
110	2.49	1.34	0.95	0.76	0.64	0.57	0.51	0.47	0.44	0.41
120	2.88	1.54	1.09	0.87	0.74	0.65	0.58	0.54	0.50	0.47
130	3.31	1.76	1.25	0.99	0.83	0.73	0.66	0.60	0.56	0.52
140	3.77	2.00	1.41	1.11	0.94	0.82	0.73	0.67	0.62	0.58
150	4.26	2.25	1.58	1.25	1.05	0.91	0.82	0.75	0.69	0.65
160	4.78	2.52	1.76	1.39	1.16	1.01	0.90	0.82	0.76	0.71
170	5.32	2.80	1.96	1.54	1.28	1.11	0.99	0.90	0.83	0.78
180	5.90	3.09	2.16	1.69	1.41	1.22	1.09	0.99	0.91	0.85
190	6.50	3.40	2.37	1.85	1.54	1.34	1.19	1.08	0.99	.92
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	**1.00**
210	7.81	4.07	2.82	2.20	1.83	1.58	1.40	1.27	1.16	1.08
220	8.50	4.42	3.06	2.39	1.98	1.71	1.51	1.37	1.25	1.16
230	9.22	4.79	3.32	2.58	2.13	1.84	1.63	1.47	1.35	1.25
240	9.98	5.18	3.58	2.78	2.30	1.98	1.75	1.58	1.44	1.34
250	10.76	5.58	3.85	2.98	2.47	2.12	1.87	1.69	1.54	1.43
260	11.57	5.99	4.13	3.20	2.64	2.27	2.00	1.80	1.65	1.52

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
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

(*Continued*)

CLOSED EXPANSION TANK SIZING
MEDIUM TEMPERATURE SYSTEM CORRECTION FACTORS (*Continued*)

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	110	120	130	140	150	160	170	180	190	200
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	1.09	1.03	0.97	0.93	0.89	0.86	0.83	0.80	0.78	0.75
230	1.17	1.10	1.04	1.00	0.95	0.92	0.88	0.85	0.83	0.81
240	1.25	1.18	1.12	1.06	1.02	0.98	0.94	0.91	0.88	0.86
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
160	5.87	3.09	2.17	1.71	1.43	1.24	1.11	1.01	0.93	0.87
170	6.19	3.25	2.27	1.79	1.49	1.30	1.16	1.05	0.97	0.90
180	6.50	3.41	2.38	1.86	1.56	1.35	1.20	1.09	1.01	0.94
190	6.82	3.57	2.49	1.94	1.62	1.40	1.25	1.13	1.04	0.97
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	**1.00**
210	7.46	3.89	2.70	2.10	1.75	1.51	1.34	1.21	1.11	1.03
220	7.78	4.05	2.80	2.18	1.81	1.56	1.38	1.25	1.15	1.06
230	8.09	4.21	2.91	2.26	1.87	1.61	1.43	1.29	1.18	1.10
240	8.41	4.36	3.02	2.34	1.94	1.67	1.47	1.33	1.22	1.13
250	8.73	4.52	3.12	2.42	2.00	1.72	1.52	1.37	1.25	1.16
260	9.05	4.68	3.23	2.50	2.06	1.77	1.56	1.41	1.29	1.19

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
80	0.59	0.57	0.55	0.53	0.52	0.51	0.49	0.48	0.48	0.47
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				
Maximum System Temperature °F	Expansion Tank Type			
	Closed Tank	Open Tank	Diaphragm 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 in the table, multiply tank size only (not 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

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	20	40	60	80	100	120	140	160	180	200
160	0.68	0.37	0.27	0.22	0.19	0.17	0.16	0.15	0.14	0.13
180	0.83	0.46	0.33	0.27	0.23	0.20	0.19	0.17	0.16	0.15
200	1.01	0.55	0.39	0.32	0.27	0.24	0.22	0.20	0.19	0.18
220	1.19	0.64	0.46	0.37	0.31	0.28	0.25	0.23	0.22	0.20
240	1.40	0.75	0.53	0.43	0.36	0.32	0.29	0.26	0.25	0.23
260	1.62	0.86	0.61	0.49	0.41	0.36	0.32	0.30	0.28	0.26
280	1.85	0.98	0.70	0.55	0.46	0.41	0.37	0.33	0.31	0.29
300	2.10	1.11	0.78	0.62	0.52	0.46	0.41	0.37	0.35	0.32
320	2.37	1.25	0.88	0.69	0.58	0.51	0.45	0.41	0.38	0.36
340	2.65	1.40	0.98	0.77	0.64	0.56	0.50	0.46	0.42	0.39
360	2.95	1.55	1.08	0.85	0.71	0.62	0.55	0.50	0.46	0.43
380	3.27	1.71	1.19	0.94	0.78	0.68	0.60	0.55	0.50	0.47
400	3.60	1.88	1.31	1.02	0.85	0.74	0.66	0.59	0.55	0.51
420	3.95	2.06	1.43	1.12	0.93	0.80	0.71	0.65	0.59	0.55
440	4.31	2.25	1.56	1.21	1.01	0.87	0.77	0.70	0.64	0.59
460	4.69	2.44	1.69	1.31	1.09	0.94	0.83	0.75	0.69	0.64
480	5.08	2.64	1.83	1.42	1.17	1.01	0.90	0.81	0.74	0.69
500	5.50	2.85	1.97	1.53	1.26	1.09	0.96	0.87	0.79	0.73
520	5.92	3.07	2.12	1.64	1.36	1.17	1.03	0.93	0.85	0.78
540	6.37	3.29	2.27	1.76	1.45	1.25	1.10	0.99	0.90	0.84
560	6.82	3.53	2.43	1.88	1.55	1.33	1.17	1.05	0.96	0.89
580	7.30	3.77	2.59	2.00	1.65	1.41	1.25	1.12	1.02	0.94
600	7.79	4.02	2.76	2.13	1.75	1.50	1.32	1.19	1.08	**1.00**
620	8.30	4.28	2.93	2.26	1.86	1.59	1.40	1.26	1.15	1.06
640	8.82	4.54	3.11	2.40	1.97	1.69	1.48	1.33	1.21	1.12
660	9.36	4.81	3.30	2.54	2.09	1.78	1.57	1.41	1.28	1.18
680	9.91	5.10	3.49	2.69	2.20	1.88	1.65	1.48	1.35	1.24
700	10.49	5.39	3.69	2.84	2.33	1.99	1.74	1.56	1.42	1.31

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.**

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

(*Continued*)

CLOSED EXPANSION TANK SIZING HIGH TEMPERATURE SYSTEM CORRECTION FACTORS (*Continued*)

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	220	240	260	280	300	320	340	360	380	400
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	0.56	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	0.65	0.61	0.58	0.56	0.54	0.52	0.50	0.48	0.47
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	1.29	1.03	0.87	0.77	0.69	0.64	0.59	0.56
260	3.62	1.93	1.37	1.09	0.92	0.81	0.73	0.67	0.62	0.58
280	3.86	2.05	1.45	1.15	0.97	0.85	0.76	0.70	0.65	0.61
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

(*Continued*)

DIAPHRAGM EXPANSION TANK SIZING
HIGH TEMPERATURE SYSTEM CORRECTION FACTORS (*Continued*)

Initial Pressure psig	Pressure Increase—psig Initial Pressure + Pressure Increase = Maximum Operating Pressure									
	20	40	60	80	100	120	140	160	180	200
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.

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
580	0.91	0.85	0.81	0.77	0.73	0.70	0.67	0.65	0.63	0.61
600	0.93	0.87	0.73	0.78	0.75	0.72	0.69	0.66	0.64	0.62
620	0.95	0.89	0.84	0.80	0.76	0.73	0.70	0.68	0.66	0.64
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.

PART 20

Glycol Piping Systems

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.

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

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.
   $c_g = 0.89$ Btu/~~Lb H_2O~~ [AC1]°F × 62.4 ~~Lbs.H_2O/Ft^3~~ × 1.0 ~~Ft^3~~ /7.48052 gal. × 60 min./hr. × 1.040 (SG)
   = 463 Btu min./hr. °F gal.
   $H_{30\%EG}$ = 463 Btu min./hr. °F gal. × GPM (gal/min.) × ΔT (°F).
   $H_{30\%EG}$ = 463 × GPM × ΔT (°F).
   50 percent propylene glycol.
   $c_g = 0.85$ Btu/~~Lb H_2O~~ °F × 62.4 ~~Lbs.H_2O/Ft^3~~ × 1.0 ~~Ft^3~~ / 7.48052 gal. × 60 min./hr. × 1.041 (SG)
   = 442 Btu min./hr. °F gal.
   $H_{50\%PG}$ = 442 Btu min./hr. °F gal. × GPM (gal/min.) × ΔT (°F).
   $H_{50\%PG}$ = 442 × GPM × ΔT (°F).

PART 21

Steam Piping Systems

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 steams 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.
5. Friction loss estimate:
   a. 2.0 × System Length (ft.) × 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).
10. Steam piping should be installed with eccentric reducers (flat on the bottom) to prevent accumulation of condensate in the pipe and thus increasing 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 increasing 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,

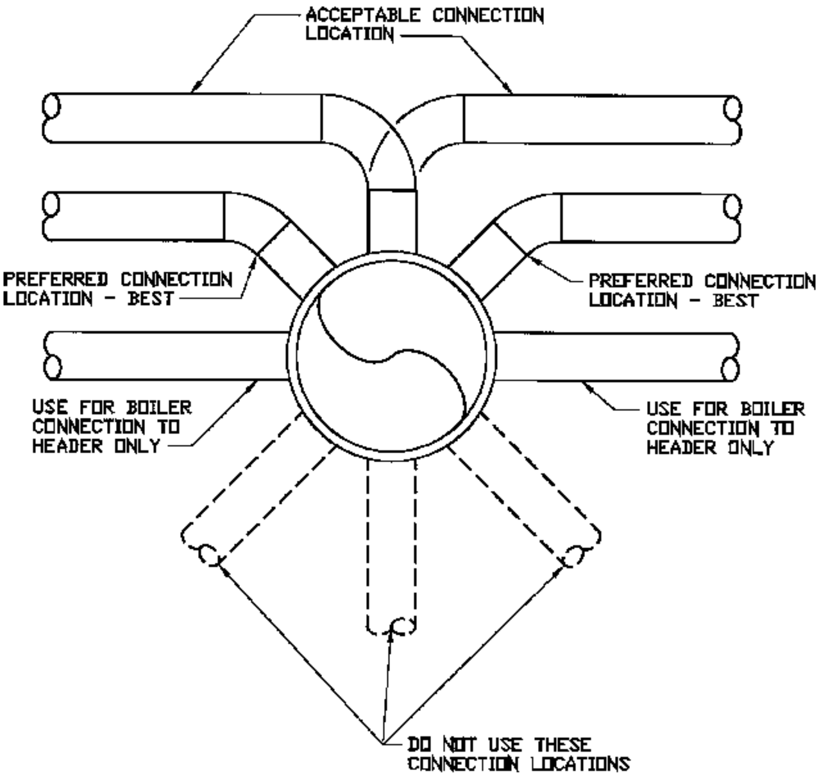


FIGURE 21.1 STEAM PIPING CONNECTIONS.

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's 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 acid; 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):
    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, *ASTM A53, Schedule 40,* Type E or S, Grade B
      Fittings: Black Cast Iron Screw Fittings, 125 lb., *ANSI/ASME B16.4*
      Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1.*
2. 2-1/2" thru 10":
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
      Fittings: Steel Butt-Welding Fittings, 125 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
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, 125 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

D. Medium Pressure Steam Pipe (16–100 psig):

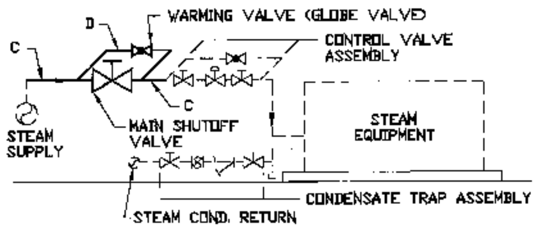
1. 1-1/2" and Smaller:
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
      Fittings: Forged Steel Socket-Weld, 150 lb., *ANSI B16.11*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   b. Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 40,* Grade B
      Fittings: Forged Steel Socket-Weld, 150 lb., *ANSI B16.11*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
2. 2" thru 10":
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
      Fittings: Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*
   b. Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 40,* Grade B
      Fittings: Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
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, 150 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   b. Pipe: Carbon Steel Pipe, *ASTM A106, 3/8" wall,* Grade B
      Fittings: Steel Butt-Welding Fittings, 150 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

E. High Pressure Steam Pipe (100–300 psig):

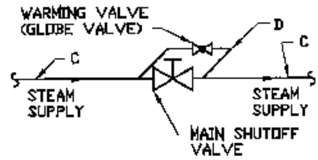
1. 1-1/2" and smaller:
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
      Fittings: Forged Steel Socket-Weld, 300 lb., *ANSI B16.11*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   b. Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B
      Fittings: Forged Steel Socket-Weld, 300 lb., *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 80,* Type E or S, Grade B
      Fittings: Steel Butt-Welding Fittings, 300 lb., *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 lb., *ANSI/ASME B16.9*
      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.



STEAM EQUIPMENT APPLICATION
SERIES A



STEAM SYSTEM
ISOLATION VALVE APPLICATION
SERIES B

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"

FIGURE 21.2 STEAM SYSTEM WARMING VALVES.

G. Steam Pressure Reducing Valves (PRV)

1. 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 thru 21.5).
2. Commercial low pressure steam systems may be provided with either gravity or pumps condensate return systems (see Figs. 21.6 and 21.7).
3. Commercial and industrial medium and high pressure steam systems are generally provided with pumped return condensate systems (see Figs. 21.8 and 21.9).

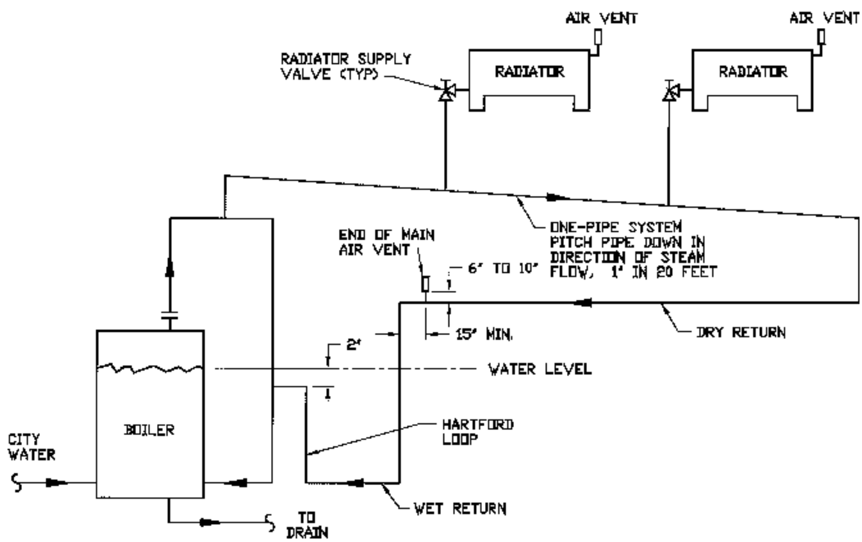


FIGURE 21.3 RESIDENTIAL LP STEAM SYSTEMS 1.

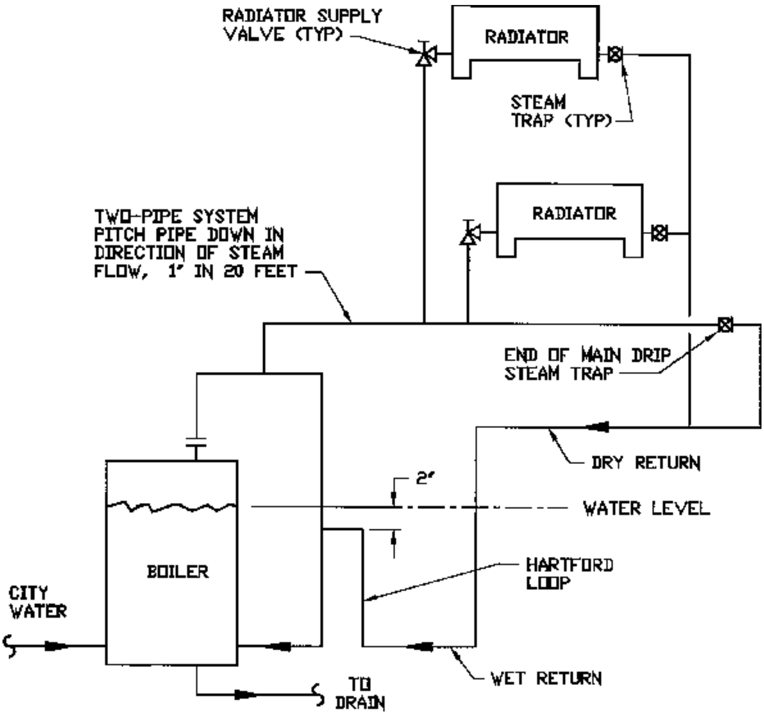


FIGURE 21.4 RESIDENTIAL LP STEAM SYSTEMS 2.

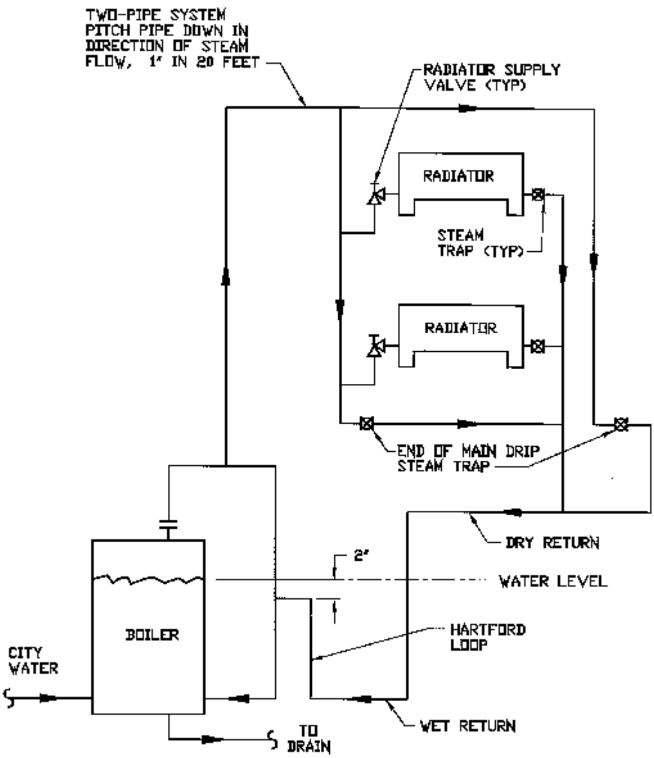


FIGURE 21.5 RESIDENTIAL LP STEAM SYSTEMS 3.

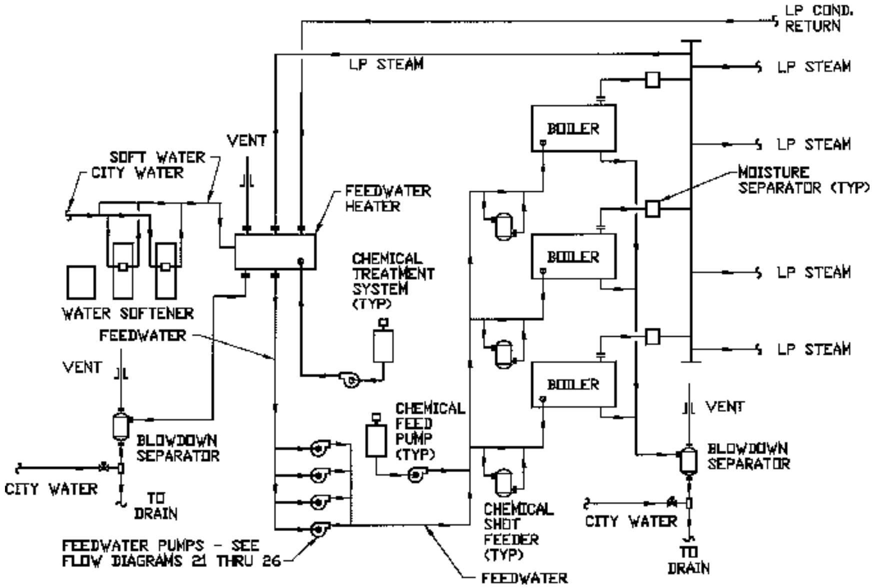


FIGURE 21.6 LOW PRESSURE STEAM SYSTEMS—GRAVITY RETURN.

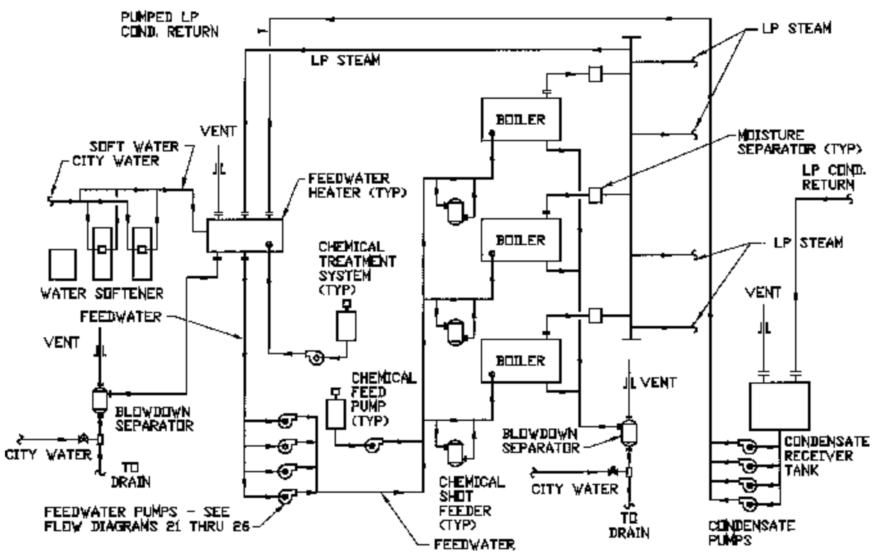


FIGURE 21.7 LOW PRESSURE STEAM SYSTEMS—PUMPED RETURN.

HIGH PRESSURE STEAM SYSTEM KEYED NOTES:

1. BOILER
2. DEAERATOR OR FEEDWATER HEATER
3. BLOWDOWN FLASH TANK
4. FEEDWATER PUMPS - SEE FLOW DIAGRAMS 21 THROUGH 26
5. CONDENSATE RECEIVER TANK
6. CONDENSATE PUMPS
7. BLOWDOWN SEPARATOR
8. BLOWDOWN HEAT EXCHANGER
9. SAMPLE COOLER
10. FLASH TANK
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)
26. FLASH STEAM TO LP STEAM SYSTEM
27. COMBINED HIGH-PRESSURE & MEDIUM-PRESSURE CONDENSATE RETURNS
28. LOW PRESSURE CONDENSATE RETURN
29. MEDIUM-PRESSURE CONDENSATE RETURN
30. HIGH-PRESSURE CONDENSATE RETURN
31. PUMPED CONDENSATE RETURN
32. CITY WATER
33. TREATED WATER
34. HEATED SOFT WATER
35. FEEDWATER

FIGURE 21.8 HP STEAM SYSTEM FLOW DIAGRAM NOTES.

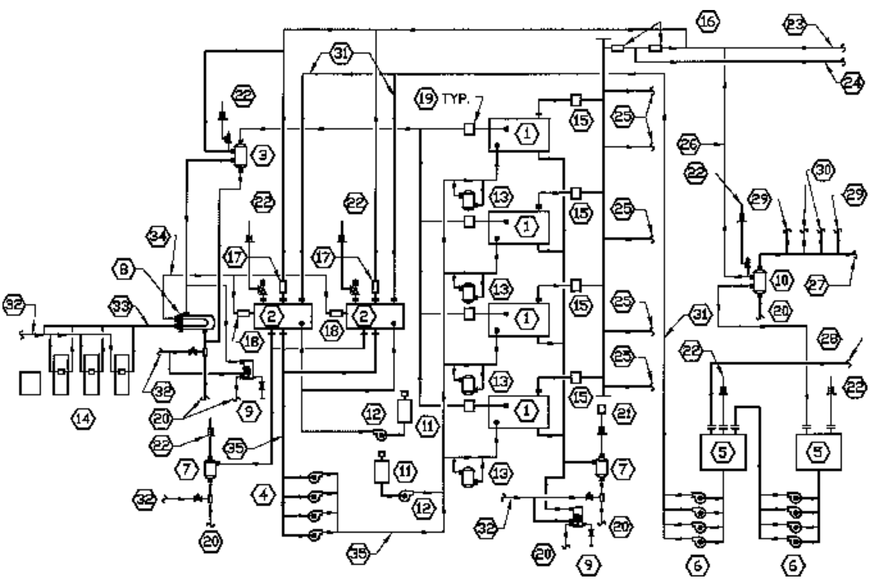


FIGURE 21.9 HIGH PRESSURE STEAM SYSTEMS—PUMPED RETURN.

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
Velocity Range 4,000–6,000 FPM	7	1/4	1.5	6,000
	10	1/2	2.0	6,000
	12	1/2	2.5	6,000
	15	1/2	3	6,000
Medium Pressure	20	1/2	4	8,000
	25	1/2–1	5	8,000
	30	1/2–1	5–6	8,000
	40	1	6–8	10,000
	50	1	8–10	10,000
Velocity Range 6,000–12,000 FPM	60	1	10–12	12,000
	75	1–2	12–15	12,000
	85	1–2	12–15	12,000
	100	1–2	15–20	12,000
High Pressure	120	2	20–24	15,000
	125	2	20–24	15,000
	150	2	24–30	15,000
	175	2	24–30	15,000
Velocity Range 6,000–15,000 FPM	200	2–5	30–40	15,000
	225	2–5	30–40	15,000
	250	2–5	30–50	15,000
	275	2–5	30–50	15,000
	300	2–5	40–60	15,000

21.03 Steam Tables

STEAM TABLES

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lbs.	Heat Content (above 32°F) Btu/lbs.		
				Sensible	Latent	Total
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	1,159.7
10	24.7	239.4	16.496	207.8	952.7	1,160.5
11	25.7	241.6	15.895	210.1	951.2	1,161.3
12	26.7	243.7	15.337	212.2	949.8	1,162.0
13	27.7	245.8	14.817	214.4	948.4	1,162.8
14	28.7	247.8	14.334	216.4	947.1	1,163.5
15	29.7	249.8	13.881	218.3	945.8	1,164.1
16	30.7	251.7	13.458	220.3	944.5	1,164.8
17	31.7	253.5	13.059	222.2	943.3	1,165.5
18	32.7	255.3	12.685	224.0	942.1	1,166.1
19	33.7	257.1	12.332	225.8	940.9	1,166.7
20	34.7	258.8	11.998	227.5	939.7	1,167.2
21	35.7	260.5	11.684	229.2	938.5	1,167.7
22	36.7	262.1	11.385	230.9	937.4	1,168.3
23	37.7	263.7	11.102	232.5	936.3	1,168.8
24	38.7	265.3	10.833	234.1	935.2	1,169.3

(Continued)

STEAM TABLES (*Continued*)

Steam Pressure psig	Steam Pressure psia	Saturation Temperature ºF	Specific Volume cu.ft./lbs.	Heat Content (above 32ºF) Btu/lbs.		
				Sensible	Latent	Total
25	39.7	266.8	10.577	235.7	934.1	1,169.8
26	40.7	268.3	10.333	237.3	933.1	1,170.4
27	41.7	269.8	10.101	238.7	932.1	1,170.8
28	42.7	271.2	9.879	240.2	931.1	1,171.3
29	43.7	272.6	9.666	241.7	930.1	1,171.8
30	44.7	274.0	9.463	243.1	929.1	1,172.2
31	45.7	275.4	9.269	244.5	928.2	1,172.7
32	46.7	276.8	9.082	245.9	927.2	1,173.1
33	47.7	278.1	8.904	247.2	926.3	1,173.5
34	48.7	279.4	8.732	248.5	925.4	1,173.9
35	49.7	280.6	8.567	249.9	924.5	1,174.4
36	50.7	281.9	8.408	251.1	923.6	1,174.7
37	51.7	283.1	8.255	252.4	922.7	1,175.1
38	52.7	284.4	8.109	253.7	921.8	1,175.5
39	53.7	285.6	7.966	254.9	921.0	1,175.9
40	54.7	286.7	7.843	256.1	920.1	1,176.2
41	55.7	287.9	7.697	257.3	919.3	1,176.6
42	56.7	289.1	7.570	258.5	918.4	1,176.9
43	57.7	290.2	7.447	259.6	917.6	1,177.2
44	58.7	291.3	7.327	260.8	916.8	1,177.6
45	59.7	292.4	7.212	261.9	916.0	1,177.9
46	60.7	293.5	7.100	263.0	915.2	1,178.2
47	61.7	294.6	6.992	264.2	914.4	1,178.6
48	62.7	295.6	6.887	265.3	913.6	1,178.9
49	63.7	296.7	6.785	266.3	912.9	1,179.2
50	64.7	297.7	6.686	267.4	912.1	1,179.5
51	65.7	298.7	6.591	268.4	911.4	1,179.8
52	66.7	299.7	6.498	269.4	910.6	1,180.0
53	67.7	300.7	6.407	270.5	909.9	1,180.4
54	68.7	301.7	6.391	271.5	909.2	1,180.7
55	69.7	302.7	6.234	272.5	908.5	1,181.0
56	70.7	303.6	6.151	273.5	907.7	1,181.2
57	71.7	304.6	6.070	274.5	907.0	1,181.5
58	72.7	305.5	5.991	275.4	906.3	1,181.7
59	73.7	306.4	5.915	276.4	905.6	1,182.0
60	74.7	307.4	5.840	277.3	905.0	1,182.3
61	75.7	308.3	5.768	278.3	904.3	1,182.6
62	76.7	309.2	5.696	279.2	903.6	1,182.8
63	77.7	310.1	5.627	280.1	902.9	1,183.0
64	78.7	310.9	5.560	281.0	902.3	1,183.3
65	79.7	311.8	5.494	281.9	901.6	1,183.5
66	80.7	312.7	5.430	282.8	901.0	1,183.8
67	81.7	313.5	5.367	283.7	900.3	1,184.0
68	82.7	314.4	5.306	284.6	899.7	1,184.3
69	83.7	315.2	5.246	285.5	899.0	1,184.5
70	84.7	316.0	5.187	286.3	898.4	1,184.7
71	85.7	316.9	5.130	287.2	897.8	1,185.0
72	86.7	317.7	5.075	288.0	897.1	1,185.1
73	87.7	318.5	5.020	288.9	896.5	1,185.4
74	88.7	319.3	4.966	289.7	895.9	1,185.6
75	89.7	320.1	4.914	290.5	895.3	1,185.8
76	90.7	320.9	4.863	291.3	894.7	1,186.0
77	91.7	321.6	4.813	292.1	894.1	1,186.2
78	92.7	322.4	4.764	292.9	893.5	1,186.4
79	93.7	323.2	4.715	293.7	892.9	1,186.6
80	94.7	323.9	4.668	294.5	892.3	1,186.8
81	95.7	324.7	4.623	295.3	891.7	1,187.0
82	96.7	325.4	4.578	296.1	891.1	1,187.2
83	97.7	326.2	4.533	296.9	890.6	1,187.5
84	98.7	326.9	4.489	297.6	890.0	1,187.6

(*Continued*)

STEAM TABLES (*Continued*)

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lbs.	Heat Content (above 32°F) Btu/lbs.		
				Sensible	Latent	Total
85	99.7	327.6	4.447	298.4	889.4	1,187.8
86	100.7	328.4	4.405	299.1	888.8	1,187.9
87	101.7	329.1	4.364	299.9	888.3	1,188.2
88	102.7	329.8	4.324	300.6	887.7	1,188.3
89	103.7	330.5	4.284	301.4	887.1	1,188.5
90	104.7	331.2	4.245	302.1	886.6	1,188.7
91	105.7	331.9	4.207	302.8	886.1	1,188.9
92	106.7	332.6	4.170	303.5	885.5	1,189.0
93	107.7	333.3	4.133	304.3	885.0	1,189.3
94	108.7	333.9	4.098	305.0	884.4	1,189.4
95	109.7	334.6	4.062	305.7	883.9	1,189.6
96	110.7	335.3	4.048	306.4	883.3	1,189.7
97	111.7	336.0	3.993	307.1	882.8	1,189.9
98	112.7	336.6	3.959	307.8	882.2	1,190.0
99	113.7	337.3	3.926	308.4	881.8	1,190.2
100	114.7	337.9	3.894	309.1	881.2	1,190.3
101	115.7	338.6	3.862	309.8	880.7	1,190.5
102	116.7	339.2	3.830	310.5	880.2	1,190.7
103	117.7	339.9	3.799	311.1	879.7	1,190.8
104	118.7	340.5	3.769	311.8	879.2	1,191.0
105	119.7	341.1	3.739	312.5	878.7	1,191.2
106	120.7	341.7	3.710	313.1	878.1	1,191.2
107	121.7	342.4	3.681	313.8	877.6	1,191.4
108	122.7	343.0	3.652	314.4	877.1	1,191.5
109	123.7	343.6	3.624	315.1	876.6	1,191.7
110	124.7	344.2	3.596	315.7	876.1	1,191.8
111	125.7	344.8	3.569	316.3	875.6	1,191.9
112	126.7	345.4	3.543	317.0	875.1	1,192.1
113	127.7	346.0	3.516	317.6	874.6	1,192.2
114	128.7	346.6	3.490	318.2	874.2	1,192.4
115	129.7	347.2	3.465	318.9	873.7	1,192.6
116	130.7	347.8	3.440	319.5	873.2	1,192.7
117	131.7	348.4	3.415	320.1	872.7	1,192.8
118	132.7	348.9	3.390	320.7	872.2	1,192.9
119	133.7	349.5	3.366	321.3	871.7	1,193.0
120	134.7	350.1	3.342	321.9	871.3	1,193.2
121	135.7	350.7	3.319	322.5	870.8	1,193.3
122	136.7	351.2	3.296	323.1	870.3	1,193.4
123	137.7	351.8	3.273	323.7	869.8	1,193.5
124	138.7	352.4	3.251	324.3	869.4	1,193.7
125	139.7	352.9	3.228	324.9	868.9	1,193.8
126	140.7	353.5	3.206	325.5	868.4	1,193.9
127	141.7	354.0	3.185	326.0	868.0	1,194.0
128	142.7	354.6	3.163	326.6	867.5	1,194.1
129	143.7	355.1	3.142	327.2	867.0	1,194.2
130	144.7	355.7	3.121	327.8	866.6	1,194.4
131	145.7	356.2	3.101	328.4	866.1	1,194.5
132	146.7	356.7	3.081	328.9	865.7	1,194.6
133	147.7	357.3	3.061	329.5	865.2	1,194.7
134	148.7	357.8	3.042	330.0	864.8	1,194.8
135	149.7	358.3	3.022	330.6	864.3	1,194.9
136	150.7	358.8	3.003	331.1	863.9	1,195.0
137	151.7	359.4	2.984	331.7	863.4	1,195.1
138	152.7	359.9	2.965	332.2	863.0	1,195.2
139	153.7	360.4	2.947	332.8	862.5	1,195.3
140	154.7	360.9	2.928	333.3	862.1	1,195.4
141	155.7	361.4	2.910	333.9	861.6	1,195.5
142	156.7	361.9	2.893	334.4	861.2	1,195.6
143	157.7	362.4	2.875	334.9	860.8	1,195.7
144	158.7	362.9	2.858	335.5	860.4	1,195.9

(*Continued*)

STEAM TABLES (*Continued*)

Steam Pressure psig	Steam Pressure psia	Saturation Temperature °F	Specific Volume cu.ft./lbs.	Heat Content (above 32°F) Btu/lbs.		
				Sensible	Latent	Total
145	159.7	363.4	2.841	336.0	859.9	1,195.9
146	160.7	363.9	2.824	336.5	859.5	1,196.0
147	161.7	364.4	2.807	337.1	859.0	1,196.1
148	162.7	364.9	2.791	337.6	858.6	1,196.2
149	163.7	365.4	2.775	338.1	858.2	1,196.3
150	164.7	365.9	2.759	338.6	857.8	1,196.4
151	165.7	366.4	2.743	339.1	857.3	1,196.4
152	166.7	366.9	2.727	339.7	856.9	1,196.6
153	167.7	367.4	2.712	340.2	856.5	1,196.7
154	168.7	367.9	2.696	340.7	856.1	1,196.8
155	169.7	368.3	2.681	341.2	855.7	1,196.9
156	170.7	368.8	2.666	341.7	855.3	1,197.0
157	171.7	369.3	2.651	342.2	854.8	1,197.0
158	172.7	369.7	2.636	342.7	854.4	1,197.1
159	173.7	370.2	2.621	343.2	854.0	1,197.2
160	174.7	370.7	2.607	343.7	853.6	1,197.3
161	175.7	371.1	2.593	344.2	853.2	1,197.4
162	176.7	371.6	2.579	344.7	852.8	1,197.5
163	177.7	372.1	2.565	345.2	852.4	1,197.6
164	178.7	372.5	2.551	345.7	852.0	1,197.7
165	179.7	373.0	2.537	346.1	851.6	1,197.7
166	180.7	373.4	2.524	346.6	851.2	1,197.8
167	181.7	373.9	2.511	347.1	850.8	1,197.9
168	182.7	374.4	2.498	347.6	850.4	1,198.0
169	183.7	374.8	2.484	348.1	850.0	1,198.1
170	184.7	375.2	2.471	348.5	849.6	1,198.1
171	185.7	375.7	2.459	349.0	849.2	1,198.2
172	186.7	376.1	2.446	349.5	848.8	1,198.3
173	187.7	376.6	2.434	350.0	848.4	1,198.4
174	188.7	377.0	2.421	350.4	848.1	1,198.5
175	189.7	377.4	2.409	350.9	847.7	1,198.6
176	190.7	377.9	2.397	351.4	847.2	1,198.6
177	191.7	378.3	2.385	351.8	846.9	1,198.7
178	192.7	378.8	2.373	352.3	846.5	1,198.8
179	193.7	379.2	2.361	352.8	846.1	1,198.9
180	194.7	379.6	2.349	353.2	845.7	1,198.9
181	195.7	380.0	2.337	353.7	845.3	1,199.0
182	196.7	380.5	2.326	354.1	844.9	1,199.0
183	197.7	380.9	2.315	354.6	844.5	1,199.1
184	198.7	381.3	2.304	355.1	844.1	1,199.2
185	199.7	381.7	2.292	355.5	843.8	1,199.3
186	200.7	382.2	2.281	355.9	843.4	1,199.3
187	201.7	382.6	2.271	356.3	843.1	1,199.4
188	202.7	383.0	2.260	356.8	842.7	1,199.5
189	203.7	383.4	2.249	357.2	842.3	1,199.5
190	204.7	383.8	2.238	357.7	841.9	1,199.6
191	205.7	384.2	2.228	358.1	841.6	1,199.7
192	206.7	384.6	2.218	358.5	841.2	1,199.7
193	207.7	385.0	2.207	359.0	840.8	1,199.8
194	208.7	385.4	2.197	359.4	840.5	1,199.9
195	209.7	385.8	2.187	359.9	840.1	1,200.0
196	210.7	386.3	2.177	360.3	839.7	1,200.0
197	211.7	386.7	2.167	360.7	839.4	1,200.1
198	212.7	387.1	2.158	361.2	838.9	1,200.1
199	213.7	387.5	2.148	361.6	838.6	1,200.2
200	214.7	387.9	2.138	362.1	838.2	1,200.3
201	215.7	388.2	2.128	362.5	837.8	1,200.3
202	216.7	388.6	2.119	362.9	837.5	1,200.4
203	217.7	389.0	2.110	363.3	837.1	1,200.4
204	218.7	389.4	2.100	363.8	836.8	1,200.6
205	219.7	389.8	2.091	364.2	836.4	1,200.6
206	220.7	390.2	2.082	364.6	836.0	1,200.6
207	221.7	390.6	2.073	365.0	835.7	1,200.7
208	222.7	391.0	2.064	365.4	835.3	1,200.7
209	223.7	391.4	2.055	365.8	835.0	1,200.8

(*Continued*)

STEAM TABLES (*Continued*)

Steam Pressure psig	Steam Pressure psia	Saturation Temperature ºF	Specific Volume cu.ft./lbs.	Heat Content (above 32ºF) Btu/lbs.		
				Sensible	Latent	Total
210	224.7	391.8	2.046	366.2	834.6	1,200.8
211	225.7	392.1	2.037	366.6	834.2	1,200.8
212	226.7	392.5	2.028	367.0	833.9	1,200.9
213	227.7	392.9	2.020	367.5	833.5	1,201.0
214	228.7	393.3	2.011	367.9	833.2	1,201.1
215	229.7	393.6	2.003	368.3	832.8	1,201.1
216	230.7	394.0	1.994	368.7	832.5	1,201.2
217	231.7	394.4	1.986	369.1	832.1	1,201.2
218	232.7	394.8	1.978	369.5	831.8	1,201.3
219	233.7	395.2	1.970	369.9	831.4	1,201.3
220	234.7	395.5	1.961	370.3	831.1	1,201.4
221	235.7	395.9	1.953	370.7	830.8	1,201.5
222	236.7	396.3	1.945	371.1	830.4	1,201.5
223	237.7	396.6	1.937	371.5	830.1	1,201.6
224	238.7	397.0	1.929	371.9	829.7	1,201.6
225	239.7	397.4	1.921	372.3	829.4	1,201.7
226	240.7	397.7	1.914	372.7	829.0	1,201.7
227	241.7	398.1	1.906	373.0	828.7	1,201.7
228	242.7	398.4	1.898	373.4	828.3	1,201.7
229	243.7	398.8	1.891	373.8	828.0	1,201.8
230	244.7	399.2	1.883	374.2	827.6	1,201.8
231	245.7	399.5	1.876	374.6	827.3	1,201.9
232	246.7	399.9	1.869	375.0	826.9	1,201.9
233	247.7	400.2	1.862	375.3	826.6	1,201.9
234	248.7	400.6	1.854	375.7	826.2	1,201.9
235	249.7	400.9	1.847	376.1	825.9	1,202.0
236	250.7	401.3	1.840	376.5	825.6	1,202.1
237	251.7	401.6	1.833	376.8	825.3	1,202.1
238	252.7	402.0	1.826	377.2	824.9	1,202.1
239	253.7	402.3	1.819	377.6	824.6	1,202.2
240	254.7	402.7	1.812	378.0	824.3	1,202.3
241	255.7	403.0	1.805	378.4	824.0	1,202.4
242	256.7	403.4	1.798	378.7	823.7	1,202.4
243	257.7	403.7	1.791	379.1	823.3	1,202.4
244	258.7	404.1	1.785	379.5	822.9	1,202.4
245	259.7	404.4	1.778	379.9	822.6	1,202.5
246	260.7	404.7	1.771	380.3	822.3	1,202.6
247	261.7	405.1	1.765	380.6	822.0	1,202.6
248	262.7	405.4	1.758	381.0	821.6	1,202.6
249	263.7	405.8	1.752	381.3	821.3	1,202.6
250	264.7	406.1	1.745	381.7	821.0	1,202.7
251	265.7	406.4	1.739	382.1	820.7	1,202.8
252	266.7	406.8	1.733	382.4	820.4	1,202.8
253	267.7	407.1	1.726	382.8	820.0	1,202.8
254	268.7	407.4	1.720	383.2	819.6	1,202.8
255	269.7	407.8	1.714	383.6	819.3	1,202.9
256	270.7	408.1	1.707	383.9	819.0	1,202.9
257	271.7	408.4	1.701	384.3	818.7	1,203.0
258	272.7	408.8	1.695	384.6	818.4	1,203.0
259	273.7	409.1	1.689	385.0	818.0	1,203.0
260	274.7	409.4	1.683	385.3	817.7	1,203.0
261	275.7	409.7	1.677	385.7	817.4	1,203.1
262	276.7	410.1	1.671	386.0	817.1	1,203.1
263	277.7	410.4	1.666	386.4	816.7	1,203.1
264	278.7	410.7	1.660	386.7	816.4	1,203.1
265	279.7	411.1	1.654	387.1	816.1	1,203.2
266	280.7	411.4	1.648	387.5	815.8	1,203.3
267	281.7	411.7	1.642	387.8	815.5	1,203.3
268	282.7	412.0	1.637	388.2	815.2	1,203.4
269	283.7	412.3	1.631	388.5	814.9	1,203.4
270	284.7	412.7	1.625	388.9	814.6	1,203.5
271	285.7	413.0	1.620	389.2	814.3	1,203.5
272	286.7	413.3	1.614	389.5	814.0	1,203.5
273	287.7	413.6	1.609	389.9	813.6	1,203.5
274	288.7	413.9	1.603	390.3	813.3	1,203.6

(*Continued*)

STEAM TABLES (*Continued*)

Steam Pressure psig	Steam Pressure psia	Saturation Temperature ºF	Specific Volume cu.ft./lbs.	Heat Content (above 32ºF) Btu/lbs.		
				Sensible	Latent	Total
275	289.7	414.2	1.598	390.6	813.0	1,203.6
276	290.7	414.5	1.593	390.9	812.7	1,203.6
277	291.7	414.9	1.587	391.3	812.3	1,203.6
278	292.7	415.2	1.582	391.6	812.0	1,203.6
279	293.7	415.5	1.577	392.0	811.7	1,203.7
280	294.7	415.8	1.571	392.3	811.4	1,203.7
281	295.7	416.1	1.566	392.6	811.1	1,203.7
282	296.7	416.4	1.561	393.0	810.8	1,203.8
283	297.7	416.7	1.556	393.3	810.5	1,203.8
284	298.7	417.0	1.551	393.7	810.2	1,203.9
285	299.7	417.3	1.546	394.0	809.9	1,203.9
286	300.7	417.6	1.541	394.3	809.6	1,203.9
287	301.7	417.9	1.536	394.7	809.3	1,204.0
288	302.7	418.2	1.531	395.0	809.0	1,204.0
289	303.7	418.5	1.526	395.3	808.7	1,204.0
290	304.7	418.8	1.521	395.7	808.4	1,204.1
291	305.7	419.2	1.516	396.0	808.1	1,204.1
292	306.7	419.5	1.511	396.3	807.8	1,204.1
293	307.7	419.8	1.507	396.6	807.5	1,204.1
294	308.7	420.1	1.502	397.0	807.2	1,204.2
295	309.7	420.4	1.497	397.3	806.9	1,204.2
296	310.7	420.6	1.492	397.6	806.6	1,204.2
297	311.7	420.9	1.488	397.9	806.3	1,204.2
298	312.7	421.2	1.483	398.3	806.0	1,204.3
299	313.7	421.5	1.478	398.6	805.7	1,204.3
300	314.7	421.8	1.474	398.9	805.4	1,204.3
310	324.7	424.7	1.429	402.1	802.4	1,204.5
320	334.7	427.6	1.387	405.3	799.4	1,204.7
330	344.7	430.4	1.347	408.3	796.5	1,204.8
340	354.7	433.1	1.310	411.3	793.7	1,205.0
350	364.7	435.7	1.274	414.3	790.9	1,205.2
360	374.7	438.3	1.240	417.1	788.1	1,205.2
370	384.7	440.9	1.208	420.0	785.4	1,205.4
380	394.7	443.4	1.178	422.8	782.6	1,205.4
390	404.7	445.8	1.149	425.5	780.0	1,205.5
400	414.7	448.2	1.121	428.2	777.4	1,205.6
410	424.7	450.6	1.095	430.8	774.8	1,205.6
420	434.7	452.9	1.069	433.4	772.2	1,205.6
430	444.7	455.2	1.045	436.0	769.6	1,205.6
440	454.7	457.4	1.022	438.6	767.0	1,205.6
450	464.7	459.6	1.000	441.0	764.5	1,205.5
460	474.7	461.8	0.979	443.5	762.0	1,205.5
470	484.7	463.9	0.958	445.9	759.5	1,205.4
480	494.7	466.0	0.939	448.3	757.1	1,205.4
490	504.7	468.1	0.920	450.6	754.7	1,205.3
500	514.7	470.1	0.901	453.0	752.2	1,205.2
510	524.7	472.1	0.884	455.2	749.9	1,205.1
520	534.7	474.1	0.867	457.5	747.5	1,205.0
530	544.7	476.0	0.851	459.8	745.1	1,204.9
540	554.7	478.0	0.835	461.9	742.8	1,204.7
550	564.7	479.9	0.820	464.1	740.5	1,204.6
560	574.7	481.7	0.805	466.3	738.2	1,204.5
570	584.7	483.6	0.791	468.4	735.9	1,204.3
580	594.7	485.4	0.777	470.6	733.6	1,204.2
590	604.7	487.2	0.764	472.7	731.3	1,204.0
600	614.7	488.9	0.751	474.7	729.1	1,203.8
610	624.7	490.7	0.739	476.7	726.9	1,203.6
620	634.7	492.4	0.727	478.7	724.7	1,203.4
630	644.7	494.1	0.715	480.7	722.5	1,203.2
640	654.7	495.8	0.704	482.7	720.3	1,203.0

(*Continued*)

STEAM TABLES (*Continued*)

Steam Pressure psig	Steam Pressure psia	Saturation Temperature ºF	Specific Volume cu.ft./lbs.	Heat Content (above 32ºF) Btu/lbs.		
				Sensible	Latent	Total
650	664.7	497.5	0.693	484.7	718.1	1,202.8
660	674.7	499.2	0.682	486.7	715.9	1,202.6
670	684.7	500.8	0.671	488.6	713.8	1,202.4
680	694.7	502.4	0.661	490.5	711.6	1,202.1
690	704.7	504.0	0.651	492.4	709.5	1,201.9
700	714.7	505.5	0.642	494.3	707.3	1,201.6
710	724.7	507.1	0.632	496.2	705.2	1,201.4
720	734.7	508.7	0.623	498.0	703.1	1,201.1
730	744.7	510.2	0.614	499.8	701.0	1,200.8
740	754.7	511.7	0.606	501.6	698.9	1,200.5
750	764.7	513.2	0.597	503.4	696.8	1,200.2
760	774.7	514.7	0.589	505.2	694.8	1,200.0
770	784.7	516.1	0.581	507.0	692.7	1,199.7
780	794.7	517.6	0.573	508.8	690.7	1,199.5
790	804.7	519.0	0.566	510.5	688.6	1,199.1
800	814.7	520.5	0.558	512.3	686.5	1,198.8
810	824.7	521.9	0.551	514.0	684.6	1,198.6
820	834.7	523.3	0.544	515.7	682.6	1,198.3
830	844.7	524.7	0.537	517.4	680.6	1,198.0
840	854.7	526.0	0.530	519.0	678.6	1,197.6
850	864.7	527.4	0.523	520.7	676.6	1,197.3
860	874.7	528.7	0.517	522.4	674.6	1,197.0
870	884.7	530.1	0.511	524.1	672.6	1,196.7
880	894.7	531.4	0.504	525.7	670.6	1,196.3
890	904.7	532.7	0.498	527.4	668.6	1,196.0
900	914.7	534.0	0.492	529.0	666.6	1,195.6
910	924.7	535.3	0.486	530.6	664.7	1,195.3
920	934.7	536.6	0.481	532.2	662.7	1,194.9
930	944.7	537.9	0.475	533.8	660.7	1,194.5
940	954.7	539.1	0.470	535.4	658.7	1,194.1
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	1,175.9
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	1,155.9
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	1,131.3
2,100	2,114.7	643.9	0.173	685.3	442.1	1,127.2
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	1,105.2
2,400	2,414.7	663.2	0.139	720.6	379.7	1,100.3
2,450	2,464.7	666.2	0.134	726.6	368.5	1,095.1
2,500	2,514.7	669.2	0.129	732.7	357.1	1,089.8

21.04 Steam Flow through Orifices

STEAM FLOW THROUGH ORIFICES

Orifice Dia. Inches	Steam Flow—lbs/hr. Steam Pressure—psig												
	2	5	10	15	25	50	75	100	125	150	200	250	300
1/32	0.3	0.5	0.6	0.7	0.9	1.5	2.1	2.7	3.3	3.9	5.1	6.3	7.4
1/16	1.3	1.9	2.3	2.8	3.8	6.1	8.5	10.8	13.2	15.6	20.3	25.1	29.8
3/32	2.8	4.2	5.3	6.3	8.5	13.8	19.1	24.4	29.7	35.1	45.7	56.4	67.0
1/8	4.5	7.5	9.4	11.2	15.0	24.5	34.0	43.4	52.9	62.4	81.3	100	119
5/32	7.8	11.7	14.6	17.6	23.5	38.3	53.1	67.9	82.7	97.4	127	156	186
3/16	11.2	16.7	21.0	25.3	33.8	55.1	76.4	97.7	119	140	183	226	268
7/32	15.3	22.9	28.7	34.4	46.0	75.0	104	133	162	191	249	307	365
1/4	20.0	29.8	37.4	45.0	60.1	98.0	136	173	212	250	325	401	477
9/32	25.2	37.8	47.4	56.9	76.1	124	172	220	268	316	412	507	603
5/16	31.2	46.6	58.5	70.3	94.0	153	212	272	331	390	508	627	745
11/32	37.7	56.4	70.7	85.1	114	185	257	329	400	472	615	758	901
3/8	44.9	67.1	84.2	101	135	221	306	391	476	561	732	902	1073
13/32	52.7	78.8	98.8	119	159	259	359	459	559	659	859	1059	1259
7/16	61.1	91.4	115	138	184	300	416	532	648	764	996	1228	1460
15/32	70.2	105	131	158	211	344	478	611	744	877	1144	1410	1676
1/2	79.8	119	150	180	241	392	544	695	847	998	1301	1604	1907

Notes:

1 Steam leaks and energy wasted: A 1/8" diameter hole in a steam pipe can discharge 62.4 lbs.Stm./hr. at 150 psig, resulting in 30 tons of coal, 4800 gallons of oil, or 7500 therms of gas to be wasted each year (assuming 8400 hour per year operation).

21.05 Flash Steam

FLASH STEAM

Steam Press. psig	Flash Steam Flow lbs. Steam / hr. per 100 lbs. of Steam Condensate / hr. Condensate Pressure psig																
	0	1	3	5	7	10	12	15	20	25	30	40	50	60	75	85	100
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	0.0						
40	7.8	7.5	6.9	6.3	5.8	5.1	4.6	4.0	3.0	2.2	1.4	0.0					
50	9.0	8.7	8.1	7.5	7.0	6.3	5.8	5.2	4.2	3.4	2.6	1.2	0.0				
60	10.0	9.7	9.1	8.5	8.0	7.3	6.9	6.2	5.3	4.5	3.7	2.3	1.1	0.0			
75	11.4	11.1	10.5	9.9	9.4	8.7	8.2	7.6	6.7	5.9	5.1	3.7	2.5	1.5	0.0		
85	12.2	11.9	11.3	10.7	10.2	9.5	9.1	8.5	7.5	6.7	6.0	4.6	3.4	2.3	0.9	0.0	
100	13.3	13.0	12.4	11.8	11.3	10.6	10.2	9.6	8.7	7.9	7.1	5.8	4.6	3.5	2.1	1.2	0.0
120	14.6	14.3	13.7	13.2	12.7	12.0	11.5	11.0	10.0	9.2	8.5	7.2	6.0	4.9	3.5	2.6	1.5
125	14.9	14.6	14.0	13.5	13.0	12.3	11.9	11.3	10.4	9.5	8.8	7.5	6.3	5.3	3.8	3.0	1.8
150	16.3	16.0	15.4	14.9	14.4	13.7	13.3	12.7	11.8	11.0	10.3	9.0	7.8	6.8	5.4	4.5	3.3

(*Continued*)

FLASH STEAM (*Continued*)

Flash Steam Flow lbs. Steam / hr. per 100 lbs. of Steam Condensate / hr.																	
Steam Press. psig	Condensate Pressure psig																
	0	1	3	5	7	10	12	15	20	25	30	40	50	60	75	85	100
175	17.6	17.3	16.7	16.2	15.7	15.0	14.6	14.0	13.1	12.3	11.6	10.3	9.2	8.1	6.7	5.9	4.7
200	18.7	18.4	17.9	17.4	16.9	16.2	15.8	15.2	14.3	13.5	12.8	11.5	10.4	9.4	8.0	7.2	6.0
225	19.8	19.5	18.9	18.4	17.9	17.3	16.9	16.3	15.4	14.6	13.9	12.6	11.5	10.5	9.1	8.3	7.2
250	20.8	20.5	19.9	19.4	18.9	18.3	17.8	17.3	16.4	15.6	14.9	13.7	12.5	11.5	10.2	9.4	8.2
275	21.7	21.4	20.8	20.3	19.8	19.2	18.8	18.2	17.4	16.6	15.9	14.6	13.5	12.5	11.2	10.4	9.2
300	22.5	22.2	21.7	21.2	20.7	20.1	19.7	19.1	18.2	17.5	16.8	15.5	14.4	13.4	12.1	11.3	10.2

21.06 Warm-up Loads

LOW PRESSURE STEAM PIPING WARM-UP LOADS

Pipe Size	Pounds of Steam per 100 Feet of Pipe							
	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
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

Pipe Size	Pounds of Steam per 100 Feet of Pipe								
	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
5"	34	35	37	40	42	44	47	49	51
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

Pipe Size	Pounds of Steam per 100 Feet of Pipe								
	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

(Continued)

HIGH PRESSURE STEAM PIPING WARM-UP LOADS (*Continued*)

Pipe Size	Pounds of Steam per 100 Feet of Pipe — Steam Pressure psig								
	120	125	150	175	200	225	250	275	300
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	384
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
72"	1,060	1,075	1,139	1,195	1,252	1,301	1,350	1,396	1,946
84"	1,238	1,254	1,329	1,395	1,461	1,518	1,576	1,630	2,241
96"	1,415	1,435	1,520	1,595	1,671	1,737	1,803	1,864	2,510
Corr. Factor	1.25	1.25	1.24	1.23	1.22	1.22	1.21	1.21	1.20

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.

21.07 Steam Operating Loads

LOW PRESSURE STEAM PIPING OPERATING LOADS

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe — 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
10"	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
16"	28	29	31	32	34	36	38	40
18"	31	32	34	36	38	40	42	44
20"	34	35	37	39	41	44	46	48
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

(*Continued*)

LOW PRESSURE STEAM PIPING OPERATING LOADS (*Continued*)

Pipe Size	Pounds of Steam per Hour per 100 Feet of Pipe							
	Steam Pressure psig							
	0	1	3	5	7	10	12	15
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

Pipe Size	Pounds of Steam Per Hour per 100 Feet of Pipe								
	Steam Pressure psig								
	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
72"	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
Corr. Factor	1.52	1.51	1.50	1.48	1.47	1.45	1.43	1.42	1.41

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.

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
16"	81	83	90	96	103	109	115	121	126
18"	91	92	100	107	115	121	128	134	141
20"	100	102	110	118	126	134	141	148	155
22"	109	111	120	129	138	146	154	161	169
24"	118	120	130	140	149	158	167	175	183
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.

21.08 Boiling Points 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

(*Continued*)

BOILING POINTS OF WATER (*Continued*)

Psia	Boiling Point ºF	Psia	Boiling Point ºF	Psia	Boiling Point ºF
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	254.1	98	326.4	825	521.9
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

21.09 Steam Heating Units of Measure

COMPARISON OF COMMON STEAM HEATING UNITS OF MEASURE

MBH (1000 Btuh)	Steam lbs./hr. (1)	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
2,000	2,115	8,333	58.0	4.13	12.4
2,500	2,644	10,417	72.5	5.17	15.5
3,000	3,173	12,500	87.0	6.20	18.6
4,000	4,230	16,667	115.9	8.27	24.8
5,000	5,288	20,833	144.9	10.3	30.9
7,500	7,931	31,250	217.4	15.5	46.5
10,000	10,575	41,667	289.9	20.7	62.1
15,000	15,862	62,500	434.8	31.0	93.0
20,000	21,150	83,333	579.7	41.3	124
25,000	26,438	104,167	724.6	51.7	155
30,000	31,725	125,000	869.6	62.0	186
35,000	37,014	145,833	1,015	72.3	217
40,000	42,301	166,667	1,159	82.7	248
50,000	52,876	208,333	1,449	103.3	310

Notes:
1 Steam flow rate is based on 15 psig steam with an enthalpy of 945.6 Btu/lb.
2 Condensate pump capacity is equal to three times the condensate flow rate.

21.10 Low Pressure Steam Pipe Sizing Tables (15 psig and Less)

1 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	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)	10,000 (114)	12,000 (136)
1/2	4	6	9						
3/4	10	14	20	18	Pressure these				
1	20	28	40	29		drop pipe	governs sizes		
1-1/4	44	62	87	49					
1-1/2	68	96	135	67	135			with	
2	137	194	274	111	222				
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	4,779	
8	5,525	7,813		1,655	3,310	4,965	6,620	8,275	9,930
10	10,082	14,258		2,609	5,218	7,826	10,435	13,044	15,653
12	16,181			3,742	7,483	11,225	14,967	18,708	22,450
14	20,959			4,562	9,123	13,685	18,247	22,809	27,370
16	30,212			6,043	12,086	18,128	24,171	30,214	36,257
18	41,576			7,732	15,463	23,195	30,927	38,659	46,390
20	55,192			9,629	19,257	28,886	38,514	48,143	57,771
22				11,733	23,466	35,200	46,933	58,666	70,399
24				14,046	28,092	42,137	56,183	70,229	84,275
26				16,566	33,132	49,698	66,265	82,831	99,397
28			with	19,294	38,589	57,883	77,178	96,472	115,767
30			sizes	22,231	44,461	66,692	88,922	111,153	133,384
32		governs		25,375	50,749	76,124	101,498	126,873	152,248
34		pipe		28,726	57,453	86,179	114,906	143,632	172,359
36	Velocity			32,286	64,572	96,859	129,145	161,431	193,717
42	these			44,213	88,425	132,638	176,851	221,064	265,276
48				58,010	116,020	174,030	232,040	290,050	348,060
54				73,678	147,356	221,034	294,712	368,390	442,069
60				91,217	182,434	273,651	364,868	456,085	547,302
72				131,907	263,815	395,722	527,629	659,537	791,444
84				180,081	360,162	540,243	720,324	900,404	1,080,485
96				235,738	471,475	707,213	942,951	1,178,689	1,414,426

Notes:

1 **Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,000 FPM.**

2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

3 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	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)	10,000 (114)	12,000 (136)
1/2	5	6	9						
3/4	10	15	21	20	Pressure these				
1	21	30	42	32		drop pipe			
1-1/4	46	65	92	55			governs sizes		
1-1/2	72	101	143	75				with	
2	145	205	290	124	248				
2-1/2	239	338	478	177	354				
3	437	619	870	274	547	821			
4	924	1,307	1,849	471	942	1,413			
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	5,345	
8	5,843	8,263		1,851	3,702	5,553	7,404	9,255	11,106

(*Continued*)

3 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	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)	10,000 (114)	12,000 (136)
10	10,662	15,078		2,918	5,835	8,753	11,670	14,588	17,506
12	17,112	24,200		4,185	8,369	12,554	16,738	20,923	25,108
14	22,165			5,102	10,204	15,305	20,407	25,509	30,611
16	31,951			6,758	13,516	20,275	27,033	33,791	40,549
18	43,968			8,647	17,294	25,941	34,588	43,235	51,883
20	58,368			10,768	21,537	32,305	43,074	53,842	64,611
22	75,290			13,122	26,245	39,367	52,489	65,611	78,734
24				15,709	31,417	47,126	62,834	78,543	94,252
26				18,527	37,055	55,582	74,110	92,637	111,164
28			with	21,579	43,157	64,736	86,315	107,893	129,472
30			sizes	24,862	49,725	74,587	99,450	124,312	149,175
32		governs		28,379	56,757	85,136	113,515	141,893	170,272
34		pipe		32,127	64,255	96,382	128,509	160,637	192,764
36				36,109	72,217	108,326	144,434	180,543	216,651
42	Velocity			49,447	98,894	148,341	197,788	247,235	296,682
48	these			64,878	129,755	194,633	259,511	324,388	389,266
54				82,401	164,801	247,202	329,603	412,003	494,404
60				102,016	204,032	306,048	408,064	510,080	612,096
72				147,524	295,047	442,571	590,094	737,618	885,141
84				201,400	402,801	604,201	805,601	1,007,001	1,208,402
96				263,646	527,292	790,939	1,054,585	1,318,231	1,581,877

Notes:

1 **Maximum recommended pressure drop/velocity: 0.125 psig/100 ft./4,000 FPM.**

2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

5 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	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)	10,000 (114)	12,000 (136)
1/2	5	7	10		Pressure				
3/4	11	15	22	22	these				
1	22	31	44	35		drop			
1-1/4	48	69	97	61		pipe			
1-1/2	75	106	150	83			governs	with	
2	153	216	305	137	275		sizes		
2-1/2	251	355	503	196	392				
3	460	651	914	302	605	907			
4	972	1,375	1,944	521	1,042	1,563			
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	10,235	12,282
10	11,212	15,856		3,226	6,453	9,679	12,906	16,132	19,359
12	17,995	25,449		4,628	9,255	13,883	18,510	23,138	27,765
14	23,309	32,964		5,642	11,284	16,926	22,567	28,209	33,851
16	33,599			7,474	14,947	22,421	29,894	37,368	44,842
18	46,237			9,562	19,125	28,687	38,250	47,812	57,375
20	61,380			11,908	23,817	35,725	47,633	59,542	71,450
22	79,175			14,511	29,023	43,534	58,045	72,557	87,068
24	99,764			17,371	34,743	52,114	69,486	86,857	104,229
26				20,489	40,977	61,466	81,955	102,443	122,932
28				23,863	47,726	71,589	95,452	119,314	143,177
30				27,494	54,988	82,483	109,977	137,471	164,965
32				31,383	62,765	94,148	125,531	156,913	188,296

(*Continued*)

5 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	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)	10,000 (114)	12,000 (136)
34				35,528	71,056	106,585	142,113	177,641	213,169
36				39,931	79,862	119,792	159,723	199,654	239,585
42				54,681	109,362	164,044	218,725	273,406	328,087
48				71,745	143,491	215,236	286,981	358,727	430,472
54	Velocity these	governs pipe	with sizes	91,123	182,247	273,370	364,493	455,616	546,740
60				112,815	225,630	338,445	451,260	564,075	676,890
72				163,140	326,280	489,419	652,559	815,699	978,839
84				222,720	445,439	668,159	890,879	1,113,598	1,336,318
96				291,555	583,109	874,664	1,166,219	1,457,774	1,749,328

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 Part 3.0.**

7 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	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)	10,000 (114)	12,000 (136)
1/2	5	7	10						
3/4	11	16	23		Pressure these				
1	23	33	46	39		drop pipe			
1-1/4	51	72	101	67					
1-1/2	79	111	157	91			governs sizes	with	
2	160	226	319	150	300				
2-1/2	263	372	526	214	429				
3	481	680	956	331	662				
4	1,016	1,438	2,033	570	1,139	1,709			
5	1,870	2,645	3,741	892	1,783	2,675	3,567		
6	3,087	4,365	6,174	1,293	2,586	3,879	5,171		
8	6,426	9,087	12,851	2,239	4,477	6,716	8,955	11,194	
10	11,726	16,583		3,529	7,057	10,586	14,115	17,644	21,172
12	18,819	26,614		5,061	10,122	15,183	20,244	25,306	30,367
14	24,376	34,473		6,170	12,341	18,511	24,682	30,852	37,023
16	35,138			8,174	16,348	24,521	32,695	40,869	49,043
18	48,354			10,458	20,917	31,375	41,833	52,292	62,750
20	64,191			13,024	26,048	39,072	52,096	65,120	78,144
22	82,801			15,871	31,742	47,613	63,483	79,354	95,225
24	104,332			18,999	37,998	56,997	75,996	94,995	113,993
26	128,924			22,408	44,816	67,224	89,633	112,041	134,449
28				26,099	52,197	78,296	104,394	130,493	156,591
30			with sizes	30,070	60,140	90,210	120,280	150,350	180,421
32		governs pipe		34,323	68,646	102,968	137,291	171,614	205,937
34				38,857	77,713	116,570	155,427	194,284	233,140
36				43,672	87,344	131,015	174,687	218,359	262,031
42	Velocity these			59,804	119,608	179,412	239,216	299,020	358,824
48				78,467	156,934	235,401	313,868	392,335	470,801
54				99,660	199,321	298,981	398,641	498,301	597,962
60				123,384	246,768	370,153	493,537	616,921	740,305
72				178,424	356,847	535,271	713,695	892,119	1,070,542
84				243,585	487,171	730,756	974,342	1,217,927	1,461,513
96				318,869	637,739	956,608	1,275,478	1,594,347	1,913,217

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 Part 3.**

10 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	8	11	15	15	Pressure				
3/4	17	24	34	27	these				
1	35	49	69	44		drop	governs		
1-1/4	76	108	152	76	151	pipe	sizes		
1-1/2	118	167	236	103	206			with	
2	240	339	479	169	339				
2-1/2	395	558	790	242	484	725			
3	723	1,016	1,445	373	747	1,120			
4	1,527	2,160	3,054	643	1,286	1,929	2,572		
5	2,810	3,974	5,620	1,006	2,013	3,019	4,025	5,031	
6	4,637	6,558		1,459	2,918	4,377	5,836	7,295	8,754
8	9,654	13,652		2,526	5,053	7,579	10,105	12,632	15,158
10	17,616	24,912		3,982	7,964	11,946	15,929	19,911	23,893
12	28,273			5,711	11,423	17,134	22,846	28,557	34,268
14	36,621			6,963	13,927	20,890	27,853	34,816	41,780
16	52,789			9,224	18,448	27,672	36,896	46,120	55,344
18				11,802	23,604	35,406	47,208	59,011	70,813
20				14,697	29,395	44,092	58,790	73,487	88,185
22				17,910	35,820	53,730	71,641	89,551	107,461
24				21,440	42,880	64,320	85,760	107,201	128,641
26				25,287	50,575	75,862	101,150	126,437	151,724
28			with	29,452	58,904	88,356	117,808	147,260	176,712
30			sizes	33,934	67,868	101,802	135,735	169,669	203,603
32		governs		38,733	77,466	116,199	154,932	193,665	232,398
34	Velocity	pipe		43,849	87,699	131,548	175,398	219,247	263,097
36	these			49,283	98,567	147,850	197,133	246,416	295,700
42				67,488	134,977	202,465	269,954	337,442	404,930
48				88,549	177,098	265,648	354,197	442,746	531,295
54				112,466	224,932	337,397	449,863	562,329	674,795
60				139,238	278,476	417,714	556,952	696,190	835,428
72				201,350	402,699	604,049	805,399	1,006,749	1,208,098
84				274,884	549,768	824,653	1,099,537	1,374,421	1,649,305
96				359,841	719,683	1,079,524	1,439,366	1,799,207	2,159,049

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 Part 3.**

12 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	8	11	16		Pressure				
3/4	18	25	36	29	these				
1	36	51	72	47		drop	governs		
1-1/4	79	112	158	81		pipe	sizes		
1-1/2	123	173	245	111	221			with	
2	249	352	497	182	365				
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	5,413	
6	4,810	6,803		1,570	3,139	4,709	6,279	7,849	9,418
8	10,013	14,161		2,718	5,436	8,154	10,873	13,591	16,309
10	18,272			4,284	8,569	12,853	17,138	21,422	25,706
12	29,326			6,145	12,290	18,435	24,580	30,725	36,870
14	37,986			7,492	14,984	22,475	29,967	37,459	44,951

(Continued)

12 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
16	54,755			9,924	19,848	29,773	39,697	49,621	59,545
18	75,351			12,698	25,396	38,094	50,792	63,490	76,188
20				15,813	31,626	47,439	63,252	79,066	94,879
22				19,270	38,539	57,809	77,079	96,348	115,618
24				23,068	46,135	69,203	92,270	115,338	138,406
26				27,207	54,414	81,621	108,828	136,034	163,241
28				31,688	63,375	95,063	126,750	158,438	190,126
30				36,510	73,019	109,529	146,039	182,548	219,058
32		governs	with	41,673	83,346	125,019	166,693	208,366	250,039
34		pipe	sizes	47,178	94,356	141,534	188,712	235,890	283,068
36	Velocity			53,024	103,048	159,073	212,097	265,121	318,145
42	these			72,611	145,223	217,834	290,445	363,056	435,668
48				95,271	190,542	285,812	381,093	476,354	571,625
54				121,003	242,006	363,008	484,011	605,014	726,017
60				149,807	299,615	449,422	599,229	749,036	898,844
72				216,634	433,267	649,901	866,535	1,083,168	1,299,802
84				295,750	591,500	887,250	1,183,000	1,478,750	1,774,500
96				387,156	774,312	1,161,469	1,548,625	1,935,781	2,322,937

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 Part 3.

15 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	8	12	16		Pressure				
3/4	19	26	37	32	these				
1	38	53	75	52		drop	governs		
1-1/4	83	117	166	90		pipe	sizes		
1-1/2	129	182	258	122	244			with	
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			
4	1,665	2,354	3,329	764	1,528	2,291	3,055		
5	3,063	4,332		1,196	2,391	3,587	4,782	5,978	
6	5,055	7,149	6,126	1,733	3,467	5,200	6,934	8,667	
8	10,522	14,881	10,110	3,002	6,003	9,005	12,006	15,008	18,010
10	19,201	27,155		4,731	9,463	14,194	18,925	23,656	28,388
12	30,817			6,786	13,572	20,358	27,143	33,929	40,715
14	39,918			8,273	16,546	24,820	33,093	41,366	49,639
16	57,540			10,959	21,918	32,878	43,837	54,796	65,755
18	79,183			14,022	28,045	42,067	56,089	70,112	84,134
20				17,462	34,925	52,387	69,849	87,312	104,774
22			with	21,279	42,559	63,838	85,118	106,397	127,676
24			sizes	25,473	50,947	76,420	101,894	127,367	152,840
26		governs		30,044	60,089	90,133	120,178	150,222	180,267
28		pipe		34,992	69,985	104,977	139,970	174,962	209,955
30	Velocity			40,317	80,635	120,952	161,270	201,587	241,905
32	these			46,019	92,039	138,058	184,078	230,097	276,117
34				52,098	104,197	156,295	208,394	260,492	312,590
36				58,554	117,109	175,663	234,218	292,772	351,326
42				80,184	160,368	240,553	320,737	400,921	481,105

(*Continued*)

15 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
48				105,207	210,414	315,621	420,828	526,035	631,242
54				133,623	267,245	400,868	534,491	668,114	801,736
60				165,431	330,863	496,294	661,725	827,157	992,588
72				239,227	478,455	717,682	956,909	1,196,137	1,435,364
84				326,595	653,190	979,785	1,306,380	1,632,975	1,959,570
96				427,534	855,069	1,282,603	1,710,138	2,137,672	2,565,207

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 Part 3.

21.11 Medium Pressure Steam Pipe Sizing Tables (20–100 psig)

20 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	9	13	18						
3/4	20	29	40						
1	41	57	81		Pressure	drop			
1-1/4	89	126	178		these	pipe	governs		
1-1/2	139	196	277				sizes	with	
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	20,836	
10	20,653	29,208		10,948	16,421	21,895	27,369	32,843	41,054
12	33,148	46,878		15,702	23,553	31,403	39,254	47,105	58,881
14	42,936	60,720		19,143	28,715	38,286	47,858	57,430	71,787
16	61,891	87,527		25,358	38,038	50,717	63,396	76,075	95,094
18	85,170	120,449		32,446	48,669	64,892	81,115	97,338	121,673
20	113,063			40,406	60,609	80,812	101,015	121,218	151,522
22	145,843			49,238	73,857	98,476	123,095	147,714	184,643
24	183,768			58,943	88,414	117,885	147,357	176,828	221,035
26	227,082			69,519	104,279	139,039	173,799	208,558	260,698
28	276,022			80,969	121,453	161,937	202,422	242,906	303,632
30	330,813		with	93,290	139,935	186,580	233,225	279,870	349,838
32	397,670		sizes	106,484	159,726	212,968	266,210	319,451	399,314
34				120,550	180,825	241,100	301,375	361,650	452,062
36		governs		135,488	203,232	270,977	338,721	406,465	508,081
42		pipe		185,537	278,306	371,075	463,844	556,612	695,765
48				243,437	365,156	486,875	608,593	730,312	912,890
54	Velocity			309,188	463,782	618,376	772,970	927,564	1,159,456
60	these			382,790	574,185	765,580	956,974	1,148,369	1,435,462
72				553,546	830,318	1,107,091	1,383,864	1,660,637	2,075,796
84				755,705	1,133,557	1,511,409	1,889,262	2,267,114	1,833,893
96				989,267	1,483,901	1,978,534	2,473,168	2,967,802	3,709,752

Notes:
1 Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000 FPM.
2 Table based on Standard Weight Steel Pipe using steam equations in Part 3.

25 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	9	13	19						
3/4	21	30	43						
1	43	61	86		Pressure				
1-1/4	95	134	190		these				
1-1/2	148	209	295			drop	governs	with	
2	299	423	599	529		pipe	sizes		
2-1/2	493	697	986	754					
3	902	1,269	1,805	1,164	1,747				
4	1,907	2,697	3,814	2,005	3,008				
5	3,509	4,963	7,018	3,138	4,708	6,277			
6	5,791	8,190	11,582	4,550	6,825	9,100	11,376		
8	12,055	17,048	24,110	7,879	11,819	15,759	19,698	23,638	
10	21,998	31,110		12,420	18,629	24,839	31,049	37,259	
12	35,306	49,930		17,813	26,719	35,626	44,532	53,438	66,798
14	45,731	64,674	43,996	21,717	32,576	43,434	54,293	65,151	81,439
16	65,920	93,225		28,768	43,152	52,536	71,920	86,304	107,880
18	90,715	128,291		36,809	55,213	73,617	92,021	110,426	138,032
20	120,424	170,306		45,839	68,758	91,677	114,597	137,516	171,895
22	155,339			55,858	83,788	111,717	139,646	167,575	209,469
24	195,732			66,868	100,302	133,735	167,169	200,603	250,754
26	241,867			78,867	118,300	157,733	197,167	236,600	295,750
28	293,993			91,855	137,783	183,710	229,638	275,565	344,457
30	352,351			105,833	158,750	211,667	264,583	317,500	396,875
32	417,171		with	120,801	181,201	241,602	302,002	362,403	453,004
34	488,677	governs	sizes	136,758	205,137	273,517	341,896	410,275	512,844
36	567,084	pipe		153,705	230,558	307,410	384,263	461,116	576,395
42				210,484	315,725	420,967	526,209	631,451	789,314
48				276,168	414,253	552,337	690,421	828,505	1,035,632
54				350,760	526,140	701,519	876,899	1,052,279	1,315,349
60	Velocity			434,257	651,386	868,515	1,085,643	1,302,772	1,628,465
72	these			627,972	941,958	1,255,944	1,569,930	1,882,916	2,354,984
84				857,312	1,285,968	1,714,624	2,143,280	2,571,936	3,214,920
96				1,122,278	1,683,417	2,244,556	2,805,695	3,366,834	4,208,542

Notes:

1 **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

30 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	10	14	20						
3/4	23	32	45						
1	46	65	91		Pressure				
1-1/4	101	142	201		these				
1-1/2	156	221	312			drop	governs		
2	317	448	633	591		pipe	sizes	with	
2-1/2	521	737	1,043	843					
3	954	1,342	1,909	1,302					
4	2,017	2,852	4,034	2,243	3,364				
5	3,711	5,249	7,423	3,510	5,266	7,021			
6	6,125	8,662	12,249	5,090	7,634	10,179			
8	12,749	18,030	25,499	8,813	13,220	17,626	22,033		

(*Continued*)

30 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr. Pressure Drop psig/100 ft. 0.25	0.5	1	Velocity FPM (mph) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
10	23,265	32,902	46,530	13,891	20,837	27,783	34,729	41,674	
12	37,340	52,806	74,679	19,924	29,886	39,848	49,810	59,772	
14	48,365	68,399		24,291	36,436	48,582	60,727	72,873	91,091
16	69,717	98,595		32,178	48,266	64,355	80,444	96,533	120,666
18	95,940	135,680		41,171	61,757	82,342	102,928	123,513	154,391
20	127,361	180,116		51,271	76,907	102,543	128,178	153,814	192,268
22	164,286	232,336		62,479	93,718	124,957	156,197	187,436	234,295
24	207,006			74,793	112,189	149,586	186,982	224,378	280,473
26	255,799			88,214	132,321	176,428	220,534	264,641	330,802
28	310,927			102,742	154,113	205,483	256,854	308,225	385,281
30	372,647			118,376	177,565	236,753	295,941	355,129	443,912
32	441,200		with	135,118	202,677	270,236	337,795	405,354	506,693
34	516,825		sizes	152,967	229,450	305,933	382,417	458,900	573,625
36	599,748			171,922	257,883	343,844	429,805	515,766	644,708
42		governs		235,430	353,145	470,860	588,575	706,290	882,862
48		pipe		308,900	463,349	617,799	772,249	926,699	1,158,373
54				392,331	588,497	784,662	980,828	1,176,994	1,471,242
60	Velocity			485,725	728,587	971,450	1,214,312	1,457,175	1,821,468
72	these			702,398	1,053,597	1,404,796	1,755,995	2,107,194	2,633,993
84				958,919	1,438,379	1,917,839	2,397,398	2,876,758	3,595,948
96				1,255,289	1,882,933	2,510,577	3,138,222	3,765,866	4,707,332

Notes:

1 **Maximum recommended pressure drop/velocity: 0.5 psig/100 ft./8,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

40 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr. Pressure Drop psig/100 ft. 0.5	1	2	Velocity FPM (mph) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	16	22	31						
3/4	35	50	71						
1	71	100	142		Pressure	drop			
1-1/4	156	221	312		these	pipe			
1-1/2	242	343	485	433			governs	with	
2	492	695	984	713			sizes		
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	10,586		
6	9,513	13,453	19,026	6,139	9,209	12,278	15,348	18,418	
8	19,802	28,005	39,605	10,631	15,946	21,261	26,577	31,892	
10	36,136	51,103		16,757	25,135	33,513	41,891	50,270	62,837
12	57,996	82,019		24,033	36,050	48,066	60,083	72,100	90,124
14	75,122	106,239		29,301	43,951	58,602	73,252	87,903	109,878
16	108,286			38,814	58,221	77,628	97,035	116,442	145,553
18	149,016			49,662	74,493	99,325	124,156	148,987	186,234
20	197,819			61,846	92,769	123,692	154,615	185,537	231,922
22	255,172		with	75,364	113,047	150,729	188,411	226,093	282,617
24	321,526		sizes	90,218	135,327	180,437	225,546	270,655	338,319
26	397,311	governs		106,407	159,611	212,815	266,018	319,222	399,028
28		pipe		123,932	185,897	247,863	309,829	371,795	464,743
30				142,791	214,186	285,582	356,977	428,373	535,466
32	Velocity			162,985	244,478	325,971	407,464	488,956	611,195
34	these			184,515	276,773	369,030	461,288	553,546	691,932
36				207,380	311,070	414,760	518,450	622,140	777,675
42				283,986	425,979	567,972	709,965	851,958	1,064,947

(*Continued*)

40 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
48				372,608	558,912	745,216	931,521	1,117,825	1,397,281
54				473,247	709,871	946,494	1,183,118	1,419,742	1,774,677
60				585,903	878,854	1,171,805	1,464,757	1,757,708	2,197,135
72				847,264	1,270,895	1,694,527	2,118,159	2,541,791	3,177,239
84				1,156,691	1,735,036	2,313,382	2,891,727	3,470,073	4,337,591
96				1,514,184	2,271,277	3,028,369	3,785,461	4,542,553	5,678,192

Notes:
1 **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

50 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	17	24	34						
3/4	38	54	76						
1	77	109	154		Pressure these	drop pipe			
1-1/4	169	239	338	508			governs sizes	with	
1-1/2	263	371	525	837					
2	533	753	1,065						
2-1/2	877	1,241	1,755	1,194					
3	1,569	2,271	3,212	1,843	2,765				
4	3,393	4,799	6,786	3,174	4,761	6,348			
5	6,244	8,830	12,488	4,968	7,453	9,937	12,421		
6	10,304	14,573	20,609	7,203	10,805	14,407	18,008		
8	21,450	30,335	42,900	12,473	18,710	24,947	31,183	37,420	
10	39,142	55,355		19,661	29,492	39,322	49,153	58,983	73,729
12	62,822	88,844		28,199	42,298	56,398	70,497	84,597	105,746
14	81,373	115,078		34,380	51,570	68,759	85,949	103,139	128,924
16	117,296			45,542	68,313	91,084	113,854	136,625	170,782
18	161,415	165,882		58,270	87,406	116,541	145,676	174,811	218,514
20	214,279			72,566	108,849	145,132	181,414	217,697	272,122
22	276,404			88,428	132,641	176,855	221,069	265,283	331,604
24	348,279			105,856	158,784	211,712	264,640	317,568	396,961
26	430,370			124,851	187,277	249,703	312,128	374,554	468,192
28	523,121			145,413	218,120	290,826	363,533	436,239	545,299
30	626,961		with sizes	167,541	251,312	335,083	418,853	502,624	628,280
32				191,236	286,854	382,473	478,091	573,709	717,136
34				216,498	324,747	432,996	541,245	649,493	811,867
36		governs pipe		243,326	364,989	486,652	608,315	729,978	912,472
42				333,210	499,815	666,420	833,025	999,630	1,249,538
48				437,194	655,790	874,387	1,092,984	1,311,581	1,639,476
54	Velocity these			555,277	832,915	1,110,553	1,388,192	1,665,830	2,082,288
60				687,459	1,031,189	1,374,918	1,718,648	2,062,378	2,577,972
72				994,123	1,491,184	1,988,245	2,485,307	2,982,368	3,727,960
84				1,357,184	2,035,776	2,714,368	3,392,960	4,071,552	5,089,440
96				1,776,643	2,664,965	3,553,286	4,441,608	5,329,929	6,662,412

Notes:
1 **Maximum recommended pressure drop/velocity: 1.0 psig/100 ft./10,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

60 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	18	25	36						
3/4	41	58	82						
1	82	116	164		Pressure these				
1-1/4	181	256	362			drop pipe	governs sizes	with	
1-1/2	281	397	562						
2	570	806	1,140	957					
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	20,608		
8	22,946	32,451	45,893	14,274	21,412	28,549	35,686	42,823	
10	41,873	59,217	83,745	22,500	33,750	45,000	56,249	67,499	
12	67,204	95,041		32,270	48,406	64,541	80,676	96,811	121,014
14	87,049	123,106		39,344	59,015	78,687	98,359	118,031	147,539
16	125,479	177,454		52,117	78,176	104,235	130,293	156,352	195,440
18	172,676	244,200		66,684	100,026	133,368	166,710	200,052	250,064
20	229,227	324,176		83,043	124,565	166,086	207,608	249,129	311,412
22	295,686			101,195	151,793	202,391	252,988	303,586	379,482
24	372,575			121,140	181,710	242,280	302,851	363,421	454,276
26	460,392			142,878	214,317	285,756	357,195	428,634	535,792
28	559,614			166,408	249,613	332,817	416,021	499,225	624,032
30	670,697			191,732	287,598	383,464	479,329	575,195	718,994
32	794,082		with sizes	218,848	328,272	437,696	547,120	656,544	820,680
34		governs pipe		247,757	371,635	495,514	619,392	743,271	929,088
36				278,459	417,688	556,917	696,146	835,376	1,044,220
42				381,321	571,981	762,641	953,302	1,143,962	1,429,952
48	Velocity these			500,318	750,477	1,000,636	1,250,795	1,500,954	1,876,192
54				635,450	953,176	1,270,901	1,588,626	1,906,351	2,382,939
60				786,718	1,180,077	1,573,436	1,966,795	2,360,154	2,950,193
72				1,137,659	1,706,489	2,275,318	2,844,148	3,412,977	4,266,221
84				1,553,141	2,329,711	3,106,282	3,882,852	4,659,423	5,824,279
96				2,033,164	3,049,746	4,066,328	5,082,909	6,099,491	7,624,364

Notes:
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 Part 3.

75 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	20	28	39						
3/4	45	63	89						
1	90	127	179		Pressure these				
1-1/4	197	279	394			drop pipe	governs sizes	with	
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	42,419		

(*Continued*)

75 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr. Pressure Drop psig/100 ft. 0.5	1	2	Velocity FPM (mph) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
10	45,652	64,562	91,304	26,745	40,117	53,489	66,862	80,234	
12	73,270	103,620		38,359	57,538	76,718	95,897	115,077	143,846
14	94,906	134,218		46,766	70,150	93,533	116,916	140,299	175,374
16	136,805	193,471		61,950	92,925	123,900	154,876	185,851	232,313
18	188,261	266,242		79,265	118,897	158,530	198,162	237,795	297,244
20	249,917	353,436		98,711	148,066	197,422	246,777	296,132	370,165
22	322,374			120,288	180,431	240,575	300,719	360,863	451,079
24	406,203			143,996	215,993	287,991	359,989	431,987	539,983
26	501,947			169,834	254,752	339,669	424,586	509,503	636,879
28	610,125			197,804	296,707	395,609	494,511	593,413	741,767
30	731,235		with	227,905	341,858	455,811	569,764	683,716	854,646
32	865,756		sizes	260,138	390,206	520,275	650,344	780,413	975,516
34	1,014,152	governs		294,501	441,751	589,001	736,252	883,502	1,104,378
36	1,176,871	pipe		330,995	496,492	661,990	827,487	992,985	1,241,231
42				453,264	679,896	906,527	1,133,159	1,359,791	1,699,739
48				594,712	892,068	1,189,424	1,486,780	1,784,136	2,230,170
54	Velocity			755,340	1,133,009	1,510,679	1,888,349	2,266,019	2,832,524
60	these			935,147	1,402,720	1,870,293	2,337,867	2,805,440	3,506,800
72				1,352,299	2,028,449	2,704,598	3,380,748	4,056,898	5,071,122
84				1,846,169	2,769,254	3,692,339	4,615,423	5,538,508	6,923,135
96				2,416,757	3,625,136	4,833,514	6,041,893	7,250,271	9,062,839

Notes:

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 Part 3.**

85 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr. Pressure Drop psig/100 ft. 0.5	1	2	Velocity FPM (mph) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	21	29	41						
3/4	47	66	94						
1	94	133	188		Pressure				
1-1/4	207	293	415		these				
1-1/2	322	455	644			drop	governs		
2	653	924	1,306	1,258		pipe	sizes		
2-1/2	1,076	1,521	2,151	1,794				with	
3	1,957	2,784	3,938	2,771					
4	4,160	5,883	8,320	4,771	7,157				
5	7,655	10,826	15,311	7,468	11,202	14,936			
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	46,873		
10	47,989	67,867	95,979	29,553	44,330	59,107	73,883	88,660	
12	77,021	108,925	154,043	42,387	63,580	84,774	105,967	127,161	
14	99,765	141,089		51,678	77,516	103,355	129,194	155,033	193,791
16	143,808	203,376		68,456	102,684	136,911	171,139	205,367	256,709
18	197,899	279,872		87,589	131,383	175,178	218,972	262,766	328,458
20	262,712	371,531		109,077	163,615	218,153	272,692	327,230	409,037
22	338,879	479,247		132,919	199,379	265,839	332,298	398,758	498,447
24	426,999			159,117	238,675	318,234	397,792	477,350	596,688
26	527,645			187,669	281,504	375,338	469,173	563,007	703,759
28	641,361			218,576	327,865	437,153	546,441	655,729	819,661
30	768,671			251,838	377,758	503,677	629,596	755,515	944,394
32	910,079			287,455	431,183	574,910	718,638	862,366	1,077,957

(*Continued*)

85 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
34	1,066,072			325,427	488,140	650,854	813,567	976,281	1,220,351
36	1,237,121			365,753	548,630	731,507	914,384	1,097,260	1,371,575
42	1,845,105			500,862	751,293	1,001,724	1,252,155	1,502,586	1,878,232
48				657,164	985,746	1,314,328	1,642,910	1,971,492	2,464,365
54		governs pipe	with sizes	834,660	1,251,989	1,669,319	2,086,649	2,503,979	3,129,973
60	Velocity			1,033,349	1,550,023	2,066,697	2,583,372	3,100,046	3,875,057
72	these			1,494,307	2,241,461	2,988,614	3,735,768	4,482,922	5,603,652
84				2,040,040	3,060,060	4,080,080	5,100,099	6,120,119	7,650,149
96				2,670,546	4,005,820	5,341,093	6,676,366	8,011,639	10,014,549

Notes:
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 Part 3.

100 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	22	31	44						
3/4	50	71	100						
1	101	142	201		Pressure				
1-1/4	222	313	443		these				
1-1/2	344	486	688			drop pipe	governs sizes		
2	698	987	1,396						
2-1/2	1,149	1,625	2,299	2,049				with	
3	2,091	2,975	4,208	3,164					
4	4,446	6,287	8,891	5,449	8,173				
5	8,181	11,569	16,362	8,529	12,793				
6	13,501	19,093	27,001	12,365	18,548	24,730			
8	28,104	39,744	56,207	21,412	32,117	42,823	53,529		
10	51,283	72,526	102,567	33,750	50,624	67,499	84,374	101,249	
12	82,308	116,402	164,617	48,406	72,608	96,811	121,014	145,217	
14	106,613	150,773	213,226	59,015	88,523	118,031	147,539	177,046	
16	153,680	217,336		78,176	117,264	156,352	195,440	234,528	293,160
18	211,483	299,083		100,026	150,039	200,052	250,064	300,077	375,097
20	280,745	397,033		124,565	186,847	249,129	311,412	373,694	467,118
22	362,139	512,142		151,793	227,689	303,586	379,482	455,379	569,223
24	456,309	645,318		181,710	272,565	363,421	454,276	545,131	681,414
26	563,863	797,422		214,317	321,475	428,634	535,792	642,951	803,688
28	685,384			249,613	374,419	499,225	624,032	748,838	936,048
30	821,433			287,598	431,397	575,195	718,994	862,793	1,078,491
32	972,548		with	328,272	492,408	656,544	820,680	984,816	1,231,020
34	1,139,248		sizes	371,635	557,453	743,271	929,088	1,114,906	1,393,632
36	1,322,038			417,688	626,532	835,376	1,044,220	1,253,064	1,566,330
42	1,971,754	governs		571,981	857,971	1,143,962	1,429,952	1,715,943	2,144,929
48	2,783,057	pipe		750,477	1,125,715	1,500,954	1,876,192	2,251,430	2,814,288
54				953,176	1,429,763	1,906,351	2,382,939	2,859,527	3,574,408
60				1,180,077	1,770,116	2,360,154	2,950,193	3,540,231	4,425,289
72	Velocity			1,706,489	2,559,733	3,412,977	4,266,221	5,119,466	6,399,332
84	these			2,329,711	3,494,567	4,659,423	5,824,279	6,989,134	8,736,418
96				3,049,746	4,574,618	6,099,491	7,624,364	9,149,237	11,436,546

Notes:
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 Part 3.

21.12 High Pressure Steam Pipe Sizing Tables (120–300 psig)

120 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	34	48	75		Pressure	drop	governs	with	
3/4	76	108	171		these	pipe	sizes		
1	154	217	344						
1-1/4	338	478	756	746					
1-1/2	525	743	1,174	1,015					
2	1,065	1,507	2,382	1,673					
2-1/2	1,755	2,481	3,923	2,387	3,581				
3	3,212	4,542	7,181	3,686	5,530				
4	6,786	9,597	15,175	6,348	9,522	12,696			
5	12,488	17,661	27,924	9,937	14,905	19,873	24,842		
6	20,609	29,145	46,083	14,407	21,610	28,813	36,017	43,220	
8	42,900	60,670		24,947	37,420	49,894	62,367	74,840	93,550
10	78,284	110,711		39,322	58,983	78,644	98,305	117,966	147,458
12	125,644	177,688		56,398	84,597	112,796	140,995	169,194	211,492
14	162,745	230,156		68,759	103,139	137,519	171,898	206,278	257,848
16	234,593	331,764		91,084	136,625	182,167	227,709	273,251	341,563
18	322,831			116,541	174,811	233,082	291,352	349,623	437,028
20	428,558			145,132	217,697	290,263	362,829	435,395	544,243
22	552,808			176,855	265,283	353,711	442,138	530,566	663,207
24	696,558			211,712	317,568	423,425	529,281	635,137	793,921
26	860,739			249,703	374,554	499,405	624,256	749,108	936,385
28	1,046,243		with	290,826	436,239	581,652	727,065	872,478	1,090,598
30	1,253,922		sizes	335,083	502,624	670,165	837,707	1,005,248	1,256,560
32				382,473	573,709	764,945	956,181	1,147,418	1,434,272
34		governs		432,996	649,493	865,991	1,082,181	1,298,987	1,623,734
36		pipe		486,652	729,978	973,304	1,216,630	1,459,956	1,824,945
42				666,420	999,630	1,332,840	1,666,050	1,999,260	2,499,076
48	Velocity			874,387	1,311,581	1,748,775	2,185,968	2,623,162	3,278,952
54	these			1,110,553	1,665,830	2,221,107	2,776,383	3,331,660	4,164,575
60				1,374,918	2,062,378	2,749,837	3,437,296	4,124,755	5,155,944
72				1,998,245	2,982,368	3,976,491	4,970,613	5,964,736	7,455,920
84				2,714,368	4,071,552	5,428,736	6,785,920	8,143,104	10,178,879
96				3,553,286	5,329,929	7,106,572	8,883,215	10,659,859	13,324,823

Notes:

1 Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000 FPM.
2 Table based on Standard Weight Steel Pipe using steam equations in Part 3.

125 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	34	48	77						
3/4	78	110	174						
1	156	221	350		Pressure	drop			
1-1/4	344	487	770		these	pipe	governs		
1-1/2	534	756	1,195	1,051				with	
2	1,084	1,533	2,424	1,733			sizes		
2-1/2	1,785	2,525	3,992	2,472	3,708				
3	3,268	4,622	7,308	3,817	5,726				
4	6,905	9,766	15,441	6,573	9,860	13,146			

(*Continued*)

125 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
5	12,707	17,971	28,414	10,289	15,433	20,578	25,722		
6	20,971	29,657	46,892	14,917	22,376	29,834	37,293	44,751	
8	43,654	61,735		25,831	38,746	51,661	64,577	77,492	96,865
10	79,659	112,655		40,715	61,073	81,430	101,788	122,145	152,682
12	127,850	180,808		58,396	87,594	116,792	145,990	175,188	218,985
14	165,603	234,198		71,195	106,793	142,391	177,988	213,586	266,983
16	238,712	337,590		94,310	141,466	188,621	235,776	282,931	353,664
18	328,499			120,670	181,005	241,339	301,674	362,009	452,511
20	436,083			150,273	225,410	300,546	375,683	450,820	563,524
22	562,515			183,121	274,681	366,242	457,802	549,363	686,703
24	708,789			219,213	328,819	438,426	548,032	657,638	822,048
26	875,854			258,549	387,823	517,098	646,372	775,647	969,559
28	1,064,614		with	301,129	451,694	602,259	752,823	903,388	1,129,235
30	1,275,940		sizes	346,954	520,431	693,908	867,385	1,040,862	1,301,077
32				396,023	594,034	792,045	990,057	1,188,068	1,485,085
34		governs		448,336	672,504	896,671	1,120,839	1,345,007	1,681,259
36		pipe		503,893	755,839	1,007,786	1,259,732	1,511,679	1,889,599
42				690,030	1,035,045	1,380,060	1,725,075	2,070,090	2,587,612
48	Velocity			905,365	1,358,047	1,810,730	2,263,412	2,716,095	3,395,119
54	these			1,149,898	1,724,847	2,299,796	2,874,745	3,449,694	4,312,117
60				1,423,629	2,135,443	2,847,258	3,559,072	4,270,886	5,338,608
72				2,058,684	3,088,027	4,117,369	5,146,711	6,176,053	7,720,067
84				2,810,532	4,215,798	5,621,064	7,026,330	8,431,596	10,539,495
96				3,679,171	5,518,757	7,358,343	9,197,928	11,037,514	13,796,893

Notes:
1 Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000 FPM.
2 Table based on Standard Weight Steel Pipe using steam equations in Part 3.

150 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	37	52	83						
3/4	84	119	188						
1	169	239	378		Pressure	drop			
1-1/4	372	526	832		these	pipe			
1-1/2	578	817	1,292	1,230			governs	with	
2	1,173	1,658	2,622	2,027			sizes		
2-1/2	1,931	2,731	4,318	2,893					
3	3,535	4,999	7,905	4,466	6,700				
4	7,470	10,564	16,703	7,691	11,537	15,382			
5	13,746	19,439	30,736	12,039	18,059	24,078	30,098		
6	22,684	32,080	50,724	17,455	26,182	34,909	43,636		
8	47,221	66,780	105,589	30,225	45,337	60,449	75,562	90,674	
10	86,168	121,861		47,641	71,462	95,282	119,103	142,923	178,654
12	138,298	195,583		68,330	102,494	136,659	170,824	204,989	256,236
14	179,135	253,336		83,306	124,960	166,613	208,266	249,919	312,399
16	258,219	365,176		110,354	165,530	220,707	275,884	331,061	413,826
18	355,343	502,531		141,197	211,795	282,394	352,992	423,590	529,488
20	471,718			175,836	263,754	351,672	439,590	527,508	659,385
22	608,481			214,272	321,407	428,543	535,679	642,815	803,518
24	766,709			256,503	384,755	513,006	641,258	769,509	961,886
26	947,425			302,531	453,796	605,061	756,327	907,592	1,134,490

(*Continued*)

150 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
28	1,151,610			352,354	528,532	704,709	880,886	1,057,063	1,321,329
30	1,380,205			405,974	608,961	811,948	1,014,935	1,217,922	1,522,403
32	1,634,114			463,390	695,085	926,780	1,158,475	1,390,170	1,737,713
34	1,914,211			524,602	786,903	1,049,204	1,311,505	1,573,806	1,967,257
36				589,610	884,415	1,179,220	1,474,025	1,768,830	2,211,038
42		governs	with	807,411	1,211,116	1,614,822	2,018,527	2,422,232	3,027,790
48		pipe	sizes	1,059,376	1,589,065	2,118,753	2,648,441	3,178,129	3,972,661
54				1,345,507	2,018,260	2,691,013	3,363,767	4,036,520	5,045,650
60	Velocity			1,665,802	2,498,703	3,331,604	4,164,505	4,997,406	6,246,757
72	these			2,408,887	3,613,330	4,817,773	6,022,217	7,226,660	9,033,325
84				3,288,631	4,932,946	6,577,262	8,221,577	9,865,893	12,332,366
96				4,305,034	6,457,551	8,610,068	10,762,586	12,915,103	16,143,878

Notes:
1 Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000 FPM.
2 Table based on Standard Weight Steel Pipe using steam equations in Part 3.

175 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	40	56	89		Pressure	drop	governs	with	
3/4	90	127	201		these	pipe	sizes		
1	181	256	405						
1-1/4	398	563	891						
1-1/2	618	875	1,383						
2	1,255	1,775	2,806	2,322					
2-1/2	2,067	2,923	4,621	3,312					
3	3,783	5,350	8,459	5,114	7,672				
4	7,993	11,304	17,874	8,807	13,211	17,614			
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	49,968		
8	50,531	71,461	112,990	34,610	51,916	69,221	86,526	103,831	
10	92,208	130,402		54,554	81,831	109,108	136,385	163,662	204,578
12	147,992	209,292		78,245	117,367	156,489	195,611	234,734	293,417
14	191,692	271,093		95,394	143,092	190,789	238,486	286,183	357,729
16	276,318	390,773		126,366	189,549	252,732	315,916	379,099	473,873
18	380,251	537,756		161,685	242,527	323,370	404,212	485,055	606,319
20	504,783	713,872		201,351	302,026	402,701	503,376	604,052	755,065
22	651,133			245,363	368,045	490,726	613,408	736,089	920,112
24	820,451			293,723	440,584	587,445	734,306	881,168	1,101,460
26	1,013,835			346,429	519,643	692,858	866,072	1,039,287	1,299,108
28	1,232,333			403,482	605,223	806,964	1,008,705	1,210,447	1,513,058
30	1,476,951			464,882	697,324	929,765	1,162,206	1,394,647	1,743,309
32	1,748,657			530,630	795,944	1,061,259	1,326,574	1,591,889	1,989,861
34	2,048,388			600,724	901,085	1,201,447	1,501,809	1,802,171	2,252,713
36	2,377,048			675,165	1,012,747	1,350,329	1,687,911	2,025,494	2,531,867
42				924,569	1,386,853	1,849,138	2,311,422	2,773,707	3,467,133
48				1,213,095	1,819,643	2,426,191	3,032,739	3,639,286	4,549,108
54				1,540,744	2,311,117	3,081,489	3,851,861	4,622,233	5,777,791
60	Velocity	governs	with	1,907,515	2,861,273	3,815,031	4,768,789	5,722,546	7,153,183
72	these	pipe	sizes	2,758,425	4,137,637	5,516,849	6,896,061	8,275,274	10,344,092
84				3,765,823	5,648,734	7,531,645	9,414,556	11,297,468	14,121,834
96				4,929,710	7,394,564	9,859,419	12,324,274	14,789,129	18,486,411

Notes:
1 Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000 FPM.
2 Table based on Standard Weight Steel Pipe using steam equations in Part 3.

200 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	42	59	94						
3/4	96	135	214						
1	192	272	430		Pressure				
1-1/4	423	598	946		these	drop	governs		
1-1/2	656	928	1,468			pipe	sizes	with	
2	1,332	1,884	2,978	2,616					
2-1/2	2,194	3,102	4,905	3,732					
3	4,015	5,679	8,979	5,763	8,644				
4	8,485	11,999	18,972	9,923	14,885				
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	56,300		
8	53,637	75,854	119,935	38,996	58,494	77,992	97,490	116,988	
10	97,876	138,418		61,467	92,200	122,934	153,667	184,401	
12	157,089	222,157		88,159	132,239	176,319	220,398	264,478	330,598
14	203,475	287,757	218,858	107,482	161,224	214,965	268,706	322,447	403,059
16	293,303	414,794		142,379	213,568	284,758	355,947	427,137	533,921
18	403,625	570,811		182,173	273,260	364,346	455,433	546,519	683,149
20	535,812	757,753		226,865	340,297	453,730	567,162	680,595	850,744
22	691,157	977,444		276,455	414,682	552,909	691,137	829,364	1,036,705
24	870,884	1,231,615		330,942	496,413	661,884	827,355	992,826	1,241,033
26	1,076,154			390,327	585,491	780,654	975,818	1,170,981	1,463,727
28	1,308,083			454,610	681,915	909,220	1,136,525	1,363,830	1,704,788
30	1,567,737			523,791	785,686	1,047,581	1,309,477	1,571,372	1,967,215
32	1,856,146		with	597,869	896,804	1,195,738	1,494,673	1,793,607	2,242,009
34	2,174,300		sizes	676,845	1,015,268	1,353,690	1,692,113	2,030,535	2,538,169
36	2,523,162			760,719	1,141,078	1,521,438	1,901,797	2,282,157	2,852,696
42	3,763,171	governs		1,041,727	1,562,590	2,083,454	2,604,317	3,125,181	3,906,476
48		pipe		1,366,815	2,050,222	2,733,629	3,417,037	4,100,444	5,125,555
54				1,735,982	2,603,973	3,471,964	4,339,955	5,207,946	6,509,933
60	Velocity			2,149,229	3,223,844	4,298,458	5,373,073	6,447,687	8,059,609
72	these			3,107,962	4,661,943	6,215,925	7,769,906	9,323,887	11,654,859
84				4,243,014	6,364,521	8,486,028	10,607,536	12,729,043	15,911,303
96				5,554,385	8,331,577	11,108,770	13,885,962	16,663,155	20,828,943

Notes:

1 **Maximum recommended pressure drop/velocity: 2.0 psig/100 ft./15,000 FPM.**

2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

225 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	44	63	99						
3/4	101	143	225						
1	203	287	453		Pressure				
1-1/4	446	631	998		these	drop	governs		
1-1/2	693	980	1,549			pipe	sizes		
2	1,405	1,987	3,142	2,912				with	
2-1/2	2,314	3,273	5,175	4,154					
3	4,236	5,991	9,473	6,414					
4	8,952	12,660	20,017	11,046	16,568				
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	108,517		

(*Continued*)

225 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
10	103,263	146,036	230,904	68,419	102,629	136,838	171,048	205,258	
12	165,735	234,384		98,131	147,196	196,262	245,327	294,392	367,990
14	214,674	303,595		119,639	179,459	239,279	299,099	358,918	448,648
16	309,447	437,623		158,483	237,724	316,966	396,207	475,449	594,311
18	425,840	602,228		202,778	304,167	405,556	506,945	608,334	760,418
20	565,302	799,458		252,525	378,787	505,050	631,312	757,575	946,968
22	729,198	1,031,241		307,724	461,585	615,447	769,309	923,171	1,153,963
24	918,816	1,299,402		368,374	552,561	736,748	920,934	1,105,121	1,381,402
26	1,135,385	1,605,676		434,476	651,714	868,952	1,086,189	1,303,427	1,629,284
28	1,380,078			506,029	759,044	1,012,059	1,265,074	1,518,088	1,897,611
30	1,654,023			583,035	874,552	1,166,070	1,457,587	1,749,105	2,186,381
32	1,958,305		with	665,492	998,238	1,330,984	1,663,730	1,996,476	2,495,595
34	2,293,971		sizes	753,401	1,130,101	1,506,802	1,883,502	2,260,202	2,825,253
36	2,662,034			846,761	1,270,142	1,693,523	2,116,903	2,540,284	3,175,355
42	3,970,291	governs		1,159,553	1,739,330	2,319,107	2,898,883	3,478,660	4,348,325
48	5,603,917	pipe		1,521,411	2,282,116	3,042,821	3,803,526	4,564,232	5,705,290
54				1,932,333	2,898,500	3,864,666	4,830,833	5,797,000	7,246,250
60				2,392,321	3,588,482	4,784,643	5,980,803	7,176,964	8,971,205
72				3,459,494	5,189,240	6,918,987	8,648,734	10,378,481	12,973,101
84	Velocity			4,722,928	7,084,391	9,445,855	11,807,319	14,168,783	17,710,978
96	these			6,182,623	9,273,934	12,365,246	15,456,557	18,547,869	23,184,836

Notes:

1 **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000 FPM.**

2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

250 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	47	66	104						
3/4	106	150	236						
1	213	301	476		Pressure				
1-1/4	468	662	1,047		these	drop	governs		
1-1/2	727	1,028	1,625			pipe	sizes		
2	1,474	2,085	3,297	3,205				with	
2-1/2	2,428	3,434	5,430	4,573					
3	4,445	6,286	9,939	7,061					
4	9,392	13,283	21,002	12,160	18,239				
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	119,460		
10	108,345	153,223	242,267	75,319	112,978	150,638	188,297	225,957	
12	173,891	245,919	388,831	108,027	162,040	216,054	270,067	324,080	
14	225,238	318,535		131,705	197,557	263,409	329,261	395,114	493,892
16	324,675	459,160		174,465	261,698	348,930	436,163	523,395	654,244
18	446,796	631,865		223,227	334,841	446,455	558,068	669,682	837,102
20	593,122	838,801		277,991	416,986	555,982	694,977	833,973	1,042,466
22	765,083	1,081,991		338,756	508,134	677,512	846,890	1,016,268	1,270,335
24	964,032	1,363,348		405,522	608,284	811,045	1,013,806	1,216,567	1,520,709
26	1,191,259	1,684,694		478,291	717,436	956,581	1,195,726	1,434,872	1,793,590
28	1,447,994	2,047,773		557,060	835,590	1,114,120	1,392,650	1,671,180	2,088,975
30	1,735,421			641,831	962,747	1,283,662	1,604,578	1,925,493	2,406,867
32	2,054,677			732,604	1,098,905	1,465,207	1,831,509	2,197,811	2,747,264

(*Continued*)

250 PSIG STEAM PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Steam Flow lbs./hr. Pressure Drop psig/100 ft. 1	2	5	Velocity FPM (mph) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
34	2,406,861			829,378	1,244,067	1,658,755	2,073,444	2,488,133	3,110,166
36	2,793,037			932,153	1,398,230	1,864,306	2,330,383	2,796,460	3,495,574
42	4,165,676			1,276,489	1,914,733	2,552,977	3,191,222	3,829,466	4,786,832
48	5,879,695	governs	with	1,674,837	2,512,256	3,349,675	4,187,094	5,024,512	6,280,640
54	7,959,549	pipe	sizes	2,127,200	3,190,800	4,254,399	5,317,999	6,381,599	7,976,999
60				2,633,575	3,950,363	5,267,151	6,583,938	7,900,726	9,875,908
72	Velocity			3,808,367	5,712,550	7,616,734	9,520,917	11,425,101	14,281,376
84	these			5,199,212	7,798,818	10,398,424	12,998,030	15,597,636	19,497,045
96				6,806,111	10,209,166	13,612,221	17,015,277	20,418,332	25,522,915

Notes:
1 **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

275 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr. Pressure Drop psig/100 ft. 1	2	5	Velocity FPM (mph) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	49	69	109						
3/4	110	156	247						
1	222	314	497		Pressure				
1-1/4	489	692	1,094		these	drop	governs		
1-1/2	759	1,074	1,689			pipe	sizes		
2	1,541	2,179	3,445					with	
2-1/2	2,537	3,589	5,674	4,994					
3	4,645	6,569	10,386	7,711					
4	9,815	13,880	21,946	13,278	19,916				
5	18,061	25,542	40,385	20,783	31,175				
6	29,805	42,151	66,646	30,133	45,199	60,265			
8	62,044	87,743	138,734	52,178	78,267	104,356	130,445		
10	113,217	160,113	253,161	82,245	123,368	164,490	205,613	246,735	
12	181,710	256,977	406,316	117,961	176,941	235,921	294,901	353,882	
14	235,367	332,859	526,296	143,816	215,723	287,631	359,539	431,447	
16	339,275	479,807		190,508	285,762	381,017	476,271	571,525	714,406
18	466,887	660,278		243,754	365,632	487,509	609,386	731,263	914,079
20	619,793	876,519		303,554	455,331	607,108	758,884	910,661	1,138,327
22	799,486	1,130,644		369,907	554,860	739,813	924,766	1,109,720	1,387,150
24	1,007,382	1,424,653		442,813	664,219	885,625	1,107,032	1,328,438	1,660,548
26	1,244,826	1,760,450		522,272	783,408	1,044,545	1,305,681	1,566,817	1,958,521
28	1,513,106	2,139,855		608,285	912,428	1,216,570	1,520,713	1,824,855	2,281,069
30	1,813,457	2,564,616		700,851	1,051,277	1,401,703	1,752,128	2,102,554	2,628,193
32	2,147,070		with	799,971	1,199,956	1,599,942	1,999,927	2,399,913	2,999,891
34	2,515,091		sizes	905,644	1,358,466	1,811,288	2,264,110	2,716,932	3,396,165
36	2,918,632			1,017,870	1,526,805	2,035,741	2,544,676	3,053,611	3,817,014
42	4,352,994			1,393,869	2,090,804	2,787,739	3,484,674	4,181,608	5,227,010
48	6,144,088	governs		1,828,849	2,743,273	3,657,698	4,572,122	5,486,547	6,858,183
54	8,317,466	pipe		2,322,809	3,484,213	4,645,617	5,807,021	6,968,426	8,710,532
60				2,875,748	4,313,623	5,751,497	7,189,371	8,627,245	10,784,057
72	Velocity			4,158,569	6,237,854	8,317,138	10,396,423	12,475,707	15,594,634
84	these			5,677,311	8,515,966	11,354,622	14,193,277	17,031,933	21,289,916
96				7,431,974	11,147,960	14,863,947	18,579,934	22,295,921	27,869,901

Notes:
1 **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

300 PSIG STEAM PIPING SYSTEMS—STEEL PIPE

Pipe Size	Steam Flow lbs./hr.								
	Pressure Drop psig/100 ft.			Velocity FPM (mph)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	51	72	113						
3/4	115	163	257						
1	232	327	518		Pressure				
1-1/4	509	720	1,139		these				
1-1/2	791	1,118	1,768			drop	governs		
2	1,604	2,269	3,587			pipe	sizes		
2-1/2	2,642	3,736	5,908	5,413				with	
3	4,836	6,839	10,814	8,359					
4	10,219	14,451	22,850	14,394	21,591				
5	18,804	26,593	42,048	22,530	33,796				
6	31,032	43,886	69,390	32,665	48,998	65,331			
8	64,598	91,356	144,446	56,564	84,846	113,128	141,410		
10	117,879	166,706	263,586	89,158	133,737	178,316	222,895		
12	189,193	267,559	423,047	127,875	191,813	255,751	319,688	383,626	
14	245,059	346,565	547,968	155,904	233,855	311,807	389,759	467,711	
16	353,245	499,564		206,521	309,781	413,042	516,302	619,563	774,454
18	486,113	687,467		264,242	396,364	528,485	660,606	792,727	990,909
20	645,315	912,613		329,068	493,602	658,136	822,671	987,205	1,234,006
22	832,408	1,177,203		400,998	601,497	801,996	1,002,495	1,202,994	1,503,743
24	1,048,864	1,483,318		480,032	720,048	960,064	1,200,081	1,440,097	1,800,121
26	1,296,086	1,832,942		566,170	849,256	1,132,341	1,415,426	1,698,511	2,123,139
28	1,575,413	2,227,971		659,413	989,119	1,318,826	1,648,532	1,978,239	2,472,799
30	1,888,133	2,670,223		759,760	1,139,639	1,519,519	1,899,399	2,279,279	2,849,099
32	2,235,482	3,161,450	with	867,210	1,300,816	1,734,421	2,168,026	2,601,631	3,252,039
34	2,618,658		sizes	981,766	1,472,648	1,963,531	2,454,414	2,945,297	3,681,621
36	3,038,816			1,103,425	1,655,137	2,206,849	2,758,562	3,310,274	4,137,843
42	4,532,243			1,511,028	2,266,541	3,022,055	3,777,569	4,533,083	5,666,353
48	6,397,091	governs		1,982,568	2,973,852	3,965,136	4,956,420	5,947,704	7,434,630
54	8,659,966	pipe		2,518,046	3,777,069	5,036,092	6,295,116	7,554,139	9,442,673
60	11,345,797			3,117,462	4,676,193	6,234,924	7,793,655	9,352,386	11,690,483
72	Velocity			4,508,107	6,762,160	9,016,214	11,270,267	13,524,321	16,905,401
84	these			6,154,503	9,231,754	12,309,005	15,386,256	18,463,508	23,079,384
96				8,056,649	12,084,973	16,113,298	20,141,622	24,169,947	30,212,433

Notes:
1 **Maximum recommended pressure drop/velocity: 5.0 psig/100 ft./15,000 FPM.**
2 **Table based on Standard Weight Steel Pipe using steam equations in Part 3.**

PART 22

Steam Condensate Piping Systems

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: 5000 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 water line 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 increasing 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 acid; above 7 is alkaline.

C. Low-Pressure Steam Condensate Pipe Materials (0–15 psig)

1. 2" and smaller:
   a. Pipe: black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
      Fittings: black cast iron screw fittings, 250 lbs., *ANSI/ASME B16.4.*
      Joints: pipe threads, general purpose (American) *ANSI/ASME B1.20.1.*
2. 2-1/2" and larger:
   a. Pipe: black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
      Fittings: steel butt-welding fittings, 250 lbs., *ANSI/ASME B16.9.*
      Joints: welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

D. Medium-Pressure Steam Condensate Pipe Materials (16–100 psig)

1. 2" and smaller:
   a. Pipe: black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
      Fittings: black cast iron screw fittings, 250 lbs., *ANSI/ASME B16.4.*
      Joints: pipe threads, general purpose (American) *ANSI/ASME B1.20.1.*
2. 2-1/2" and larger:
   a. Pipe: black steel pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
      Fittings: steel butt-welding fittings, 250 lbs., *ANSI/ASME B16.9.*
      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, *ASTM A53, Schedule 80,* 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 80,* 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.*

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) Bucket traps.
      3) 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 is 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%).
   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 Resistance	Excellent	Good	Good
Resistance to Hydraulic Shock	Excellent	Poor	Poor
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	Fair	Poor	Poor
Usual Mechanical Failure Mode	Open	Closed with air vent open	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 non-condensables 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 and body	Condensate backs up into the drain line and/or process

(*Continued*)

STEAM TRAP COMPARISON (*Continued*)

Characteristic	Steam Trap Type		
	Inverted Bucket	Float & Thermostatic	Liquid Expansion Thermostatic
	Must have water seal to operate; subject to losing prime	Some thermostatic air vent designs are susceptible to corrosion	
	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

Characteristic	Steam Trap Type		
	Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynamic
Method of Operation	Intermittent	Intermittent	Intermittent
No Load	No action	No action	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 Freezing; Cast Iron Trap Not Recommended	Good	Good	Good
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

(*Continued*)

STEAM TRAP COMPARISON (*Continued*)

Characteristic	Steam Trap Type		
	Balanced Pressure Thermostatic	Bimetal Thermostatic	Thermodynamic
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 noncondensables at startup	Maximum discharge of noncondensables at startup	Handles wide pressure range
	Unlikely to freeze	Unlikely to freeze and unlikely to be damaged if it does freeze	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 conditions below freezing	Constant-pressure, constant-load applications
	Installations subject to ambient conditions below freezing		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

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 3 5	0 0 0	1/8 1/8 1/8	5,000 5,000 5,000
	7 10 12 15	0 3 4 5	1/8 1/4 1/4 1/4	5,000 5,000 5,000 5,000
Medium Pressure	20 25 30	6 8 10	1/4 1/4 1/4	5,000 5,000 5,000
	40 50 60	13 16 20	1/4 1/4 1/4	5,000 5,000 5,000
	75 85 100	25 28 33	1/4 1/4 1/4	5,000 5,000 5,000
High Pressure	120 125 150	40 41 50	1/4 1/4 1/4	5,000 5,000 5,000
	175 200 225	58 66 75	1/4 1/2 1/2	5,000 5,000 5,000
	250 275 300	83 91 100	1/2 1/2 1/2	5,000 5,000 5,000

22.03 Low-Pressure Steam Condensate System Pipe Sizing Tables (15 psig and Less)

1 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 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2 3/4 1	843 2,067 4,329	1,192 2,923 6,122	1,686 4,134 8,658	3,954 6,577	Pressure with these	drop pipe	governs with
1–1/4 1–1/2 2	9,965 15,758 32,660	14,093 22,285 46,189	19,930 31,515 65,321	11,729 16,158 27,000	17,594 24,237 40,500	54,000	
2-1/2 3 4	54,310 100,865 216,701	76,806 142,645		38,753 60,396 105,124	58,130 90,594 157,686	77,507 120,792 210,247	96,883 150,989 262,809
5 6 8	405,300			166,358 238,345 417,533	249,536 357,518 626,299	332,715 476,690 835,065	415,894 595,863 1,043,831
10 12 14				682,684 991,486 1,213,661	1,024,026 1,487,228 1,820,491	1,365,369 1,982,971 2,427,322	1,706,711 2,478,714 3,034,152

(*Continued*)

1 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				1,615,821	2,423,731	3,231,642	4,039,552
18				2,075,432	3,113,148	4,150,864	5,188,580
20				2,592,495	3,888,742	5,184,990	6,481,237
22				3,167,009	4,750,513	6,334,018	7,917,522
24				3,798,974	5,698,462	7,597,949	9,497,436
26				4,488,391	6,732,587	8,976,782	11,220,978
28				5,235,260	7,852,889	10,470,519	13,088,149
30				6,039,579	9,059,369	12,079,159	15,098,948
32	Velocity	governs	with	6,901,350	10,352,026	13,802,701	17,253,376
34	these	pipe	sizes	7,820,573	11,730,859	15,641,146	19,551,432
36				8,797,247	13,195,870	17,594,494	21,993,117
42				12,071,977	18,107,966	24,143,954	30,179,943
48				15,863,770	23,795,655	31,727,540	39,659,425
54				20,172,626	30,258,938	40,345,251	50,431,564
60				24,998,544	37,497,816	49,997,088	62,496,360
72				36,201,568	54,302,353	72,403,137	90,503,921
84				49,472,844	74,209,266	98,945,687	123,682,109
96				64,812,370	97,218,554	129,624,739	162,030,924

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	293	414	586	1,373	Pressure	drop	
3/4	718	1,015	1,436	2,285	with these	pipe	
1	1,504	2,127	3,008				governs
1–1/4	3,462	4,895	6,923	4,074	6,112		sizes
1–1/2	5,474	7,741	10,947	5,613	8,419	18,758	
2	11,345	16,045	22,690	9,379	14,069		
2–1/2	18,866	26,680		13,462	20,193	26,923	33,654
3	35,037	49,550		20,980	31,469	41,959	52,449
4	75,275			36,517	54,775	73,033	91,292
5				57,787	86,681	115,575	144,468
6	140,788			82,794	124,190	165,587	206,984
8				145,038	217,556	290,075	362,594
10				237,143	355,714	474,286	592,857
12				344,411	516,616	688,822	861,027
14				421,588	632,381	843,175	1,053,969
16				561,285	841,928	1,122,570	1,403,213
18				720,940	1,081,409	1,441,879	1,802,349
20			with	900,551	1,350,826	1,801,102	2,251,377
22			sizes	1,100,119	1,650,178	2,200,238	2,750,297
24		governs		1,319,644	1,979,466	2,639,287	3,299,109
26	Velocity	pipe		1,559,125	2,338,688	3,118,251	3,897,813
28	these			1,818,564	2,727,846	3,637,128	4,546,410
30				2,097,959	3,146,939	4,195,918	5,244,898
32				2,397,311	3,595,967	4,794,622	5,993,278
34				2,716,620	4,074,930	5,433,240	6,791,550
36				3,055,886	4,583,829	6,111,771	7,639,714
42				4,193,424	6,290,135	8,386,847	10,483,559
48				5,510,573	8,265,859	11,021,145	13,776,432
54				7,007,333	10,511,000	14,014,666	17,518,333
60				8,683,705	13,025,557	17,367,409	21,709,262

(*Continued*)

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)	5,000 (57)
72				12,575,282	18,862,922	25,150,563	31,438,204
84				17,185,304	25,777,955	34,370,607	42,963,259
96				22,513,770	33,770,656	45,027,541	56,284,426
Steam Condensate Flow lbs./hr. 1 psig Back Pressure							
1/2	461	653	923				
3/4	1,132	1,601	2,264	2,232	Pressure	drop	
1	2,370	3,352	4,741	3,713	with these	pipe	governs
1–1/4	5,456	7,716	10,912	6,621	9,932		sizes
1–1/2	8,628	12,201	17,255	9,121	13,682		
2	17,882	25,289	35,764	15,242	22,862	30,483	
2–1/2	29,736	42,053		21,876	32,814	43,753	54,691
3	55,226	78,101		34,093	51,140	68,187	85,234
4	118,648			59,342	89,014	118,685	148,356
5				93,909	140,863	187,818	234,772
6	221,910			134,546	201,819	269,092	336,365
8				235,697	353,546	471,394	589,243
10				385,375	578,063	770,751	963,438
12				559,694	839,541	1,119,388	1,399,234
14				685,112	1,027,668	1,370,224	1,712,779
16				912,131	1,368,197	1,824,262	2,280,328
18				1,171,582	1,757,373	2,343,163	2,928,954
20				1,463,464	2,195,195	2,926,927	3,658,659
22				1,787,777	2,681,665	3,575,554	4,469,442
24			with	2,144,521	3,216,782	4,289,043	5,361,304
26		governs	sizes	2,533,697	3,800,546	5,067,395	6,334,243
28	Velocity	pipe		2,955,305	4,432,957	5,910,609	7,388,262
30	these			3,409,343	5,114,015	6,818,686	8,523,358
32				3,895,813	5,843,720	7,791,626	9,739,533
34				4,414,714	6,622,071	8,829,429	11,036,786
36				4,966,047	7,449,070	9,932,094	12,415,117
42				6,814,632	10,221,949	13,629,265	17,036,581
48				8,955,100	13,432,650	17,910,200	22,387,750
54				11,387,450	17,081,174	22,774,899	28,468,624
60				14,111,681	21,167,521	28,223,362	35,279,202
72				20,435,790	30,653,684	40,871,579	51,089,474
84				27,927,426	41,891,139	55,854,852	69,818,565
96				36,586,590	54,879,885	73,173,180	91,466,476

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	183	259	366				
3/4	449	635	898	858	Pressure	drop	
1	940	1,329	1,880	1,428	with these	pipe	governs
1–1/4	2,163	3,060	4,327	2,546	3,820		sizes
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	21,034
3	21,898	30,969		13,112	19,668	26,224	32,781
4	47,047			22,823	34,234	45,646	57,057
5				36,117	54,176	72,234	90,293
6	87,993			51,746	77,619	103,492	129,365
8				90,649	135,973	181,297	226,621

(*Continued*)

5 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
10				148,214	222,322	296,429	370,536
12				215,257	322,885	430,513	538,142
14				263,492	395,238	526,984	658,730
16				350,803	526,205	701,606	877,008
18				450,587	675,881	901,174	1,126,468
20				562,844	844,266	1,125,689	1,407,111
22				687,574	1,031,361	1,375,149	1,718,936
24				824,777	1,237,166	1,649,555	2,061,943
26				974,453	1,461,680	1,948,907	2,436,133
28				1,136,602	1,704,904	2,273,205	2,841,506
30	Velocity	governs	with	1,311,224	1,966,837	2,622,449	3,278,061
32	these	pipe	sizes	1,498,319	2,247,479	2,996,639	3,745,799
34				1,697,888	2,546,831	3,395,775	4,244,719
36				1,909,929	2,864,893	3,819,857	4,774,821
42				2,620,890	3,931,335	5,241,780	6,552,224
48				3,444,108	5,166,162	6,888,216	8,610,270
54				4,379,583	6,569,375	8,759,166	10,948,958
60				5,427,315	8,140,973	10,854,631	13,568,289
72				7,859,551	11,789,327	15,719,102	19,648,878
84				10,740,815	16,111,222	21,481,629	26,852,037
96				14,071,107	21,106,660	28,142,213	35,177,766
Steam Condensate Flow lbs./hr. 1 psig Back Pressure							
1/2	240	340	481	1,163	Pressure	drop	
3/4	590	834	1,179	1,934	with these	pipe	
1	1,235	1,746	2,470				governs
1–1/4	2,843	4,020	5,685	3,450	5,175		sizes
1–1/2	4,495	6,357	8,990	4,752	7,128	15,882	
2	9,317	13,176	18,634	7,941	11,911		
2–1/2	15,493	21,910		11,398	17,097	22,795	28,494
3	28,773	40,691		17,763	26,644	35,526	44,407
4	61,817			30,918	46,377	61,836	77,295
5				48,927	73,391	97,855	122,318
6	115,617			70,100	105,149	140,199	175,249
8				122,800	184,200	245,600	307,001
10				200,784	301,176	401,568	501,960
12				291,605	437,408	583,210	729,013
14				356,949	535,423	713,898	892,372
16				475,228	712,842	950,456	1,188,070
18				610,404	915,606	1,220,808	1,526,010
20				762,477	1,143,715	1,524,954	1,906,192
22			with	931,447	1,397,170	1,862,894	2,328,617
24			sizes	1,117,314	1,675,971	2,234,627	2,793,284
26		governs		1,320,078	1,980,116	2,640,155	3,300,194
28		pipe		1,539,739	2,309,608	3,079,477	3,849,346
30	Velocity			1,776,296	2,664,445	3,552,593	4,440,741
32	these			2,029,751	3,044,627	4,059,503	5,074,378
34				2,300,103	3,450,155	4,600,207	5,750,258
36				2,587,352	3,881,028	5,174,704	6,468,380
42				3,550,481	5,325,721	7,100,962	8,876,202
48				4,665,682	6,998,524	9,331,365	11,664,206
54				5,932,957	8,899,435	11,865,914	14,832,392
60				7,352,304	11,028,457	14,704,609	18,380,761
72				10,647,218	15,970,827	21,294,436	26,618,045
84				14,550,424	21,825,635	29,100,847	36,376,059
96				19,061,921	28,592,881	38,123,842	47,654,802

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	136	192	271	636	Pressure	drop	
3/4	333	471	666	1,059	with these	pipe	
1	697	986	1,394				governs
1–1/4	1,604	2,269	3,208	1,888	2,832		sizes
1–1/2	2,537	3,587	5,073	2,601	3,902	8,693	
2	5,258	7,435	10,515	4,346	6,520		
2–1/2	8,743	12,364		6,238	9,358	12,477	15,596
3	16,237	22,962		9,722	14,583	19,444	24,306
4	34,884			16,922	25,384	33,845	42,306
5				26,780	40,169	53,559	66,949
6	65,243			38,368	57,552	76,736	95,919
8				67,213	100,819	134,425	168,031
10				109,896	164,843	219,791	274,739
12				159,605	239,408	319,210	399,013
14				195,370	293,055	390,740	488,425
16				260,108	390,162	520,215	650,269
18				334,094	501,141	668,188	835,235
20				417,328	625,993	834,657	1,043,321
22			with	509,811	764,717	1,019,622	1,274,528
24			sizes	611,542	917,313	1,223,084	1,528,856
26		governs		722,522	1,083,782	1,445,043	1,806,304
28	Velocity	pipe		842,749	1,264,124	1,685,498	2,106,873
30	these			972,225	1,458,337	1,944,450	2,430,562
32				1,110,949	1,666,424	2,221,898	2,777,373
34				1,258,921	1,888,382	2,517,843	3,147,304
36				1,416,142	2,124,213	2,832,284	3,540,355
42				1,943,294	2,914,941	3,886,588	4,858,235
48				2,553,680	3,830,520	5,107,360	6,384,200
54				3,247,301	4,870,951	6,494,601	8,118,252
60				4,024,156	6,036,234	8,048,312	10,060,390
72				5,827,570	8,741,354	11,655,139	14,568,924
84				7,963,921	11,945,882	15,927,842	19,909,803
96				10,433,211	15,649,816	20,866,421	26,083,027
Steam Condensate Flow lbs./hr. 1 psig Back Pressure							
1/2	166	235	333	805	Pressure	drop	
3/4	408	577	816	1,338	with these	pipe	
1	854	1,208	1,709				governs
1–1/4	1,967	2,781	3,933	2,387	3,580		sizes
1–1/2	3,110	4,398	6,220	3,288	4,932	10,988	
2	6,446	9,116	12,892	5,494	8,241		
2–1/2	10,719	15,159		7,886	11,828	15,771	19,714
3	19,907	28,153		12,289	18,434	24,579	30,724
4	42,769			21,391	32,086	42,782	53,477
5				33,851	50,776	67,702	84,627
6	79,991			48,499	72,749	96,998	121,248
8				84,961	127,441	169,921	212,402
10				138,914	208,372	277,829	347,286
12				201,750	302,625	403,500	504,375
14				246,959	370,438	493,918	617,397
16			with	328,791	493,187	657,583	821,979
18			sizes	422,314	633,471	844,629	1,055,786
20		governs		527,528	791,291	1,055,055	1,318,819
22		pipe		644,431	966,647	1,288,862	1,611,078
24	Velocity			773,025	1,159,538	1,546,050	1,932,563
26	these			913,310	1,369,964	1,826,619	2,283,274
28				1,065,284	1,597,926	2,130,568	2,663,211
30				1,228,949	1,843,424	2,457,899	3,072,373
32				1,404,305	2,106,457	2,808,609	3,510,762
34				1,591,351	2,387,026	3,182,701	3,978,376
36				1,790,087	2,685,130	3,580,173	4,475,217
42				2,456,437	3,684,656	4,912,875	6,141,093

(*Continued*)

7 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
48 54 60				3,228,001 4,104,778 5,086,769	4,842,002 6,157,167 7,630,153	6,456,002 8,209,557 10,173,537	8,070,003 10,261,946 12,716,922
72 84 96				7,366,389 10,066,863 13,188,190	11,049,584 15,100,294 19,782,284	14,732,779 20,133,726 26,376,379	18,415,973 25,167,157 32,970,474

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2 3/4 1	101 247 518	143 350 732	202 494 1,035	473 786	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	1,191 1,884 3,905	1,685 2,664 5,523	2,383 3,768 7,810	1,402 1,932 3,228	2,104 2,898 4,842	6,457	
2–1/2 3 4	6,494 12,060 25,910	9,183 17,055		4,634 7,221 12,569	6,950 10,832 18,854	9,267 14,442 25,138	11,584 18,053 31,423
5 6 8	48,460			19,891 28,498 49,922	29,836 42,747 74,884	39,781 56,996 99,845	49,726 71,244 124,806
10 12 14				81,625 118,547 145,112	122,438 177,821 217,667	163,251 237,094 290,223	204,063 296,368 362,779
16 18 20				193,196 248,149 309,972	289,794 372,224 464,958	386,392 496,299 619,944	482,990 620,374 774,931
22 24 26			with sizes	378,664 454,225 536,655	567,996 681,338 804,983	757,328 908,450 1,073,311	946,660 1,135,563 1,341,639
28 30 32	Velocity these	governs pipe		625,955 722,124 825,161	938,932 1,083,185 1,237,742	1,251,910 1,444,247 1,650,323	1,564,887 1,805,309 2,062,904
34 36 42				935,068 1,051,845 1,443,389	1,402,603 1,577,767 2,165,083	1,870,137 2,103,689 2,886,777	2,337,671 2,629,612 3,608,471
48 54 60				1,896,755 2,411,944 2,988,956	2,845,133 3,617,917 4,483,435	3,793,510 4,823,889 5,977,913	4,741,888 6,029,861 7,472,391
72 84 96				4,328,448 5,915,231 7,749,305	6,492,673 8,872,847 11,623,958	8,656,897 11,830,463 15,498,610	10,821,121 14,788,078 19,373,263
Steam Condensate Flow lbs./hr. 1 psig Back Pressure							
1/2 3/4 1	118 289 605	167 408 855	235 578 1,210	569 947	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	1,392 2,201 4,563	1,969 3,113 6,452	2,784 4,403 9,125	1,689 2,327 3,889	2,534 3,491 5,833	7,778	
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	13,954 21,747 37,852

(*Continued*)

10 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5				23,960	35,940	47,921	59,901
6	56,619			34,329	51,493	68,657	85,821
8				60,137	90,205	120,273	150,342
10				98,326	147,489	196,652	245,816
12				142,803	214,204	285,605	357,006
14				174,802	262,203	349,604	437,005
16				232,725	349,087	465,450	581,812
18				298,922	448,383	597,844	747,305
20				373,394	560,091	746,788	933,485
22				456,141	684,211	912,281	1,140,352
24				547,162	820,743	1,094,324	1,367,905
26		governs	with	646,458	969,687	1,292,916	1,616,144
28	Velocity	pipe	sizes	754,028	1,131,043	1,508,057	1,885,071
30	these			869,874	1,304,810	1,739,747	2,174,684
32				993,993	1,490,990	1,987,987	2,484,984
34				1,126,388	1,689,582	2,252,776	2,815,970
36				1,267,057	1,900,586	2,534,114	3,167,643
42				1,738,713	2,608,069	3,477,426	4,346,782
48				2,284,840	3,427,261	4,569,681	5,712,101
54				2,905,440	4,358,160	5,810,880	7,263,599
60				3,600,511	5,400,767	7,201,022	9,001,278
72				5,214,070	7,821,105	10,428,140	13,035,174
84				7,125,516	10,688,274	14,251,032	17,813,790
96				9,334,850	14,002,275	18,669,700	23,337,125
Steam Condensate Flow lbs./hr. 3 psig Back Pressure							
1/2	167	236	333		Pressure	drop	
3/4	408	578	817	1,417	with these	pipe	
1	855	1,210	1,711				governs
1–1/4	1,969	2,784	3,938	2,527	3,791		sizes
1–1/2	3,113	4,403	6,227	3,481	5,222	11,635	
2	6,453	9,126	12,906	5,817	8,726		
2–1/2	10,730	15,175		8,350	12,524	16,699	20,874
3	19,928	28,183		13,013	19,519	26,025	32,531
4	42,814			22,649	33,974	45,299	56,623
5				35,842	53,764	71,685	89,606
6	80,076			51,352	77,029	102,705	128,381
8				89,959	134,939	179,918	224,898
10				147,087	220,631	294,174	367,718
12				213,620	320,429	427,239	534,049
14				261,488	392,232	522,976	653,721
16				348,135	522,203	696,270	870,338
18				447,160	670,740	894,321	1,117,901
20				558,564	837,845	1,117,127	1,396,409
22				682,345	1,023,517	1,364,690	1,705,862
24			with	818,504	1,227,757	1,637,009	2,046,261
26		governs	sizes	967,042	1,450,563	1,934,084	2,417,605
28	Velocity	pipe		1,127,958	1,691,937	2,255,916	2,819,895
30	these			1,301,252	1,951,878	2,602,504	3,253,130
32				1,486,924	2,230,386	2,973,848	3,717,310
34				1,684,974	2,527,461	3,369,949	4,212,436
36				1,895,403	2,843,104	3,790,805	4,738,507
42				2,600,957	3,901,435	5,201,913	6,502,392
48				3,417,914	5,126,871	6,835,828	8,544,785
54				4,346,274	6,519,411	8,692,549	10,865,686
60				5,386,038	8,079,057	10,772,076	13,465,095
72				7,799,775	11,699,663	15,599,551	19,499,438
84				10,659,126	15,988,688	21,318,251	26,647,814
96				13,964,089	20,946,133	27,928,178	34,910,222

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 3.

12 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.125	Pressure Drop psig/100 ft. 0.25	Pressure Drop psig/100 ft. 0.5	Velocity FPM (mph) 2,000 (23)	Velocity FPM (mph) 3,000 (34)	Velocity FPM (mph) 4,000 (45)	Velocity FPM (mph) 5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	87	123	174		Pressure	drop	
3/4	213	301	426	408	with these	pipe	
1	446	631	893	678			governs
1–1/4	1,028	1,453	2,055	1,210	1,814		sizes
1–1/2	1,625	2,298	3,250	1,666	2,499		
2	3,368	4,763	6,736	2,784	4,177	5,569	
2–1/2	5,601	7,921		3,996	5,995	7,993	9,991
3	10,402	14,710		6,228	9,342	12,457	15,571
4	22,347			10,841	16,261	21,682	27,102
5	41,797			17,156	25,733	34,311	42,889
6				24,579	36,869	49,159	61,448
8				43,058	64,587	86,116	107,645
10				70,402	105,603	140,804	176,005
12				102,247	153,370	204,494	255,617
14				125,159	187,738	250,318	312,897
16				166,632	249,947	333,263	416,579
18				214,029	321,043	428,058	535,072
20				267,351	401,027	534,702	668,378
22			with	326,598	489,897	653,196	816,494
24			sizes	391,769	587,654	783,538	979,423
26		governs		462,865	694,298	925,731	1,157,163
28	Velocity	pipe		539,886	809,829	1,079,772	1,349,715
30	these			622,832	934,247	1,245,663	1,557,079
32				711,702	1,067,553	1,423,404	1,779,254
34				806,497	1,209,745	1,612,993	2,016,241
36				907,216	1,360,824	1,814,432	2,268,040
42				1,244,923	1,867,384	2,489,845	3,112,307
48				1,635,951	2,453,927	3,271,903	4,089,878
54				2,080,302	3,120,453	4,160,604	5,200,755
60				2,577,975	3,866,962	5,155,950	6,444,937
72				3,733,287	5,599,930	7,466,573	9,333,217
84				5,101,887	7,652,831	10,203,774	12,754,718
96				6,683,776	10,025,663	13,367,551	16,709,439
Steam Condensate Flow lbs./hr. 1 psig Back Pressure							
1/2	100	141	199		Pressure	drop	
3/4	245	346	489	482	with these	pipe	
1	512	724	1,024	802			governs
1–1/4	1,179	1,667	2,357	1,430	2,146		sizes
1–1/2	1,864	2,636	3,728	1,970	2,956		
2	3,863	5,463	7,726	3,293	4,939	6,585	
2–1/2	6,424	9,085		4,726	7,089	9,452	11,815
3	11,930	16,872		7,365	11,048	14,730	18,413
4	25,631			12,820	19,229	25,639	32,049
5	47,939			20,287	30,430	40,574	50,717
6				29,066	43,598	58,131	72,664
8				50,917	76,376	101,834	127,293
10				83,252	124,878	166,504	208,130
12				120,909	181,364	241,819	302,274
14			with	148,003	222,005	296,006	370,008
16			sizes	197,046	295,569	394,091	492,614
18		governs		253,094	379,641	506,189	632,736
20	Velocity	pipe		316,149	474,223	632,298	790,372
22	these			386,210	579,314	772,419	965,524
24				463,276	694,915	926,553	1,158,191
26				547,349	821,024	1,094,699	1,368,373
28				638,428	957,642	1,276,856	1,596,070
30				736,513	1,104,770	1,473,026	1,841,283
32				841,604	1,262,406	1,683,208	2,104,011

(*Continued*)

12 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				953,701	1,430,552	1,907,403	2,384,253
36				1,072,805	1,609,207	2,145,609	2,682,011
42				1,472,151	2,208,226	2,944,301	3,680,376
48				1,934,551	2,901,827	3,869,102	4,836,378
54				2,460,007	3,690,010	4,920,013	6,150,016
60				3,048,516	4,572,775	6,097,033	7,621,291
72				4,414,700	6,622,050	8,829,400	11,036,750
84				6,033,102	9,049,654	12,066,205	15,082,756
96				7,903,723	11,855,585	15,807,447	19,759,308
Steam Condensate Flow lbs./hr. 3 psig Back Pressure							
1/2	134	189	268		Pressure	drop	
3/4	329	465	657	1,140	with these	pipe	
1	688	973	1,376				governs
1–1/4	1,584	2,240	3,168	2,033	3,049		sizes
1–1/2	2,504	3,542	5,009	2,801	4,201	9,359	
2	5,191	7,341	10,382	4,680	7,020		
2–1/2	8,632	12,207		6,717	10,075	13,434	16,792
3	16,031	22,671		10,468	15,702	20,936	26,170
4	34,442			18,220	27,330	36,440	45,550
5				28,833	43,250	57,666	72,083
6	64,417			41,310	61,965	82,620	103,275
8				72,367	108,551	144,734	180,918
10				118,323	177,485	236,647	295,809
12				171,845	257,768	343,690	429,613
14				210,353	315,529	420,705	525,882
16				280,055	420,083	560,111	700,139
18				359,716	539,573	719,431	899,289
20				449,333	674,000	898,667	1,123,333
22			with	548,909	823,363	1,097,817	1,372,272
24			sizes	658,441	987,662	1,316,883	1,646,103
26		governs		777,932	1,166,898	1,555,863	1,944,829
28	Velocity	pipe		907,380	1,361,069	1,814,759	2,268,449
30	these			1,046,785	1,570,177	2,093,570	2,616,962
32				1,196,148	1,794,222	2,392,296	2,990,369
34				1,355,468	2,033,202	2,710,936	3,388,670
36				1,524,746	2,287,119	3,049,492	3,811,865
42				2,092,325	3,138,488	4,184,650	5,230,813
48				2,749,522	4,124,283	5,499,044	6,873,804
54				3,496,336	5,244,504	6,992,672	8,740,841
60				4,332,768	6,499,153	8,665,537	10,931,921
72				6,274,486	9,411,729	12,548,972	15,686,215
84				8,574,674	12,862,012	17,149,349	21,436,686
96				11,233,334	16,850,001	22,466,667	28,083,334

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	73	103	146				
3/4	179	253	358	342	Pressure	drop	
1	375	530	750	570	with these	pipe	governs
1–1/4	863	1,221	1,726	1,016	1,524		sizes
1–1/2	1,365	1,930	2,730	1,400	2,099	4,677	
2	2,829	4,001	5,658	2,339	3,508		

(*Continued*)

15 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	4,704	6,652		3,357	5,035	6,713	8,391
3	8,736	12,355		5,231	7,847	10,462	13,078
4	18,769			9,105	13,658	18,210	22,763
5				14,409	21,613	28,818	36,022
6	35,105			20,644	30,966	41,288	51,610
8				36,164	54,246	72,328	90,411
10				59,130	88,695	118,260	147,825
12				85,877	128,815	171,753	214,692
14				105,120	157,680	210,240	262,801
16				139,953	209,929	279,906	349,882
18				179,762	269,643	359,524	449,405
20				224,547	336,820	449,094	561,367
22			with	274,308	411,462	548,616	685,770
24			sizes	329,045	493,568	658,090	822,613
26		governs		388,758	583,137	777,517	971,896
28	Velocity	pipe		453,448	680,172	906,895	1,133,619
30	these			523,113	784,670	1,046,226	1,307,783
32				597,755	896,632	1,195,510	1,494,387
34				677,372	1,016,059	1,354,745	1,693,431
36				761,966	1,142,949	1,523,933	1,904,916
42				1,045,604	1,568,406	2,091,209	2,614,011
48				1,374,027	2,061,041	2,748,055	3,435,068
54				1,747,235	2,620,853	3,494,471	4,368,088
60				2,165,228	3,247,842	4,330,456	5,413,071
72				3,135,569	4,703,353	6,271,138	7,838,922
84				4,285,049	6,427,574	8,570,099	10,712,624
96				5,613,670	8,420,505	11,227,340	14,034,175
Steam Condensate Flow lbs./hr. 1 psig Back Pressure							
1/2	82	116	164	398	Pressure	drop	
3/4	202	285	403	661	with these	pipe	governs
1	422	597	845				sizes
1–1/4	972	1,375	1,944	1,180	1,769		
1–1/2	1,537	2,174	3,074	1,625	2,438	5,431	
2	3,186	4,506	6,372	2,715	4,073		
2–1/2	5,298	7,492		3,897	5,846	7,795	9,744
3	9,839	13,915		6,074	9,111	12,148	15,185
4	21,139			10,572	15,859	21,145	26,431
5				16,731	25,096	33,462	41,827
6	39,536			23,971	35,956	47,942	59,927
8				41,992	62,988	83,984	104,980
10				68,659	102,988	137,318	171,647
12				99,716	149,573	199,431	249,289
14				122,060	183,090	244,120	305,150
16				162,506	243,759	325,012	406,265
18				208,730	313,095	417,460	521,825
20				260,732	391,098	521,464	651,830
22			with	318,512	477,768	637,024	796,280
24			sizes	382,070	573,105	764,140	955,175
26		governs		451,406	677,109	902,812	1,128,515
28	Velocity	pipe		526,520	789,780	1,053,040	1,316,299
30	these			607,412	911,118	1,214,823	1,518,529
32				694,082	1,041,122	1,388,163	1,735,204
34				786,530	1,179,794	1,573,059	1,966,324
36				884,755	1,327,133	1,769,511	2,211,889
42				1,214,101	1,821,152	2,428,202	3,035,253
48				1,595,449	2,393,173	3,190,898	3,988,622
54				2,028,798	3,043,198	4,057,597	5,071,996
60				2,514,150	3,771,225	5,028,300	6,285,375
72				3,640,859	5,461,289	7,281,718	9,102,148
84				4,975,576	7,463,364	9,951,152	12,438,940
96				6,518,301	9,777,451	13,036,601	16,295,751

(*Continued*)

15 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 3 psig Back Pressure							
1/2	105	149	211		Pressure	drop	
3/4	258	366	517	897	with these	pipe	
1	541	766	1,083				governs
1–1/4	1,246	1,762	2,492	1,599	2,399		sizes
1–1/2	1,970	2,786	3,941	2,203	3,305	7,363	
2	4,084	5,775	8,168	3,682	5,522		
2–1/2	6,791	9,604		5,284	7,926	10,568	13,210
3	12,612	17,836		8,235	12,353	16,470	20,588
4	27,096			14,334	21,501	28,668	35,835
5				22,683	34,025	45,367	56,709
6	50,677			32,499	48,749	64,999	81,248
8				56,932	85,398	113,864	142,330
10				93,087	139,630	186,173	232,716
12				135,193	202,789	270,386	337,982
14				165,487	248,231	330,975	413,718
16				220,323	330,485	440,647	550,808
18				282,993	424,490	565,986	707,483
20				353,497	530,245	706,993	883,741
22			with	431,834	647,751	863,667	1,079,584
24		governs	sizes	518,005	777,007	1,036,009	1,295,011
26		pipe		612,009	918,014	1,224,018	1,530,023
28	Velocity			713,848	1,070,771	1,427,695	1,784,619
30	these			823,520	1,235,279	1,647,039	2,058,799
32				941,025	1,411,538	1,882,051	2,352,563
34				1,066,365	1,599,547	2,132,730	2,665,912
36				1,199,538	1,799,307	2,399,076	2,998,845
42				1,646,060	2,469,090	3,292,120	4,115,150
48				2,163,085	3,244,628	4,326,171	5,407,713
54				2,750,614	4,125,921	5,501,228	6,876,535
60				3,408,646	5,112,970	6,817,293	8,521,616
72				4,936,221	7,404,332	9,872,443	12,340,554
84				6,745,810	10,118,715	13,491,620	16,864,526
96				8,837,413	13,256,119	17,674,826	22,093,532
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	138	195	276		Pressure	drop	
3/4	338	478	676	1,233	with these	pipe	
1	708	1,001	1,416				governs
1–1/4	1,630	2,305	3,260	2,200	4,545		sizes
1–1/2	2,577	3,645	5,154	3,030	7,595	10,126	
2	5,342	7,554	10,683	5,063			
2–1/2	8,883	12,562		7,267	10,901	14,534	28,314
3	16,497	23,330	17,765	11,326	16,988	22,651	49,282
4	35,442			19,713	29,569	39,426	
5				31,196	46,793	62,391	77,989
6	66,288			44,695	67,042	89,390	111,737
8	107,770			78,296	117,445	156,593	195,741
10				128,018	192,027	256,036	320,045
12				185,925	278,888	371,850	464,813
14				227,588	341,382	455,176	568,970
16		governs	with	303,002	454,502	606,003	757,504
18		pipe	sizes	389,189	583,783	778,377	972,972
20	Velocity			486,149	729,224	972,298	1,215,373
22	these			593,883	890,825	1,187,766	1,484,708
24				712,390	1,068,586	1,424,781	1,780,976
26				841,671	1,262,507	1,683,342	2,104,178
28				981,725	1,472,588	1,963,450	2,454,313
30				1,132,553	1,698,829	2,265,105	2,831,382
32				1,294,154	1,941,230	2,588,307	3,235,384

(*Continued*)

15 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				1,466,528	2,199,792	2,933,056	3,666,319
36				1,649,675	2,474,513	3,299,351	4,124,189
42				2,263,759	3,395,638	4,527,517	5,659,397
48				2,974,802	4,462,204	5,949,605	7,437,006
54				3,782,807	5,674,210	7,565,613	9,457,017
60				4,687,772	7,031,657	9,375,543	11,719,429
72				6,788,583	10,182,874	13,577,165	16,971,457
84				9,277,236	13,915,854	18,554,472	23,193,090
96				12,153,731	18,230,597	24,307,462	30,384,328

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	59	83	118				
3/4	144	204	288	276	Pressure	drop	
1	302	427	604	459	with these	pipe	governs
1–1/4	695	983	1,390	818	1,227		sizes
1–1/2	1,099	1,555	2,199	1,127	1,691	3,767	
2	2,279	3,222	4,557	1,884	2,826		
2–1/2	3,789			2,704	4,056	5,407	6,759
3	7,037	5,359		4,214	6,320	8,427	10,534
4	15,119	9,952		7,334	11,001	14,668	18,336
5				11,606	17,410	23,213	29,016
6	28,277			16,629	24,943	33,257	41,572
8				29,130	43,695	58,260	72,825
10				47,629	71,444	95,258	119,073
12				69,173	103,760	138,347	172,934
14				84,674	127,011	169,348	211,685
16				112,732	169,098	225,463	281,829
18				144,798	217,196	289,595	361,994
20				180,872	271,308	361,743	452,179
22				220,954	331,431	441,908	552,385
24			with	265,045	397,567	530,089	662,612
26		governs	sizes	313,144	469,715	626,287	782,859
28		pipe		365,251	547,876	730,501	913,127
30	Velocity			421,366	632,049	842,732	1,053,415
32	these			481,490	722,234	962,979	1,203,724
34				545,621	818,432	1,091,243	1,364,053
36				613,761	920,642	1,227,523	1,534,404
42				842,231	1,263,346	1,684,462	2,105,577
48				1,106,775	1,660,162	2,213,549	2,766,937
54				1,407,392	2,111,089	2,814,785	3,518,481
60				1,744,084	2,616,127	3,488,169	4,360,211
72				2,525,691	3,788,536	5,051,382	6,314,227
84				3,451,594	5,177,391	6,903,187	8,628,984
96				4,521,793	6,782,690	9,043,586	11,304,483

(*Continued*)

20 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2 3/4 1	98 241 505	139 341 714	197 482 1,010	880	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	1,163 1,839 3,811	1,644 2,600 5,389	2,325 3,677 7,622	1,569 2,162 3,612	3,242 5,418	7,224	
2–1/2 3 4	6,337 11,769 25,284	8,962 16,644	12,674	5,184 8,080 14,063	7,776 12,119 21,095	10,369 16,159 28,126	20,199 35,158
5 6 8	47,290 76,883			22,255 31,885 55,856	33,382 47,828 83,785	44,510 63,770 111,713	55,637 79,713 139,641
10 12 14				91,328 132,638 162,360	136,991 198,957 243,540	182,655 265,276 324,720	228,319 331,595 405,900
16 18 20				216,160 277,646 346,817	324,240 416,468 520,225	432,320 555,291 693,634	540,400 694,114 867,042
22 24 26		governs pipe	with sizes	423,674 508,216 600,445	635,510 762,324 900,667	847,347 1,016,432 1,200,889	1,059,184 1,270,541 1,501,111
28 30 32	Velocity these			700,358 807,958 923,243	1,050,538 1,211,937 1,384,865	1,400,717 1,615,916 1,846,487	1,750,896 2,019,895 2,308,109
34 36 42				1,046,215 1,176,871 1,614,956	1,569,322 1,765,307 2,422,433	2,092,429 2,353,742 3,229,911	2,615,536 2,942,178 4,037,389
48 54 60				2,122,211 2,698,638 3,344,236	3,183,317 4,047,957 5,016,354	4,244,422 5,397,276 6,688,472	5,305,528 6,746,595 8,360,589
72 84 96				4,842,945 6,618,340 8,670,419	7,264,418 9,927,509 13,005,628	9,685,891 13,236,679 17,340,838	12,107,363 16,545,849 21,676,047
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2 3/4 1	123 301 631	174 426 892	246 602 1,262	1,150	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	1,452 2,296 4,759	2,053 3,247 6,730	2,904 4,592 9,518	2,050 2,824 4,719	4,236 7,079	9,438	
2–1/2 3 4	7,913 14,697 31,575	11,191 20,785 44,654	15,827	6,773 10,556 18,374	10,160 15,834 27,560	13,547 21,112 36,747	26,390 45,934
5 6 8	59,055 96,011			29,076 41,658 72,976	43,614 62,487 109,464	58,152 83,316 145,953	72,690 104,145 182,441
10 12 14				119,320 173,292 212,124	178,979 259,938 318,185	238,639 346,584 424,247	298,299 433,230 530,309
16 18 20		governs pipe	with sizes	282,413 362,744 453,116	423,620 544,116 679,674	564,826 725,488 906,232	706,033 906,860 1,132,790
22 24 26	Velocity these			553,530 663,985 784,481	830,294 995,977 1,176,721	1,107,059 1,327,969 1,568,962	1,383,824 1,659,961 1,961,202
28 30 32				915,018 1,055,597 1,206,218	1,372,528 1,583,396 1,809,327	1,830,037 2,111,195 2,412,435	2,287,546 2,638,993 3,015,544

(*Continued*)

20 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				1,366,879	2,050,319	2,733,759	3,417,198
36				1,537,582	2,306,374	3,075,165	3,843,956
42				2,109,940	3,164,909	4,219,879	5,274,849
48				2,772,669	4,159,003	5,545,338	6,931,672
54				3,525,771	5,288,656	7,051,541	8,814,426
60				4,369,244	6,553,866	8,738,489	10,923,111
72				6,327,308	9,490,963	12,654,617	15,818,271
84				8,646,861	12,970,292	17,293,722	21,617,153
96				11,327,903	16,991,854	22,655,806	28,319,757

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 3.**

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 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	50	71	100				
3/4	123	174	246	235	Pressure	drop	governs
1	257	364	515	391	with these	pipe	sizes
1–1/4	593	838	1,185	697	1,046		
1–1/2	937	1,325	1,874	961	1,441		
2	1,942	2,746	3,884	1,605	2,408	3,211	
2–1/2	3,229	4,567		2,304	3,456	4,609	5,761
3	5,997	8,482		3,591	5,387	7,182	8,978
4	12,885			6,251	9,376	12,501	15,626
5	24,099			9,892	14,837	19,783	24,729
6				14,172	21,258	28,344	35,430
8				24,826	37,239	49,653	62,066
10				40,592	60,888	81,184	101,480
12				58,953	88,430	117,906	147,383
14				72,164	108,245	144,327	180,409
16				96,076	144,114	192,152	240,190
18				123,404	185,106	246,808	308,510
20				154,148	231,223	308,297	385,371
22				188,309	282,463	376,617	470,772
24			with	225,885	338,827	451,770	564,712
26		governs	sizes	266,877	400,316	533,755	667,193
28	Velocity	pipe		311,286	466,929	622,571	778,214
30	these			359,110	538,665	718,220	897,775
32				410,351	615,526	820,701	1,025,876
34				465,007	697,511	930,014	1,162,518
36				523,080	784,619	1,046,159	1,307,699
42				717,793	1,076,690	1,435,586	1,794,483
48				943,251	1,414,877	1,886,502	2,358,128
54				1,199,453	1,799,180	2,398,907	2,998,634
60				1,486,400	2,229,600	2,972,800	3,716,000
72				2,152,526	3,228,789	4,305,051	5,381,314
84				2,941,629	4,412,443	5,883,257	7,354,071
96				3,853,708	5,780,563	7,707,417	9,634,271
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	78	111	157				
3/4	192	272	384		Pressure	drop	governs
1	402	569	805	701	with these	pipe	sizes
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	

(*Continued*)

25 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	5,047	7,138	10,095	4,129	6,194	8,259	16,089
3	9,374	13,257		6,436	9,653	12,871	28,004
4	20,140			11,202	16,803	22,403	
5	37,668			17,727	26,590	35,453	44,316
6				25,397	38,096	50,795	63,493
8				44,491	66,737	88,982	111,228
10				72,745	109,117	145,490	181,862
12				105,650	158,475	211,300	264,124
14				129,324	193,986	258,648	323,310
16				172,177	258,266	344,354	430,443
18				221,152	331,728	442,304	552,880
20				276,249	414,373	552,497	690,621
22				337,467	506,201	674,934	843,668
24		governs pipe	with sizes	404,807	607,211	809,615	1,012,019
26				478,270	717,405	956,539	1,195,674
28	Velocity these			557,854	836,781	1,115,708	1,394,634
30				643,560	965,340	1,287,119	1,608,899
32				735,387	1,103,081	1,470,775	1,838,469
34				833,337	1,250,006	1,666,674	2,083,343
36				937,409	1,406,113	1,874,817	2,343,522
42				1,286,354	1,929,531	2,572,708	3,215,885
48				1,690,396	2,535,595	3,380,793	4,225,991
54				2,149,535	3,224,303	4,299,071	5,373,838
60				2,663,771	3,995,656	5,327,542	6,659,427
72				3,857,532	5,786,298	7,715,064	9,643,830
84				5,271,680	7,907,520	10,543,360	13,179,200
96				6,906,214	10,359,322	13,812,429	17,265,536
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	94	133	188		Pressure with these	drop pipe	
3/4	231	326	461	880			governs sizes
1	483	683	966				
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	5,420		
2	3,644	5,153	7,288	3,613			
2–1/2	6,059	8,569	12,119	5,186	7,780	10,373	20,207
3	11,254	15,915		8,083	12,124	16,166	35,172
4	24,178	34,192		14,069	21,103	28,138	
5	45,220			22,264	33,396	44,528	55,660
6	73,517			31,898	47,847	63,796	79,745
8				55,879	83,819	111,758	139,698
10				91,365	137,047	182,729	228,412
12				132,692	199,038	265,384	331,730
14				162,426	243,639	324,852	406,065
16				216,248	324,372	432,495	540,619
18				277,758	416,637	555,516	694,396
20				346,957	520,436	693,915	867,394
22				423,846	635,768	847,691	1,059,614
24		governs pipe	with sizes	508,422	762,634	1,016,845	1,271,056
26				600,688	901,032	1,201,376	1,501,720
28	Velocity these			700,643	1,050,964	1,401,285	1,751,607
30				808,286	1,212,429	1,616,572	2,020,715
32				923,618	1,385,427	1,847,236	2,309,045
34				1,046,639	1,569,959	2,093,278	2,616,598
36				1,177,349	1,766,023	2,354,698	2,943,372
42				1,615,611	2,423,416	3,231,222	4,039,027
48				2,123,072	3,184,608	4,246,144	5,307,681
54				2,699,733	4,049,599	5,399,466	6,749,332
60				3,345,593	5,018,389	6,691,186	8,363,982
72				4,844,910	7,267,366	9,689,821	12,112,276
84				6,621,025	9,931,538	13,242,050	16,552,563
96				8,673,937	13,010,905	17,347,874	21,684,842

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 3.

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 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	44	63	88	207	Pressure	drop	
3/4	108	153	217	345	with these	pipe	
1	227	321	454				governs
1–1/4	523	739	1,046	615	923		sizes
1–1/2	827	1,169	1,653	848	1,272	2,833	
2	1,714	2,423	3,427	1,417	2,125		
2–1/2	2,849	4,030		2,033	3,050	4,066	5,083
3	5,292	7,484		3,169	4,753	6,337	7,922
4	11,369			5,515	8,273	11,030	13,788
5				8,728	13,092	17,456	21,820
6	21,264			12,505	18,757	25,009	31,261
8				21,906	32,858	43,811	54,764
10				35,817	53,725	71,633	89,541
12				52,018	78,026	104,035	130,044
14				63,674	95,511	127,348	159,184
16				84,773	127,159	169,546	211,932
18				108,886	163,329	217,772	272,215
20				136,013	204,020	272,026	340,033
22			with	166,155	249,232	332,309	415,387
24			sizes	199,310	298,965	398,621	498,276
26		governs		235,480	353,220	470,960	588,700
28	Velocity	pipe		274,664	411,996	549,328	686,660
30	these			316,862	475,293	633,724	792,155
32				362,074	543,111	724,148	905,185
34				410,300	615,450	820,601	1,025,751
36				461,541	692,311	923,082	1,153,852
42				633,347	950,020	1,266,694	1,583,367
48				832,280	1,248,421	1,664,561	2,080,701
54				1,058,341	1,587,512	2,116,682	2,645,853
60				1,311,529	1,967,294	2,623,059	3,278,823
72				1,899,287	2,848,931	3,798,575	4,748,218
84				2,595,555	3,893,332	5,191,109	6,488,886
96				3,400,331	5,100,496	6,800,662	8,500,827
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	66	94	132		Pressure	drop	
3/4	162	230	325	592	with these	pipe	
1	340	481	680				governs
1–1/4	782	1,107	1,565	1,056			sizes
1–1/2	1,237	1,750	2,475	1,455	2,182	4,861	
2	2,564	3,627	5,129	2,431	3,646		
2–1/2	4,264	6,031		3,489	5,233	6,978	13,593
3	7,920	11,200	8,529	5,437	8,156	10,874	23,660
4	17,015			9,464	14,196	18,928	
5	31,824			14,977	22,465	29,953	37,441
6	51,739			21,457	32,186	42,915	53,643
8				37,589	56,383	75,178	93,972
10				61,459	92,189	122,919	153,649
12				89,260	133,889	178,519	223,149
14				109,261	163,892	218,523	273,153
16		governs	with	145,466	218,199	290,932	363,665
18		pipe	sizes	186,843	280,265	373,686	467,108
20	Velocity			233,392	350,089	466,785	583,481
22	these			285,114	427,671	570,227	712,784
24				342,007	513,011	684,014	855,018
26				404,073	606,109	808,145	1,010,182
28				471,310	706,966	942,621	1,178,276
30				543,720	815,580	1,087,441	1,359,301
32				621,302	931,953	1,242,604	1,553,256

(*Continued*)

30 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				704,056	1,056,084	1,408,113	1,760,141
36				791,983	1,187,974	1,583,965	1,979,956
42				1,086,794	1,630,191	2,173,588	2,716,985
48				1,428,155	2,142,232	2,856,309	3,570,387
54				1,816,064	2,724,097	3,632,129	4,540,161
60				2,250,523	3,375,785	4,501,047	5,626,309
72				3,259,089	4,888,633	6,518,178	8,147,722
84				4,453,851	6,680,777	8,907,702	11,134,628
96				5,834,810	8,752,215	11,669,620	14,587,025
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	78	110	155		Pressure	drop	
3/4	190	269	381	727	with these	pipe	
1	399	564	797				governs
1–1/4	918	1,298	1,836	1,296	2,678		sizes
1–1/2	1,451	2,052	2,903	1,785	4,474	5,966	
2	3,008	4,254	6,016	2,983			
2–1/2	5,002	7,074		4,281	6,422	8,562	16,680
3	9,290	13,137	10,004	6,672	10,008	13,344	29,034
4	19,958	28,225		11,613	17,420	23,227	
5	37,328			18,378	27,567	36,756	45,945
6	60,686			26,331	39,496	52,662	65,827
8				46,127	69,190	92,253	115,316
10				75,419	113,128	150,838	188,547
12				109,534	164,300	219,067	273,834
14				134,078	201,117	268,156	335,195
16				178,506	267,760	357,013	446,266
18				229,282	343,922	458,563	573,204
20				286,404	429,605	572,807	716,009
22				349,873	524,809	699,745	874,681
24				419,688	629,533	839,377	1,049,221
26		governs	with	495,851	743,777	991,702	1,239,628
28	Velocity	pipe	sizes	578,361	867,541	1,156,721	1,445,902
30	these			667,217	1,000,826	1,334,434	1,668,043
32				762,421	1,143,631	1,524,841	1,906,052
34				863,971	1,295,956	1,727,942	2,159,927
36				971,868	1,457,802	1,943,736	2,429,670
42				1,333,641	2,000,462	2,667,282	3,334,103
48				1,752,536	2,628,804	3,505,072	4,381,340
54				2,228,553	3,342,830	4,457,106	5,571,383
60				2,761,692	4,142,538	5,523,384	6,904,230
72				3,999,336	5,999,005	7,998,673	9,998,341
84				5,465,469	8,198,203	10,930,938	13,663,672
96				7,160,089	10,740,134	14,320,179	17,900,224
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	99	139	197		Pressure		
3/4	242	342	484	981	with these		
1	506	716	1,013			drop	governs
1–1/4	1,166	1,649	2,331	1,749	3,614	pipe	sizes
1–1/2	1,843	2,607	3,687	2,409	6,039		
2	3,821	5,403	7,641	4,026			
2–1/2	6,353	8,985		5,778	8,668	11,557	22,514
3	11,800	16,687	12,707	9,005	13,508	18,011	39,187
4	25,350	35,851		15,675	23,512	31,350	
5	47,413			24,805	37,208	49,610	62,013
6	77,083			35,539	53,309	71,078	88,848
8				62,257	93,386	124,515	155,644
10				101,794	152,690	203,587	254,484
12				147,838	221,758	295,677	369,596
14				180,966	271,450	361,933	452,416

(*Continued*)

30 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				240,932	361,398	481,863	602,329
18				309,463	464,195	618,927	773,658
20				386,562	579,842	773,123	966,404
22				472,226	708,339	944,452	1,180,565
24				566,457	849,686	1,132,914	1,416,143
26				669,255	1,003,882	1,338,510	1,673,137
28				780,619	1,170,928	1,561,237	1,951,547
30				900,549	1,350,824	1,801,098	2,251,373
32	Velocity	governs	with	1,029,046	1,543,569	2,058,092	2,572,615
34	these	pipe	sizes	1,166,109	1,749,164	2,332,219	2,915,274
36				1,311,739	1,967,609	2,623,479	3,279,348
42				1,800,028	2,700,041	3,600,055	4,500,069
48				2,365,414	3,548,121	4,730,828	5,913,535
54				3,007,899	4,511,848	6,015,797	7,519,746
60				3,727,481	5,591,222	7,454,963	9,318,703
72				5,397,941	8,096,912	10,795,882	13,494,853
84				7,376,794	11,065,190	14,753,587	18,441,984
96				9,664,039	14,496,058	19,328,077	24,160,097

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 3.**

40 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 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	37	52	73	172	Pressure	drop	
3/4	90	127	180	286	with these	pipe	
1	188	266	376				governs
1–1/4	433	613	867	510	765		sizes
1–1/2	685	969	1,370	703	1,054	2,348	
2	1,420	2,008	2,840	1,174	1,761		
2–1/2	2,361	3,339		1,685	2,527	3,370	4,212
3	4,385	6,202		2,626	3,939	5,252	6,565
4	9,422			4,571	6,856	9,141	11,426
5				7,233	10,849	14,466	18,082
6	17,622			10,363	15,544	20,726	25,907
8				18,154	27,230	36,307	45,384
10				29,682	44,523	59,364	74,205
12				43,108	64,662	86,216	107,770
14				52,768	79,152	105,536	131,920
16				70,253	105,380	140,506	175,633
18				90,236	135,354	180,472	225,590
20			with	112,717	169,076	225,434	281,793
22		governs	sizes	137,696	206,544	275,392	344,240
24		pipe		165,173	247,759	330,346	412,932
26	Velocity			195,147	292,721	390,295	487,869
28	these			227,620	341,430	455,240	569,050
30				262,590	393,886	525,181	656,476
32				300,059	450,088	600,117	750,147
34				340,025	510,037	680,050	850,062
36				382,489	573,733	764,978	956,222
42				524,869	787,303	1,049,737	1,312,171
48				689,729	1,034,594	1,379,458	1,724,323
54				877,071	1,315,606	1,754,141	2,192,677
60				1,086,893	1,630,340	2,173,786	2,717,233

(*Continued*)

40 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
72				1,573,981	2,360,972	3,147,962	3,934,953
84				2,150,993	3,226,490	4,301,986	5,377,483
96				2,817,929	4,226,894	5,635,858	7,044,823
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	52	74	104		Pressure	drop	
3/4	128	180	255	465	with these	pipe	
1	267	378	534				governs
1–1/4	615	870	1,230	830	1,715		sizes
1–1/2	972	1,375	1,945	1,143	2,865	3,820	
2	2,015	2,850	4,031	1,910			
2–1/2	3,351	4,739		2,742	4,112	5,483	10,682
3	6,224	8,802	6,702	4,273	6,409	8,545	18,593
4	13,371			7,437	11,156	14,874	
5	25,008			11,769	17,654	23,538	29,423
6	40,658			16,862	25,293	33,724	42,155
8				29,539	44,308	59,077	73,846
10				48,297	72,445	96,594	120,742
12				70,143	105,215	140,286	175,358
14				85,861	128,791	171,722	214,652
16				114,312	171,468	228,624	285,780
18				146,827	220,241	293,655	367,068
20				183,407	275,111	366,814	458,518
22				224,051	336,077	448,103	560,129
24				268,760	403,140	537,520	671,900
26		governs	with	317,533	476,300	635,067	793,833
28	Velocity	pipe	sizes	370,371	555,556	740,742	925,927
30	these			427,273	640,909	854,546	1,068,182
32				488,239	732,359	976,478	1,220,598
34				553,270	829,905	1,106,540	1,383,175
36				622,365	933,548	1,244,730	1,555,913
42				854,037	1,281,056	1,708,075	2,135,094
48				1,122,290	1,683,434	2,244,579	2,805,724
54				1,427,121	2,140,682	2,854,243	3,567,804
60				1,768,533	2,652,800	3,537,066	4,421,333
72				2,561,096	3,841,644	5,122,193	6,402,741
84				3,499,979	5,249,968	6,999,957	8,749,946
96				4,585,180	6,877,770	9,170,361	11,462,951
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	59	84	119		Pressure	drop	
3/4	146	206	291	556	with these	pipe	
1	305	432	610				governs
1–1/4	702	993	1,405	992	2,049		sizes
1–1/2	1,111	1,571	2,221	1,366	3,424	4,566	
2	2,302	3,256	4,604	2,283			
2–1/2	3,828	5,414		3,277	4,915	6,553	12,766
3	7,110	10,055	7,656	5,106	7,660	10,213	22,221
4	15,275	21,602		8,888	13,332	17,777	
5	28,568			14,066	21,098	28,131	35,164
6	46,446			20,152	30,228	40,304	50,381
8				35,303	52,954	70,605	88,257
10				57,721	86,582	115,443	144,303
12				83,831	125,746	167,661	209,577
14		governs	with	102,616	153,924	205,232	256,539
16		pipe	sizes	136,619	204,928	273,237	341,547
18	Velocity			175,479	263,219	350,958	438,698
20	these			219,197	328,795	438,394	547,992
22				267,772	401,659	535,545	669,431
24				321,206	481,808	642,411	803,014
26				379,496	569,244	758,992	948,740

(*Continued*)

40 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				442,644	663,966	885,289	1,106,611
30				510,650	765,975	1,021,300	1,276,625
32				583,513	875,270	1,167,026	1,458,783
34				661,234	991,851	1,322,468	1,653,085
36				743,812	1,115,719	1,487,625	1,859,531
42				1,020,693	1,531,039	2,041,386	2,551,732
48				1,341,291	2,011,937	2,682,582	3,353,228
54				1,705,607	2,558,411	3,411,215	4,264,018
60				2,113,642	3,170,462	4,227,283	5,284,104
72				3,060,864	4,591,296	6,121,728	7,652,160
84				4,182,958	6,274,437	8,365,916	10,457,395
96				5,479,924	8,219,886	10,959,848	13,699,810
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	72	102	144		Pressure		
3/4	177	250	353	717	with these		
1	370	523	740			drop	governs
1–1/4	852	1,205	1,704	1,278	2,641	pipe	sizes
1–1/2	1,347	1,905	2,694	1,761	4,414		
2	2,792	3,949	5,585	2,942			
2–1/2	4,643	6,567		4,223	6,335	8,446	16,454
3	8,624	12,196	9,287	6,582	9,872	13,163	28,640
4	18,527	26,202		11,456	17,184	22,912	
5	34,652			18,129	27,193	36,258	45,322
6	56,336			25,974	38,961	51,948	64,934
8				45,501	68,251	91,002	113,752
10				74,396	111,594	148,792	185,989
12				108,048	162,071	216,095	270,119
14				132,259	198,389	264,518	330,648
16				176,085	264,127	352,169	440,212
18				226,171	339,256	452,342	565,427
20				282,518	423,777	565,036	706,295
22				345,126	517,689	690,252	862,815
24				413,995	620,992	827,989	1,034,987
26		governs	with	489,124	733,686	978,248	1,222,810
28	Velocity	pipe	sizes	570,514	855,771	1,141,029	1,426,286
30	these			658,165	987,248	1,316,331	1,645,413
32				752,077	1,128,116	1,504,154	1,880,193
34				852,250	1,278,375	1,704,500	2,130,624
36				958,683	1,438,025	1,917,366	2,396,708
42				1,315,548	1,973,322	2,631,096	3,288,870
48				1,728,760	2,593,140	3,457,520	4,321,900
54				2,198,319	3,297,479	4,396,638	5,495,798
60				2,724,225	4,086,338	5,448,451	6,810,564
72				3,945,079	5,917,619	7,890,158	9,862,698
84				5,391,321	8,086,982	10,782,642	13,478,303
96				7,062,952	10,594,427	14,125,903	17,657,379
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	82	116	164		Pressure		
3/4	201	284	402		with these		
1	421	595	842			drop	governs
1–1/4	969	1,371	1,938	1,508		pipe	sizes
1–1/2	1,533	2,167	3,065	2,077	5,207		
2	3,177	4,492	6,353	3,471			
2–1/2	5,282	7,470		4,982	7,474	9,965	19,412
3	9,810	13,873	10,564	7,765	11,647	15,530	33,788
4	21,076	29,806		13,515	20,273	27,031	
5	39,419			21,388	32,082	42,776	53,470
6	64,086			30,643	45,965	61,286	76,608
8				53,680	80,521	107,361	134,201

(*Continued*)

40 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
10				87,770	131,655	175,540	219,424
12				127,471	191,207	254,942	318,678
14				156,035	234,053	312,070	390,088
16				207,739	311,609	415,478	519,348
18				266,829	400,244	533,659	667,074
20				333,306	499,959	666,612	833,265
22				407,169	610,753	814,338	1,017,922
24				488,418	732,627	976,836	1,221,045
26				577,053	865,580	1,154,106	1,442,633
28				673,075	1,009,612	1,346,150	1,682,687
30	Velocity these	governs pipe	with sizes	776,483	1,164,724	1,552,966	1,941,207
32				887,277	1,330,916	1,774,554	2,218,193
34				1,005,458	1,508,186	2,010,915	2,513,644
36				1,131,024	1,696,537	2,262,049	2,827,561
42				1,552,042	2,328,064	3,104,085	3,880,106
48				2,039,537	3,059,305	4,079,074	5,098,842
54				2,593,508	3,890,262	5,187,016	6,483,770
60				3,213,956	4,820,934	6,427,911	8,034,889
72				4,654,281	6,981,421	9,308,561	11,635,701
84				6,360,512	9,540,767	12,721,023	15,901,279
96				8,332,649	12,498,973	16,665,297	20,831,622

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 3.**

50 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 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	32	45	64		Pressure with these	drop pipe	governs sizes
3/4	78	111	156	150			
1	164	232	328	249			
1–1/4	377	533	754	444	666		
1–1/2	596	843	1,193	611	917		
2	1,236	1,748	2,472	1,022	1,533	2,044	
2–1/2	2,055	2,907		1,467	2,200	2,933	3,666
3	3,817	5,398		2,286	3,428	4,571	5,714
4	8,201			3,978	5,967	7,957	9,946
5	15,338			6,296	9,443	12,591	15,739
6				9,020	13,530	18,040	22,550
8				15,801	23,702	31,602	39,503
10				25,836	38,753	51,671	64,589
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			with sizes	78,543	117,814	157,085	196,357
20		governs pipe		98,110	147,166	196,221	245,276
22				119,852	179,779	239,705	299,631
24	Velocity these			143,769	215,653	287,537	359,421
26				169,859	254,788	339,718	424,647
28				198,123	297,185	396,247	495,308
30				228,562	342,843	457,124	571,405
32				261,175	391,762	522,350	652,937
34				295,962	443,943	591,924	739,905
36				332,923	499,385	665,847	832,308
42				456,852	685,279	913,705	1,142,131

(*Continued*)

50 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
48				600,349	900,524	1,200,698	1,500,873
54				763,414	1,145,120	1,526,827	1,908,534
60				946,046	1,419,069	1,892,092	2,365,115
72				1,370,013	2,055,020	2,740,027	3,425,034
84				1,872,252	2,808,378	3,744,504	4,680,630
96				2,452,762	3,679,143	4,905,523	6,131,904
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	44	62	88		Pressure with these	drop pipe	governs sizes
3/4	108	152	215				
1	225	318	450	392			
1–1/4	518	733	1,037	700			
1–1/2	820	1,159	1,639	964	1,446		
2	1,699	2,403	3,398	1,610	2,416	3,221	
2–1/2	2,825	3,995	5,650	2,311	3,467	4,623	
3	5,247	7,420		3,602	5,403	7,204	9,005
4	11,273			6,270	9,405	12,540	15,675
5	21,083			9,922	14,883	19,844	24,805
6	34,277			14,215	21,323	28,431	35,539
8				24,903	37,354	49,805	62,257
10				40,717	61,075	81,434	101,792
12				59,135	88,702	118,269	147,836
14				72,386	108,578	144,771	180,964
16				96,371	144,557	192,743	240,928
18				123,784	185,675	247,567	309,459
20				154,622	231,934	309,245	386,556
22				188,888	283,332	377,776	472,220
24				226,580	339,870	453,159	566,449
26		governs pipe	with sizes	267,698	401,547	535,396	669,245
28	Velocity these			312,243	468,365	624,486	780,608
30				360,215	540,322	720,429	900,537
32				411,613	617,419	823,225	1,029,032
34				466,437	699,656	932,875	1,166,093
36				524,688	787,033	1,049,377	1,311,721
42				720,001	1,080,002	1,440,002	1,800,003
48				946,152	1,419,229	1,892,305	2,365,381
54				1,203,143	1,804,714	2,406,285	3,007,857
60				1,490,972	2,236,458	2,981,944	3,727,429
72				2,159,146	3,238,720	4,318,293	5,397,866
84				2,950,676	4,426,015	5,901,353	7,376,691
96				3,865,562	5,798,343	7,731,123	9,663,904
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	49	70	99		Pressure with these	drop pipe	governs sizes
3/4	121	171	242				
1	253	358	507	462			
1–1/4	583	825	1,167	824			
1–1/2	923	1,305	1,845	1,135	1,702		
2	1,912	2,704	3,824	1,896	2,844	3,792	
2–1/2	3,180	4,497	6,359	2,722	4,082	5,443	
3	5,905	8,351		4,241	6,362	8,483	10,603
4	12,687	17,942		7,382	11,074	14,765	18,456
5	23,728			11,683	17,524	23,365	29,207
6	38,577			16,738	25,107	33,476	41,845
8				29,322	43,983	58,644	73,305
10		governs pipe	with sizes	47,942	71,914	95,885	119,856
12				69,628	104,443	139,257	174,071
14	Velocity these			85,231	127,847	170,462	213,078
16				113,473	170,210	226,947	283,683
18				145,750	218,625	291,500	364,375
20				182,062	273,092	364,123	455,154

(*Continued*)

50 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
22				222,408	333,612	444,815	556,019
24				266,788	400,183	533,577	666,971
26				315,204	472,806	630,407	788,009
28				367,654	551,480	735,307	919,134
30				424,138	636,207	848,276	1,060,345
32				484,657	726,986	969,314	1,211,643
34				549,211	823,816	1,098,422	1,373,027
36				617,799	926,699	1,235,598	1,544,498
42				847,772	1,271,658	1,695,544	2,119,430
48				1,114,056	1,671,084	2,228,112	2,785,140
54				1,416,651	2,124,977	2,833,303	3,541,629
60				1,755,558	2,633,338	3,511,117	4,388,896
72				2,542,307	3,813,460	5,084,614	6,355,767
84				3,474,301	5,211,452	6,948,602	8,685,753
96				4,551,541	6,827,312	9,103,082	11,378,853
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	58	83	117		Pressure with these		
3/4	143	203	286	581		drop pipe	governs sizes
1	300	424	600				
1–1/4	690	976	1,381	1,036			
1–1/2	1,092	1,544	2,184	1,427	2,140		
2	2,263	3,200	4,526	2,384	3,577		
2–1/2	3,763	5,322	7,526	3,422	5,134	6,845	
3	6,989	9,883		5,334	8,001	10,668	13,334
4	15,015	21,234		9,284	13,926	18,568	23,210
5	28,082			14,692	22,038	29,383	36,729
6	45,655			21,049	31,574	42,098	52,623
8				36,874	55,311	73,748	92,185
10				60,291	90,436	120,581	150,726
12				87,562	131,343	175,124	218,905
14				107,183	160,775	214,366	267,958
16				142,699	214,049	285,399	356,749
18				183,290	274,934	366,579	458,224
20				228,953	343,430	457,907	572,383
22				279,691	419,536	559,382	699,227
24				335,502	503,254	671,005	838,756
26		governs pipe	with sizes	396,387	594,581	792,775	990,969
28	Velocity these			462,346	693,520	924,693	1,155,866
30				533,379	800,068	1,066,758	1,333,447
32				609,485	914,228	1,218,971	1,523,713
34				690,666	1,035,998	1,381,331	1,726,664
36				776,919	1,165,379	1,553,839	1,942,299
42				1,066,124	1,599,186	2,132,247	2,665,309
48				1,400,992	2,101,488	2,801,984	3,502,480
54				1,781,524	2,672,286	3,563,048	4,453,810
60				2,207,720	3,311,579	4,415,439	5,519,299
72				3,197,103	4,795,654	6,394,205	7,992,757
84				4,369,141	6,553,712	8,738,282	10,922,853
96				5,723,835	8,585,752	11,447,670	14,309,587
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	65	92	130		Pressure with these		
3/4	160	226	320			drop pipe	governs sizes
1	335	474	670				
1–1/4	771	1,090	1,542	1,199			
1–1/2	1,219	1,724	2,438	1,652	4,141		
2	2,526	3,573	5,052	2,761			
2–1/2	4,201	5,941	8,402	3,962	5,944	7,925	
3	7,802	11,033		6,175	9,263	12,351	15,438
4	16,762	23,704		10,749	16,123	21,497	26,871

(*Continued*)

50 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5	31,349			17,010	25,514	34,019	42,524
6	50,967			24,370	36,555	48,740	60,925
8				42,691	64,037	85,383	106,729
10				69,802	104,704	139,605	174,506
12				101,376	152,065	202,753	253,441
14				124,093	186,140	248,186	310,233
16				165,213	247,819	330,426	413,032
18				212,207	318,310	424,413	530,517
20				265,075	397,612	530,150	662,687
22				323,817	485,726	647,634	809,543
24				388,434	582,651	776,868	971,084
26		governs pipe	with sizes	458,925	688,387	917,849	1,147,311
28	Velocity these			535,290	802,934	1,070,579	1,338,224
30				617,529	926,293	1,235,058	1,543,822
32				705,642	1,058,464	1,411,285	1,764,106
34				799,630	1,199,445	1,599,260	1,999,075
36				899,492	1,349,238	1,798,984	2,248,730
42				1,234,324	1,851,485	2,468,647	3,085,809
48				1,622,023	2,433,035	3,244,046	4,055,058
54				2,062,591	3,093,886	4,125,181	5,156,477
60				2,556,026	3,834,040	5,112,053	6,390,066
72				3,701,502	5,552,253	7,403,004	9,253,755
84				5,058,450	7,587,675	10,116,901	12,646,126
96				6,626,871	9,940,306	13,253,742	16,567,177
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	77	108	153		Pressure with these		
3/4	188	266	376				governs sizes
1	394	557	788			drop pipe	
1–1/4	907	1,283	1,814	1,483			
1–1/2	1,434	2,028	2,869	2,044	5,122		
2	2,973	4,204	5,946	3,415			
2–1/2	4,943	6,991	9,887	4,901	7,352	9,802	
3	9,181	12,984	18,362	7,638	11,458	15,277	33,238
4	19,724	27,894		13,295	19,943	26,590	
5	36,890			21,040	31,559	42,079	52,599
6	59,976	52,171		30,144	45,216	60,288	75,360
8	126,990			52,806	79,209	105,613	132,016
10				86,341	129,511	172,681	215,851
12				125,395	188,093	250,791	313,488
14				153,494	230,242	306,989	383,736
16				204,356	306,535	408,713	510,891
18				262,484	393,727	524,969	656,211
20				327,878	491,818	655,757	819,696
22				400,539	600,808	801,077	1,001,346
24				480,465	720,697	960,929	1,201,161
26			with sizes	567,657	851,485	1,135,313	1,419,142
28	Velocity these	governs pipe		662,115	993,172	1,324,229	1,655,287
30				763,839	1,145,758	1,527,678	1,909,597
32				872,829	1,309,243	1,745,658	2,182,072
34				989,085	1,483,627	1,978,170	2,472,712
36				1,112,607	1,668,910	2,225,214	2,781,517
42				1,526,769	2,290,154	3,053,539	3,816,923
48				2,006,326	3,009,488	4,012,651	5,015,814
54				2,551,276	3,826,914	5,102,552	6,378,190
60				3,161,620	4,742,431	6,323,241	7,904,051
72				4,578,491	6,867,737	9,156,983	11,446,228
84				6,256,938	9,385,408	12,513,877	15,642,346
96				8,196,962	12,295,443	16,393,924	20,492,404

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2 3/4 1	29 70 147	41 99 208	57 141 294	134 224	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	339 536 1,110	479 757 1,570	677 1,071 2,220	399 549 918	598 824 1,376	1,835	
2–1/2 3 4	1,846 3,428 7,365	2,610 4,848		1,317 2,053 3,573	1,976 3,079 5,359	2,634 4,105 7,145	3,293 5,131 8,932
5 6 8	13,774			5,654 8,100 14,190	8,481 12,150 21,285	11,308 16,201 28,380	14,134 20,251 35,475
10 12 14				23,201 33,696 41,247	34,802 50,544 61,870	46,403 67,392 82,494	58,004 84,241 103,117
16 18 20				54,915 70,535 88,107	82,372 105,802 132,161	109,829 141,070 176,215	137,287 176,337 220,269
22 24 26		governs pipe	with sizes	107,633 129,110 152,541	161,449 193,666 228,811	215,265 258,221 305,081	269,082 322,776 381,351
28 30 32	Velocity these			177,923 205,259 234,546	266,885 307,888 351,820	355,847 410,517 469,093	444,808 513,147 586,366
34 36 42				265,787 298,980 410,273	398,680 448,469 615,410	531,573 597,959 820,546	664,467 747,449 1,025,683
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	1,347,849 1,713,946 2,123,975
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	3,075,828 4,203,408 5,506,715
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2 3/4 1	39 95 198	55 134 280	77 189 396	345	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	456 721 1,494	644 1,019 2,112	911 1,441 2,987	615 847 1,416	1,271 2,124	2,831	
2–1/2 3 4	2,484 4,613 9,910	3,512 6,523	4,967	2,032 3,167 5,512	3,048 4,750 8,268	4,064 6,333 11,024	7,917 13,780
5 6 8	18,535 30,133			8,723 12,497 21,892	13,084 18,746 32,839	17,445 24,994 43,785	21,806 31,243 54,731
10 12 14				35,795 51,986 63,636	53,693 77,980 95,454	71,590 103,973 127,271	89,488 129,966 159,089
16 18 20		governs pipe	with sizes	84,722 108,821 135,932	127,083 163,231 203,898	169,444 217,642 271,864	211,805 272,052 339,830
22 24 26	Velocity these			166,055 199,191 235,339	249,083 298,786 353,009	332,110 398,382 470,678	415,138 497,977 588,348
28 30 32				274,499 316,672 361,857	411,749 475,008 542,786	548,999 633,344 723,715	686,249 791,681 904,643

(*Continued*)

60 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34 36 42				410,055 461,265 632,968	615,082 691,897 949,452	820,110 922,529 1,265,936	1,025,137 1,153,161 1,582,420
48 54 60				831,782 1,057,708 1,310,744	1,247,674 1,586,562 1,966,117	1,663,565 2,115,416 2,621,489	2,079,456 2,644,270 3,276,861
72 84 96				1,898,151 2,594,001 3,398,296	2,847,226 3,891,002 5,097,444	3,796,301 5,188,002 6,796,592	4,745,377 6,485,003 8,495,740
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2 3/4 1	43 105 221	61 149 312	86 211 441	402	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	508 803 1,665	718 1,136 2,355	1,016 1,607 3,330	717 988 1,651	1,482 2,477	3,302	
2–1/2 3 4	2,769 5,142 11,047	3,915 7,272 15,623	5,537	2,370 3,693 6,428	3,555 5,540 9,642	4,740 7,386 12,857	9,233 16,071
5 6 8	20,662 33,591			10,173 14,575 25,532	15,259 21,862 38,298	20,346 29,150 51,064	25,432 36,437 63,830
10 12 14				41,746 60,630 74,216	62,619 90,944 111,323	83,493 121,259 148,431	104,366 151,574 185,539
16 18 20				98,808 126,913 158,531	148,212 190,370 237,797	197,615 253,826 317,063	247,019 317,283 396,329
22 24 26		governs pipe	with sizes	193,663 232,308 274,466	290,495 348,462 411,699	387,326 464,616 548,932	484,158 580,770 686,165
28 30 32	Velocity these			320,137 369,321 422,019	480,205 553,982 633,028	640,274 738,643 844,037	800,342 923,303 1,055,047
34 36 42				478,229 537,953 738,203	717,344 806,930 1,107,305	956,459 1,075,906 1,476,407	1,195,573 1,344,883 1,845,508
48 54 60				970,072 1,233,559 1,528,665	1,455,108 1,850,339 2,292,998	1,940,144 2,467,119 3,057,330	2,425,180 3,083,898 3,821,663
72 84 96				2,213,732 3,025,273 3,963,287	3,320,598 4,537,909 5,944,931	4,427,464 6,050,545 7,926,574	5,534,330 7,563,181 9,908,218
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2 3/4 1	50 123 257	71 174 364	100 246 514	498	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	592 936 1,941	837 1,324 2,744	1,184 1,873 3,881	888 1,224 2,045	1,836 3,067		
2–1/2 3 4	3,227 5,993 12,876	4,564 8,476 18,209	6,454	2,935 4,574 7,961	4,402 6,861 11,942	5,870 9,148 15,923	11,435 19,904
5 6 8	24,082 39,152			12,599 18,051 31,621	18,898 27,076 47,432	25,198 36,102 63,243	31,497 45,127 79,053

(*Continued*)

60 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
10				51,702	77,554	103,405	129,256
12				75,089	112,634	150,178	187,723
14				91,915	137,873	183,831	229,788
16				122,373	183,559	244,745	305,931
18				157,181	235,771	314,361	392,952
20				196,340	294,510	392,680	490,850
22				239,850	359,775	479,700	599,625
24				287,711	431,567	575,423	719,278
26				339,924	509,885	679,847	849,809
28				396,487	594,730	792,974	991,217
30	Velocity these	governs pipe	with sizes	457,401	686,102	914,802	1,143,503
32				522,667	784,000	1,045,333	1,306,666
34				592,283	888,424	1,184,566	1,480,707
36				666,250	999,375	1,332,501	1,665,626
42				914,259	1,371,388	1,828,517	2,285,647
48				1,201,426	1,802,139	2,402,852	3,003,565
54				1,527,753	2,291,629	3,055,506	3,819,382
60				1,893,239	2,839,858	3,786,477	4,733,097
72				2,741,688	4,112,532	5,483,376	6,854,220
84				3,746,774	5,620,161	7,493,549	9,366,936
96				4,908,497	7,362,746	9,816,995	12,271,243
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	55	78	111				
3/4	136	192	271		Pressure with these		
1	284	402	568			drop pipe	governs sizes
1–1/4	654	924	1,307	1,017			
1–1/2	1,033	1,462	2,067	1,401	3,511		
2	2,142	3,029	4,284	2,341			
2–1/2	3,562	5,037		3,360	5,040	6,720	13,090
3	6,615	9,356	7,124	5,236	7,854	10,472	22,785
4	14,213	20,100		9,114	13,671	18,228	
5	26,582			14,423	21,634	28,846	36,057
6	43,216			20,664	30,996	41,328	51,660
8				36,199	54,299	72,398	90,498
10				59,187	88,781	118,375	147,968
12				85,960	128,940	171,919	214,899
14				105,222	157,833	210,444	263,055
16				140,088	210,132	280,177	350,221
18				179,936	269,903	359,871	449,839
20				224,764	337,146	449,528	561,910
22				274,573	411,860	549,146	686,433
24		governs pipe	with sizes	329,363	494,045	658,726	823,408
26				389,134	583,701	778,268	972,836
28				453,886	680,829	907,772	1,134,715
30	Velocity these			523,619	785,428	1,047,238	1,309,047
32				598,333	897,499	1,196,666	1,495,832
34				678,027	1,017,041	1,356,055	1,695,069
36				762,703	1,144,055	1,525,406	1,906,758
42				1,046,615	1,569,923	2,093,231	2,616,538
48				1,375,356	2,063,034	2,750,712	3,438,390
54				1,748,925	2,623,387	3,497,850	4,372,312
60				2,167,322	3,250,983	4,334,644	5,418,305
72				3,138,601	4,707,901	6,277,202	7,846,502
84				4,289,193	6,433,789	8,578,386	10,722,982
96				5,619,098	8,428,647	11,238,196	14,047,745

(*Continued*)

60 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	64	90	128		Pressure		
3/4	157	221	313		with these		
1	328	464	656			drop	governs
1–1/4	755	1,067	1,510	1,235		pipe	sizes
1–1/2	1,194	1,688	2,387	1,701	4,263		
2	2,474	3,499	4,948	2,842			
2–1/2	4,114	5,818	8,228	4,079	6,118	8,158	
3	7,640	10,805	15,281	6,357	9,535	12,713	27,661
4	16,415	23,214		11,064	16,596	22,129	
5	30,700			17,509	26,264	35,018	43,773
6	49,912	43,417		25,086	37,629	50,172	62,715
8	105,681			43,946	65,918	87,891	109,864
10				71,853	107,779	143,706	179,632
12				104,354	156,532	208,709	260,886
14				127,739	191,608	255,477	319,346
16				170,066	255,099	340,132	425,165
18				218,440	327,661	436,881	546,101
20				272,862	409,292	545,723	682,154
22				333,330	499,994	666,659	833,324
24				399,844	599,766	799,688	999,611
26			with	472,406	708,609	944,812	1,181,014
28			sizes	551,014	826,521	1,102,028	1,377,535
30	Velocity	governs		635,669	953,504	1,271,338	1,589,173
32	these	pipe		726,371	1,089,557	1,452,742	1,815,928
34				823,120	1,234,680	1,646,240	2,057,800
36				925,915	1,388,873	1,851,831	2,314,788
42				1,270,583	1,905,874	2,541,165	3,176,456
48				1,669,671	2,504,506	3,339,342	4,174,177
54				2,123,181	3,184,771	4,246,361	5,307,951
60				2,631,111	3,946,667	5,262,222	6,577,778
72				3,810,236	5,715,354	7,620,472	9,525,590
84				5,207,045	7,810,568	10,414,091	13,017,613
96				6,821,539	10,232,309	13,643,079	17,053,848
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	81	114	162		Pressure		
3/4	198	280	396		with these		
1	415	587	830			drop	governs
1–1/4	956	1,352	1,911	1,681		pipe	sizes
1–1/2	1,511	2,137	3,022	2,316	5,805		
2	3,132	4,430	6,265	3,870			
2–1/2	5,209	7,366	10,417	5,555	8,332	17,314	
3	9,673	13,680	19,347	8,657	12,985	30,136	37,669
4	20,782	29,391		15,068	22,602		
5	38,870			23,845	35,767	47,689	59,612
6	63,194	54,970		34,163	51,244	68,326	85,407
8	133,803			59,847	89,770	119,693	149,616
10				97,852	146,778	195,704	244,630
12				142,114	213,170	284,227	355,284
14			with	173,959	260,938	347,918	434,897
16			sizes	231,602	347,403	463,204	579,005
18	Velocity	governs		297,480	446,220	594,960	743,700
20	these	pipe		371,592	557,389	743,185	928,981
22				453,940	680,910	907,880	1,134,849
24				544,522	816,783	1,089,044	1,361,305
26				643,339	965,008	1,286,677	1,608,347

(*Continued*)

60 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				750,390	1,125,585	1,500,781	1,875,976
30				865,677	1,298,515	1,731,353	2,164,191
32				989,198	1,483,796	1,978,395	2,472,994
34				1,120,953	1,681,430	2,241,907	2,802,383
36				1,260,944	1,891,416	2,521,888	3,152,360
42				1,730,324	2,595,486	3,460,648	4,325,809
48				2,273,816	3,410,724	4,547,633	5,684,541
54				2,891,421	4,337,132	5,782,843	7,228,554
60				3,583,139	5,374,709	7,166,278	8,957,848
72				5,188,913	7,783,369	10,377,825	12,972,282
84				7,091,137	10,636,705	14,182,273	17,727,841
96				9,289,811	13,934,716	18,579,622	23,224,527

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	25	36	50	118	Pressure with these	drop pipe	governs sizes
3/4	62	87	124	197			
1	130	183	259				
1–1/4	298	422	596	351	526		
1–1/2	471	667	943	483	725	1,616	
2	977	1,382	1,954	808	1,212		
2–1/2	1,625	2,298		1,159	1,739	2,319	2,899
3	3,018	4,268		1,807	2,710	3,614	4,517
4	6,483			3,145	4,718	6,290	7,863
5				4,977	7,466	9,954	12,443
6	12,126			7,131	10,696	14,262	17,827
8				12,492	18,738	24,984	31,230
10				20,425	30,637	40,850	51,062
12				29,664	44,496	59,327	74,159
14				36,311	54,466	72,622	90,777
16				48,343	72,514	96,686	120,857
18				62,094	93,140	124,187	155,234
20				77,563	116,345	155,127	193,908
22				94,752	142,128	189,504	236,880
24			with sizes	113,659	170,489	227,319	284,148
26		governs pipe		134,286	201,428	268,571	335,714
28				156,631	234,946	313,261	391,577
30	Velocity these			180,695	271,042	361,389	451,736
32				206,477	309,716	412,955	516,193
34				233,979	350,969	467,958	584,948
36				263,200	394,799	526,399	657,999
42				361,174	541,761	722,349	902,936
48				474,619	711,928	949,237	1,186,547
54				603,533	905,299	1,207,066	1,508,832
60				747,917	1,121,875	1,495,833	1,869,791
72				1,083,093	1,624,640	2,166,186	2,707,733
84				1,480,149	2,220,223	2,960,297	3,700,371
96				1,939,083	2,908,624	3,878,165	4,847,707

(*Continued*)

75 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	33	47	66		Pressure with these	drop pipe	governs sizes
3/4	81	115	163				
1	170	241	341	297			
1–1/4	392	555	785	530			
1–1/2	621	878	1,241	730	1,094		
2	1,286	1,819	2,573	1,219	1,829	2,438	
2–1/2	2,139	3,025	4,278	1,750	2,625	3,500	
3	3,972	5,618		2,727	4,091	5,454	6,818
4	8,534			4,747	7,120	9,494	11,867
5	15,962			7,512	11,268	15,024	18,780
6	25,951			10,762	16,144	21,525	26,906
8				18,854	28,281	37,707	47,134
10				30,827	46,240	61,653	77,067
12				44,771	67,156	89,541	111,927
14				54,803	82,204	109,606	137,007
16				72,963	109,444	145,925	182,406
18				93,716	140,574	187,433	234,291
20				117,064	175,596	234,129	292,661
22				143,007	214,510	286,013	357,516
24				171,543	257,315	343,086	428,858
26		governs pipe	with sizes	202,674	304,011	405,347	506,684
28	Velocity these			236,399	354,598	472,797	590,997
30				272,718	409,077	545,435	681,794
32				311,631	467,447	623,262	779,078
34				353,139	529,708	706,277	882,847
36				397,240	595,861	794,481	993,101
42				545,111	817,667	1,090,222	1,362,778
48				716,330	1,074,495	1,432,660	1,790,825
54				910,897	1,366,345	1,821,793	2,277,242
60				1,128,811	1,693,217	2,257,623	2,822,029
72				1,634,685	2,452,027	3,269,370	4,086,712
84				2,233,951	3,350,926	4,467,901	5,584,876
96				2,926,608	4,389,912	5,853,216	7,316,521
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	37	52	73		Pressure with these	drop pipe	governs sizes
3/4	90	127	180				
1	188	266	377	343			
1–1/4	433	613	867	612			
1–1/2	685	969	1,370	843	1,264		
2	1,420	2,009	2,840	1,408	2,113	2,817	
2–1/2	2,362	3,340	4,723	2,021	3,032	4,043	
3	4,386	6,203		3,150	4,726	6,301	7,876
4	9,423	13,327		5,483	8,225	10,967	13,709
5	17,625			8,677	13,016	17,355	21,694
6	28,654			12,432	18,649	24,865	31,081
8				21,779	32,669	43,558	54,448
10				35,610	53,415	71,220	89,025
12				51,717	77,576	103,435	129,293
14				63,306	94,960	126,613	158,266
16				84,284	126,425	168,567	210,709
18		governs pipe	with sizes	108,258	162,386	216,515	270,644
20				135,228	202,843	270,457	338,071
22	Velocity these			165,196	247,794	330,392	412,990
24				198,160	297,240	396,320	495,400
26				234,121	351,182	468,242	585,303
28				273,079	409,618	546,158	682,697
30				315,034	472,550	630,067	787,584
32				359,985	539,977	719,970	899,962

(*Continued*)

75 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				407,933	611,899	815,866	1,019,832
36				458,878	688,316	917,755	1,147,194
42				629,692	944,539	1,259,385	1,574,231
48				827,478	1,241,217	1,654,956	2,068,695
54				1,052,234	1,578,352	2,104,469	2,630,586
60				1,303,962	1,955,942	2,607,923	3,259,904
72				1,888,328	2,832,492	3,776,656	4,720,820
84				2,580,578	3,870,867	5,161,155	6,451,444
96				3,380,710	5,071,066	6,761,421	8,451,776
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	42	60	84		Pressure		
3/4	103	146	206	419	with these		
1	216	306	432			drop	governs
1–1/4	498	704	995	747		pipe	sizes
1–1/2	787	1,113	1,574	1,028	1,543		
2	1,631	2,306	3,262	1,718	2,578		
2–1/2	2,712	3,835		2,466	3,700	4,933	
3	5,037	7,123	5,424	3,844	5,766	7,688	9,610
4	10,821	15,303		6,691	10,036	13,381	16,727
5	20,238			10,588	15,882	21,176	26,470
6	32,902			15,170	22,755	30,339	37,924
8				26,574	39,861	53,148	66,436
10				43,450	65,175	86,900	108,625
12				63,104	94,656	126,208	157,760
14				77,244	115,867	154,489	193,111
16				102,840	154,260	205,681	257,101
18				132,093	198,139	264,185	330,231
20				165,001	247,502	330,003	412,504
22				201,567	302,350	403,134	503,917
24				241,789	362,683	483,578	604,472
26		governs	with	285,667	428,501	571,335	714,168
28	Velocity	pipe	sizes	333,202	499,804	666,405	833,006
30	these			384,394	576,591	768,788	960,985
32				439,242	658,863	878,484	1,098,105
34				497,747	746,620	995,494	1,244,367
36				559,908	839,862	1,119,816	1,399,770
42				768,331	1,152,497	1,536,662	1,920,828
48				1,009,663	1,514,494	2,019,326	2,524,157
54				1,283,903	1,925,855	2,567,807	3,209,759
60				1,591,053	2,386,580	3,182,106	3,977,633
72				2,304,079	3,456,118	4,608,158	5,760,197
84				3,148,740	4,723,110	6,297,480	7,871,850
96				4,125,037	6,187,556	8,250,074	10,312,593
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	46	65	92		Pressure		
3/4	113	159	225		with these		
1	236	334	472			drop	governs
1–1/4	543	768	1,087	845		pipe	sizes
1–1/2	859	1,215	1,719	1,165	2,919		
2	1,781	2,519	3,562	1,946			
2–1/2	2,961	4,188		2,793	4,190	5,587	
3	5,500	7,778	5,923	4,353	6,530	8,707	10,884
4	11,817	16,711		7,578	11,366	15,155	18,944
5	22,101			11,991	17,987	23,983	29,979
6	35,931			17,180	25,771	34,361	42,951
8				30,097	45,145	60,193	75,242
10				49,209	73,814	98,419	123,023
12				71,468	107,203	142,937	178,671
14				87,483	131,225	174,967	218,708

(*Continued*)

75 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				116,472	174,708	232,944	291,180
18				149,602	224,403	299,203	374,004
20				186,873	280,309	373,745	467,182
22				228,285	342,427	456,570	570,712
24				273,838	410,758	547,677	684,596
26				323,533	485,300	647,066	808,833
28				377,369	566,053	754,738	943,422
30				435,346	653,019	870,692	1,088,365
32	Velocity these	governs pipe	with sizes	497,464	746,197	994,929	1,243,661
34				563,724	845,586	1,127,448	1,409,310
36				634,125	951,187	1,268,250	1,585,312
42				870,174	1,305,262	1,740,349	2,175,436
48				1,143,495	1,715,243	2,286,990	2,858,738
54				1,454,087	2,181,130	2,908,174	3,635,217
60				1,801,950	2,702,924	3,603,899	4,504,874
72				2,609,488	3,914,232	5,218,976	6,523,720
84				3,566,111	5,349,166	7,132,221	8,915,276
96				4,671,817	7,007,726	9,343,634	11,679,543
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	52	74	104		Pressure		
3/4	128	181	256		with these		
1	268	379	536			drop	governs
1–1/4	617	872	1,234	1,009		pipe	sizes
1–1/2	975	1,379	1,951	1,390	3,483		
2	2,022	2,859	4,043	2,322			
2–1/2	3,362	4,754		3,333	5,000	6,666	
3	6,243	8,830	6,723	5,195	7,792	10,389	22,604
4	13,414	18,970	12,487	9,041	13,562	18,083	
5	25,088			14,308	21,462	28,616	35,770
6	40,787	35,479		20,500	30,749	40,999	51,249
8	86,360			35,911	53,867	71,822	89,778
10				58,716	88,075	117,433	146,791
12				85,276	127,914	170,552	213,189
14				104,385	156,577	208,769	260,962
16				138,974	208,460	277,947	347,434
18				178,504	267,756	357,008	446,260
20				222,976	334,463	445,951	557,439
22				272,388	408,583	544,777	680,971
24				326,743	490,114	653,485	816,856
26			with sizes	386,038	579,057	772,076	965,095
28	Velocity these	governs pipe		450,275	675,412	900,549	1,125,687
30				519,453	779,179	1,038,905	1,298,632
32				593,572	890,358	1,187,144	1,483,930
34				672,633	1,008,949	1,345,265	1,681,581
36				756,634	1,134,952	1,513,269	1,891,586
42				1,038,288	1,557,432	2,076,575	2,595,719
48				1,364,413	2,046,619	2,728,825	3,411,031
54				1,735,009	2,602,514	3,470,018	4,337,523
60				2,150,077	3,225,116	4,300,154	5,375,193
72				3,113,628	4,670,442	6,227,256	7,784,069
84				4,255,065	6,382,597	8,510,130	10,637,662
96				5,574,388	8,361,582	11,148,776	13,935,970
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	64	90	128		Pressure		
3/4	157	222	313		with these		
1	328	464	656			drop	governs
1–1/4	755	1,068	1,511	1,329		pipe	sizes
1–1/2	1,195	1,689	2,389	1,831	4,589		
2	2,476	3,502	4,952	3,059			

(*Continued*)

75 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	4,117	5,823	8,234	4,391	6,586	13,686	29,777
3	7,647	10,814	15,293	6,843	10,264	23,821	
4	16,428	23,233		11,911	17,866		
5	30,726	43,453		18,849	28,273	37,697	47,122
6	49,953			27,005	40,508	54,010	67,513
8	105,768			47,307	70,961	94,615	118,268
10				77,350	116,024	154,699	193,374
12				112,337	168,506	224,675	280,843
14				137,510	206,265	275,021	343,776
16				183,076	274,614	366,152	457,690
18				235,151	352,726	470,301	587,877
20				293,735	440,602	587,470	734,337
22				358,829	538,243	717,657	897,071
24				430,432	645,647	860,863	1,076,079
26			with sizes	508,544	762,816	1,017,088	1,271,360
28	Velocity these	governs pipe		593,166	889,748	1,186,331	1,482,914
30				684,297	1,026,445	1,368,593	1,710,742
32				781,937	1,172,906	1,563,874	1,954,843
34				886,087	1,329,130	1,772,174	2,215,217
36				996,746	1,495,119	1,993,492	2,491,865
42				1,367,780	2,051,670	2,735,559	3,419,449
48				1,797,398	2,696,096	3,594,795	4,493,494
54				2,285,600	3,428,400	4,571,200	5,714,000
60				2,832,386	4,248,579	5,664,773	7,080,966
72				4,101,712	6,152,568	8,203,424	10,254,280
84				5,605,375	8,408,062	11,210,749	14,013,436
96				7,343,374	11,015,061	14,686,749	18,358,436
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	78	110	156		Pressure with these	drop pipe	governs sizes
3/4	191	270	381				
1	399	565	799				
1–1/4	919	1,300	1,839	1,723	5,948		
1–1/2	1,454	2,056	2,908	2,373			
2	3,014	4,262	6,027	3,966			
2–1/2	5,011	7,087	10,022	5,692	8,538	17,741	38,600
3	9,307	13,162	18,614	8,871	13,306	30,880	
4	19,995	28,277		15,440	23,160		
5	37,397	52,888		24,434	36,651	48,868	61,084
6	60,799	85,983		35,007	52,510	70,014	87,517
8	128,734			61,325	91,988	122,650	153,313
10	246,797			100,269	150,404	200,539	250,673
12				145,625	218,437	291,249	364,061
14				178,257	267,385	356,513	445,642
16				237,324	355,986	474,648	593,310
18				304,829	457,244	609,659	762,073
20				380,773	571,160	761,546	951,933
22				465,155	697,732	930,310	1,162,887
24				557,975	836,962	1,115,950	1,394,937
26			with sizes	659,233	988,850	1,318,466	1,648,083
28		governs pipe		768,929	1,153,394	1,537,859	1,922,324
30				887,064	1,330,596	1,774,128	2,217,660
32	Velocity these			1,013,637	1,520,455	2,027,273	2,534,092
34				1,148,648	1,722,971	2,297,295	2,871,619
36				1,292,097	1,938,145	2,584,193	3,230,242
42				1,773,073	2,659,610	3,546,146	4,432,683
48				2,329,993	3,494,990	4,659,986	5,824,983
54				2,962,857	4,444,285	5,925,714	7,407,142
60				3,671,664	5,507,496	7,343,329	9,179,161
72				5,317,110	7,975,665	10,634,220	13,292,775
84				7,266,330	10,899,495	14,532,660	18,165,825
96				9,519,325	14,278,988	19,038,650	23,798,313

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 3.

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 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	24	33	47	110	Pressure	drop	
3/4	58	82	115	184	with these	pipe	
1	121	171	242				governs
1–1/4	278	393	556	327	491		sizes
1–1/2	440	622	880	451	677	1,508	
2	912	1,290	1,824	754	1,131		
2–1/2	1,516	2,144		1,082	1,623	2,164	2,705
3	2,816	3,982		1,686	2,529	3,372	4,215
4	6,050			2,935	4,402	5,870	7,337
5				4,644	6,967	9,289	11,611
6	11,315			6,654	9,981	13,309	16,636
8				11,657	17,486	23,314	29,143
10				19,060	28,590	38,119	47,649
12				27,681	41,522	55,362	69,203
14				33,884	50,826	67,768	84,710
16				45,112	67,668	90,223	112,779
18				57,944	86,915	115,887	144,859
20				72,379	108,569	144,759	180,948
22			with	88,419	132,629	176,838	221,048
24			sizes	106,063	159,094	212,125	265,157
26		governs		125,310	187,966	250,621	313,276
28	Velocity	pipe		146,162	219,243	292,324	365,405
30	these			168,618	252,927	337,235	421,544
32				192,677	289,016	385,355	481,693
34				218,341	327,511	436,682	545,852
36				245,608	368,413	491,217	614,021
42				337,035	505,552	674,070	842,587
48				442,897	664,346	885,794	1,107,243
54				563,195	844,793	1,126,390	1,407,988
60				697,929	1,046,893	1,395,858	1,744,822
72				1,010,704	1,516,056	2,021,407	2,526,759
84				1,381,222	2,071,832	2,762,443	3,453,054
96				1,809,482	2,714,224	3,618,965	4,523,706
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	31	43	61		Pressure	drop	
3/4	75	106	150	274	with these	pipe	
1	157	223	315				governs
1–1/4	362	512	725	489			sizes
1–1/2	573	810	1,146	674	1,010	2,251	
2	1,188	1,680	2,375	1,126	1,689		
2–1/2	1,975	2,793		1,616	2,424	3,231	6,295
3	3,668	5,187	3,950	2,518	3,777	5,036	10,957
4	7,880			4,383	6,574	8,766	
5	14,738			6,936	10,404	13,871	17,339
6	23,960			9,937	14,906	19,874	24,843
8				17,408	26,111	34,815	43,519
10				28,462	42,693	56,925	71,156
12				41,337	62,005	82,674	103,342
14				50,600	75,899	101,199	126,499
16		governs	with	67,366	101,050	134,733	168,416
18		pipe	sizes	86,528	129,793	173,057	216,321
20	Velocity			108,086	162,128	216,171	270,214
22	these			132,038	198,057	264,076	330,095
24				158,386	237,579	316,772	395,965
26				187,129	280,693	374,258	467,822
28				218,267	327,401	436,534	545,668
30				251,801	377,701	503,601	629,501
32				287,729	431,594	575,459	719,323

(*Continued*)

85 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				326,053	489,080	652,107	815,133
36				366,772	550,159	733,545	916,931
42				503,302	754,953	1,006,603	1,258,254
48				661,388	992,082	1,322,776	1,653,470
54				841,032	1,261,548	1,682,064	2,102,579
60				1,042,233	1,563,349	2,084,465	2,605,582
72				1,509,306	2,263,959	3,018,612	3,773,266
84				2,062,609	3,093,913	4,125,217	5,156,522
96				2,702,140	4,053,210	5,404,280	6,755,351
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	34	48	67				
3/4	83	117	165	315	Pressure with these	drop pipe	
1	173	245	346				governs sizes
1–1/4	398	563	797	562			
1–1/2	630	891	1,260	775	1,162		
2	1,305	1,846	2,611	1,294	1,942	2,589	
2–1/2	2,171	3,070		1,858	2,787	3,716	
3	4,031	5,701	4,341	2,896	4,343	5,791	7,239
4	8,661	12,249		5,040	7,560	10,080	12,600
5				7,976	11,964	15,952	19,940
6	16,199			11,427	17,141	22,854	28,568
8	26,337			20,018	30,027	40,036	50,045
10				32,730	49,096	65,461	81,826
12				47,536	71,303	95,071	118,839
14				58,187	87,281	116,375	145,469
16				77,468	116,203	154,937	193,671
18				99,504	149,256	199,008	248,760
20				124,294	186,441	248,588	310,735
22				151,838	227,757	303,676	379,596
24				182,137	273,206	364,274	455,343
26		governs pipe	with sizes	215,190	322,785	430,380	537,976
28				250,998	376,497	501,996	627,495
30	Velocity these			289,560	434,340	579,120	723,900
32				330,876	496,315	661,753	827,191
34				374,947	562,421	749,895	937,369
36				421,773	632,659	843,546	1,054,432
42				578,776	868,163	1,157,551	1,446,939
48				760,568	1,140,853	1,521,137	1,901,421
54				967,151	1,450,726	1,934,302	2,417,877
60				1,198,524	1,797,785	2,397,047	2,996,309
72				1,735,638	2,603,457	3,471,277	4,339,096
84				2,371,913	3,557,869	4,743,826	5,929,782
96				3,107,347	4,661,020	6,214,694	7,768,367
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	38	54	77				
3/4	94	133	188	382	Pressure with these		
1	197	279	395			drop pipe	governs sizes
1–1/4	454	642	908	681			
1–1/2	718	1,016	1,436	939	1,408		
2	1,489	2,105	2,977	1,569	2,353		
2–1/2	2,475	3,501		2,251	3,377	4,503	
3	4,597	6,502	4,951	3,509	5,263	7,018	8,772
4	9,877	13,968		6,107	9,161	12,215	15,268
5				9,665	14,497	19,329	24,162
6	18,473			13,847	20,770	27,694	34,617
8	30,033	governs pipe	with sizes	24,257	36,386	48,514	60,643
10				39,661	59,492	79,323	99,153
12	Velocity these			57,601	86,402	115,203	144,004
14				70,509	105,764	141,018	176,273

(*Continued*)

85 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				93,873	140,809	187,746	234,682
18				120,575	180,862	241,149	301,436
20				150,614	225,921	301,228	376,535
22				183,991	275,986	367,982	459,977
24				220,706	331,059	441,411	551,764
26				260,758	391,137	521,516	651,895
28				304,148	456,223	608,297	760,371
30				350,876	526,314	701,752	877,191
32				400,942	601,413	801,884	1,002,355
34				454,345	681,518	908,690	1,135,863
36				511,086	766,629	1,022,172	1,277,715
42				701,335	1,052,003	1,402,671	1,753,338
48				921,624	1,382,436	1,843,248	2,304,059
54				1,171,952	1,757,927	2,343,903	2,929,879
60				1,452,319	2,178,478	2,904,638	3,630,797
72				2,103,171	3,154,757	4,206,343	5,257,928
84				2,874,181	4,311,272	5,748,362	7,185,453
96				3,765,348	5,648,023	7,530,697	9,413,371
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	42	59	83		Pressure with these	drop pipe	governs sizes
3/4	102	145	205				
1	214	303	429				
1–1/4	494	698	987	768			
1–1/2	781	1,104	1,561	1,058	2,652		
2	1,618	2,288	3,235	1,768			
2–1/2	2,690	3,804		2,537	3,806	5,075	
3	4,996	7,065	5,380	3,954	5,932	7,909	9,886
4	10,734	15,180		6,883	10,325	13,766	17,208
5	20,075			10,892	16,339	21,785	27,231
6	32,638			15,606	23,409	31,212	39,015
8				27,338	41,008	54,677	68,346
10				44,699	67,049	89,399	111,749
12				64,919	97,378	129,837	162,296
14				79,466	119,199	158,931	198,664
16				105,798	158,696	211,595	264,494
18				135,891	203,837	271,782	339,728
20				169,746	254,619	339,493	424,366
22				207,363	311,045	414,726	518,408
24				248,742	373,113	497,484	621,855
26		governs pipe	with sizes	293,882	440,823	587,764	734,705
28				342,784	514,176	685,568	856,960
30	Velocity these			395,448	593,172	790,896	988,619
32				451,873	677,810	903,746	1,129,683
34				512,060	768,090	1,024,120	1,280,150
36				576,009	864,013	1,152,018	1,440,022
42				790,425	1,185,638	1,580,851	1,976,063
48				1,038,697	1,558,045	2,077,394	2,596,742
54				1,320,824	1,981,236	2,641,647	3,302,059
60				1,636,806	2,455,209	3,273,611	4,092,014
72				2,370,335	3,555,503	4,740,671	5,925,839
84				3,239,286	4,858,929	6,478,572	8,098,215
96				4,243,658	6,365,486	8,487,315	10,609,144
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	47	67	94		Pressure with these	drop pipe	governs sizes
3/4	115	163	231				
1	242	342	483				
1–1/4	556	786	1,112	909			
1–1/2	879	1,243	1,758	1,253	3,140		
2	1,822	2,577	3,645	2,093			
2–1/2	3,030	4,285		3,004	4,507	6,009	
3	5,628	7,959	6,060	4,682	7,023	9,364	20,374
4	12,091	17,099	11,255	8,150	12,225	16,300	

(*Continued*)

85 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5	22,613	31,980		12,897	19,345	25,794	32,242
6	36,764			18,478	27,717	36,956	46,195
8	77,843			32,369	48,554	64,739	80,923
10				52,925	79,388	105,851	132,313
12				76,865	115,298	153,731	192,163
14				94,090	141,134	188,179	235,224
16				125,267	187,901	250,534	313,168
18				160,899	241,348	321,797	402,247
20				200,984	301,476	401,968	502,460
22				245,524	368,285	491,047	613,809
24				294,517	441,775	589,034	736,292
26			with sizes	347,964	521,946	695,929	869,911
28	Velocity these	governs pipe		405,866	608,798	811,731	1,014,664
30				468,221	702,331	936,442	1,170,552
32				535,030	802,545	1,070,060	1,337,575
34				606,293	909,440	1,212,586	1,515,733
36				682,010	1,023,015	1,364,020	1,705,025
42				935,885	1,403,827	1,871,770	2,339,712
48				1,229,845	1,844,768	2,459,690	3,074,613
54				1,563,891	2,345,836	3,127,782	3,909,727
60				1,938,022	2,907,033	3,876,044	4,845,055
72				2,806,541	4,209,811	5,613,082	7,016,352
84				3,835,402	5,753,103	7,670,803	9,588,504
96				5,024,605	7,536,907	10,049,209	12,561,511
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	57	80	114		Pressure with these	drop pipe	governs sizes
3/4	139	197	278				
1	292	412	583				
1–1/4	671	949	1,343	1,181			
1–1/2	1,061	1,501	2,123	1,627	4,077		
2	2,200	3,111	4,400	2,718			
2–1/2	3,658	5,174	7,317	3,902	5,852		
3	6,795	9,609	13,589	6,080	9,121	12,161	
4	14,598	20,644		10,584	15,875	21,167	26,459
5	27,302	38,611		16,748	25,123	33,497	41,871
6	44,387			23,996	35,994	47,992	59,990
8	93,983			42,036	63,054	84,072	105,090
10				68,731	103,096	137,462	171,827
12				99,820	149,730	199,640	249,551
14				122,188	183,282	244,377	305,471
16				162,677	244,015	325,353	406,692
18				208,949	313,424	417,898	522,373
20				261,006	391,509	522,011	652,514
22				318,846	478,269	637,693	797,116
24				382,471	573,706	764,942	956,177
26			with sizes	451,880	677,819	903,759	1,129,699
28	Velocity these	governs pipe		527,072	790,609	1,054,145	1,317,681
30				608,049	912,074	1,216,099	1,520,123
32				694,810	1,042,215	1,389,620	1,737,025
34				787,355	1,181,033	1,574,710	1,968,388
36				885,684	1,328,526	1,771,368	2,214,210
42				1,215,376	1,823,063	2,430,751	3,038,439
48				1,597,123	2,395,685	3,194,247	3,992,809
54				2,030,928	3,046,392	4,061,856	5,077,320
60				2,516,789	3,775,183	5,033,578	6,291,972
72				3,644,681	5,467,021	7,289,361	9,111,701
84				4,980,798	7,471,197	9,961,597	12,451,996
96				6,525,142	9,787,713	13,050,284	16,312,855

(*Continued*)

85 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	68	96	136		Pressure		
3/4	167	236	333		with these		
1	349	494	698			drop	governs
1–1/4	804	1,136	1,607	1,506		pipe	sizes
1–1/2	1,271	1,797	2,542	2,074	5,199		
2	2,634	3,725	5,268	3,466			
2–1/2	4,380	6,194	8,760	4,975	7,462	15,506	
3	8,134	11,504	16,268	7,753	11,629	26,989	33,737
4	17,476	24,714		13,495	20,242		
5	32,685	46,224		21,355	32,033	42,710	53,388
6	53,139	75,150		30,596	45,894	61,192	76,491
8	112,514			53,598	80,398	107,197	133,996
10				87,636	131,454	175,271	219,089
12	215,701			127,276	190,915	254,553	318,191
14				155,797	233,695	311,594	389,492
16				207,422	311,133	414,844	518,555
18				266,422	399,633	532,844	666,055
20				332,797	499,195	665,594	831,992
22				406,547	609,820	813,094	1,016,367
24				487,672	731,508	975,344	1,219,179
26			with	576,172	864,258	1,152,344	1,440,429
28		governs	sizes	672,047	1,008,070	1,344,094	1,680,117
30		pipe		775,297	1,162,945	1,550,593	1,938,242
32	Velocity			885,922	1,328,883	1,771,843	2,214,804
34	these			1,003,922	1,505,883	2,007,843	2,509,804
36				1,129,297	1,693,945	2,258,593	2,823,242
42				1,549,672	2,324,507	3,099,343	3,874,179
48				2,036,422	3,054,632	4,072,843	5,091,054
54				2,589,546	3,884,320	5,179,093	6,473,866
60				3,209,046	4,813,569	6,418,093	8,022,616
72				4,647,171	6,970,757	9,294,342	11,617,928
84				6,350,796	9,526,194	12,701,592	15,876,989
96				8,319,920	12,479,881	16,639,841	20,799,801

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	22	31	43	101	Pressure	drop	
3/4	53	75	106	168	with these	pipe	
1	111	157	222				governs
1–1/4	255	361	510	300	450		sizes
1–1/2	403	571	807	414	621	1,382	
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	3,866
4	5,548			2,691	4,037	5,383	6,728
5				4,259	6,388	8,518	10,647
6	10,376			6,102	9,153	12,204	15,255
8				10,689	16,034	21,379	26,723
10				17,478	26,216	34,955	43,694
12				25,383	38,075	50,767	63,458
14				31,071	46,607	62,142	77,678

(*Continued*)

100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16 18 20	Velocity these	governs pipe	with sizes	41,367 53,134 66,371	62,051 79,700 99,557	82,734 106,267 132,742	103,418 132,834 165,928
22 24 26				81,079 97,258 114,908	121,619 145,888 172,363	162,159 194,517 229,817	202,698 243,146 287,271
28 30 32				134,029 154,621 176,683	201,044 231,931 265,025	268,058 309,241 353,366	335,073 386,552 441,708
34 36 42				200,216 225,220 309,058	300,325 337,831 463,586	400,433 450,441 618,115	500,541 563,051 772,644
48 54 60				406,132 516,444 639,994	609,198 774,666 959,991	812,264 1,032,889 1,279,988	1,015,331 1,291,111 1,599,984
72 84 96				926,805 1,266,566 1,659,277	1,390,208 1,899,849 2,488,916	1,853,610 2,533,132 3,318,554	2,317,013 3,166,416 4,148,193
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2 3/4 1	28 68 143	39 96 202	56 136 285	248	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	328 519 1,076	464 734 1,522	657 1,038 2,152	443 610 1,020	915 1,530	2,039	
2–1/2 3 4	1,789 3,323 7,138	2,530 4,699	3,578	1,464 2,281 3,970	2,195 3,422 5,956	2,927 4,562 7,941	5,703 9,926
5 6 8	13,351 21,706	governs pipe	with sizes	6,283 9,002 15,769	9,425 13,503 23,654	12,566 18,004 31,539	15,708 22,505 39,424
10 12 14	Velocity these			25,784 37,447 45,838	38,676 56,170 68,757	51,568 74,893 91,676	64,459 93,617 114,595
16 18 20				61,027 78,385 97,914	91,540 117,578 146,871	122,053 156,771 195,828	152,567 195,964 244,785
22 24 26				119,612 143,481 169,519	179,419 215,221 254,278	239,225 286,961 339,037	299,031 358,701 423,797
28 30 32				197,727 228,104 260,652	296,590 342,156 390,978	395,453 456,209 521,304	494,316 570,261 651,630
34 36 42				295,369 332,257 455,937	443,054 498,385 683,906	590,739 664,513 911,875	738,423 830,641 1,139,843
48 54 60				599,147 761,885 944,151	898,720 1,142,827 1,416,226	1,198,293 1,523,769 1,888,302	1,497,867 1,904,711 2,360,377
72 84 96				1,367,270 1,868,502 2,447,849	2,050,904 2,802,753 3,671,774	2,734,539 3,737,004 4,895,698	3,418,174 4,671,256 6,119,623
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2 3/4 1	30 74 156	43 105 221	61 149 312	284	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	359 568 1,177	508 803 1,664	718 1,135 2,353	507 698 1,167	1,047 1,750	2,333	

(*Continued*)

100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2 3 4	1,956 3,634 7,806	2,767 5,139 11,040	3,913	1,675 2,610 4,543	2,512 3,915 6,814	3,349 5,220 9,085	6,524 11,356
5 6 8	14,600 23,737			7,189 10,299 18,042	10,783 15,449 27,063	14,377 20,598 36,084	17,971 25,748 45,105
10 12 14				29,500 42,843 52,444	44,249 64,265 78,666	58,999 85,687 104,888	73,749 107,108 131,110
16 18 20				69,822 89,682 112,025	104,733 134,523 168,038	139,643 179,364 224,050	174,554 224,205 280,063
22 24 26		governs pipe	with sizes	136,851 164,159 193,949	205,276 246,238 290,924	273,701 328,317 387,898	342,126 410,396 484,873
28 30 32	Velocity these			226,222 260,978 298,216	339,333 391,467 447,324	452,445 521,956 596,432	565,556 652,445 745,540
34 36 42				337,937 380,140 521,646	506,905 570,210 782,468	675,874 760,281 1,043,291	844,842 950,351 1,304,114
48 54 60				685,494 871,685 1,080,219	1,028,241 1,307,527 1,620,329	1,370,988 1,743,370 2,160,438	1,713,734 2,179,212 2,700,548
72 84 96				1,564,316 2,137,785 2,800,625	2,346,474 3,206,677 4,200,938	3,128,632 4,275,570 5,601,251	3,910,790 5,344,462 7,001,564
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2 3/4 1	34 84 176	49 119 250	69 169 353	342	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	406 642 1,331	574 908 1,883	812 1,285 2,663	609 840 1,403	1,259 2,104		
2–1/2 3 4	2,214 4,112 8,834	3,131 5,815 12,493	4,428	2,014 3,138 5,462	3,020 4,707 8,193	4,027 6,276 10,924	7,845 13,655
5 6 8	16,522 26,861			8,644 12,384 21,695	12,966 18,576 32,542	17,288 24,769 43,390	21,610 30,961 54,237
10 12 14				35,472 51,517 63,061	53,208 77,276 94,592	70,944 103,034 126,123	88,680 128,793 157,653
16 18 20				83,957 107,839 134,705	125,936 161,758 202,058	167,915 215,677 269,410	209,894 269,597 336,763
22 24 26		governs pipe	with sizes	164,557 197,393 233,215	246,835 296,090 349,823	329,113 394,787 466,430	411,391 493,483 583,038
28 30 32	Velocity these			272,022 313,814 358,592	408,033 470,721 537,887	544,044 627,629 717,183	680,055 784,536 896,479
34 36 42				406,354 457,102 627,255	609,531 685,652 940,883	812,708 914,203 1,254,511	1,015,885 1,142,754 1,568,139
48 54 60				824,276 1,048,162 1,298,915	1,236,413 1,572,243 1,948,372	1,648,551 2,096,324 2,597,830	2,060,689 2,620,405 3,247,287
72 84 96				1,881,020 2,570,590 3,367,626	2,821,530 3,855,886 5,051,440	3,762,040 5,141,181 6,735,253	4,702,550 6,426,476 8,419,066

(*Continued*)

100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	37	53	74		Pressure		
3/4	91	129	182		with these	drop	governs
1	191	270	382			pipe	sizes
1–1/4	439	621	878	683			
1–1/2	694	982	1,389	941	2,359		
2	1,439	2,035	2,878	1,573			
2–1/2	2,393	3,384		2,257	3,386	4,514	8,795
3	4,444	6,285	4,786	3,518	5,277	7,036	15,308
4	9,548	13,503		6,123	9,185	12,246	
5	17,859			9,690	14,534	19,379	24,224
6	29,034			13,883	20,824	27,765	34,707
8				24,320	36,479	48,639	60,799
10				39,764	59,645	79,527	99,409
12				57,750	86,625	115,500	144,375
14				70,691	106,036	141,382	176,727
16				94,115	141,173	188,230	235,288
18				120,886	181,328	241,771	302,214
20				151,002	226,504	302,005	377,506
22				184,466	276,698	368,931	461,164
24				221,275	331,912	442,550	553,187
26		governs	with	261,431	392,146	522,861	653,577
28	Velocity	pipe	sizes	304,933	457,399	609,866	762,332
30	these			351,781	527,672	703,562	879,453
32				401,976	602,964	803,952	1,004,940
34				455,517	683,275	911,034	1,138,792
36				512,404	768,606	1,024,808	1,281,011
42				703,144	1,054,716	1,406,288	1,757,860
48				924,001	1,386,001	1,848,001	2,310,002
54				1,174,974	1,762,461	2,349,948	2,937,436
60				1,456,065	2,184,097	2,912,129	3,640,161
72				2,108,596	3,162,893	4,217,191	5,271,489
84				2,881,594	4,322,391	5,763,188	7,203,985
96				3,775,060	5,662,589	7,550,119	9,437,649
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	41	59	83		Pressure		
3/4	102	144	203		with these	drop	governs
1	213	301	426			pipe	sizes
1–1/4	490	694	981	802			
1–1/2	776	1,097	1,551	1,105	2,770		
2	1,608	2,273	3,215	1,847			
2–1/2	2,673	3,780	5,346	2,650	3,975	5,301	
3	4,964	7,021	9,929	4,130	6,196	8,261	17,973
4	10,666	15,084		7,189	10,784	14,379	
5	19,948			11,377	17,066	22,754	28,443
6	32,432	28,211		16,300	24,451	32,601	40,751
8	68,670			28,555	42,832	57,110	71,387
10				46,689	70,033	93,377	116,721
12				67,807	101,711	135,615	169,518
14				83,002	124,503	166,004	207,505
16			with	110,505	165,758	221,011	276,264
18			sizes	141,938	212,907	283,876	354,845
20	Velocity	governs		177,300	265,950	354,600	443,250
22	these	pipe		216,591	324,886	433,182	541,477
24				259,811	389,716	519,621	649,527
26				306,960	460,440	613,919	767,399
28				358,038	537,057	716,076	895,094
30				413,045	619,567	826,090	1,032,612
32				471,981	707,972	943,962	1,179,953

(*Continued*)

100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
34				534,847	802,270	1,069,693	1,337,116
36				601,641	902,462	1,203,282	1,504,103
42				825,599	1,238,398	1,651,198	2,063,997
48				1,084,918	1,627,378	2,169,837	2,712,296
54				1,379,600	2,069,400	2,759,199	3,448,999
60				1,709,643	2,564,464	3,419,285	4,274,107
72				2,475,814	3,713,721	4,951,628	6,189,535
84				3,383,433	5,075,149	6,766,865	8,458,581
96				4,432,498	6,648,747	8,864,996	11,081,245
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	49	70	99		Pressure with these	drop pipe	governs sizes
3/4	121	171	242				
1	253	358	507				
1–1/4	583	825	1,166	1,026			
1–1/2	922	1,304	1,845	1,413	3,543		
2	1,912	2,703	3,823	2,362			
2–1/2	3,179	4,495	6,357	3,390	5,085	10,566	
3	5,904	8,349	11,807	5,283	7,925	18,392	22,989
4	12,683	17,937		9,196	13,794		
5	23,722			14,552	21,828	29,105	36,381
6	38,567	33,548		20,849	31,274	41,699	52,124
8	81,659			36,524	54,786	73,048	91,310
10				59,718	89,578	119,437	149,296
12				86,731	130,097	173,462	216,828
14				106,166	159,249	212,332	265,415
16				141,345	212,018	282,691	353,363
18				181,550	272,325	363,100	453,875
20				226,781	340,171	453,561	566,952
22				277,037	415,555	554,074	692,592
24				332,318	498,478	664,637	830,796
26			with sizes	392,626	588,939	785,252	981,565
28	Velocity these	governs pipe		457,959	686,938	915,918	1,144,897
30				528,317	792,476	1,056,635	1,320,793
32				603,701	905,552	1,207,403	1,509,254
34				684,111	1,026,167	1,368,222	1,710,278
36				769,547	1,154,320	1,539,093	1,923,867
42				1,056,006	1,584,010	2,112,013	2,640,016
48				1,387,697	2,081,545	2,775,393	3,469,242
54				1,764,618	2,646,926	3,529,235	4,411,544
60				2,186,769	3,280,153	4,373,538	5,466,922
72				3,166,763	4,750,144	6,333,526	7,916,907
84				4,327,679	6,491,518	8,655,358	10,819,197
96				5,669,517	8,504,275	11,339,034	14,173,792
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	58	82	116		Pressure with these	drop pipe	governs sizes
3/4	142	201	285				
1	298	422	596				
1–1/4	686	971	1,373	1,286			
1–1/2	1,086	1,535	2,171	1,772	4,441		
2	2,250	3,182	4,500	2,961			
2–1/2	3,741	5,291	7,483	4,250	6,374	13,246	
3	6,948	9,827	13,897	6,623	9,934	23,055	28,819
4	14,928	21,112		11,527	17,291		
5	27,920	39,486		18,242	27,363	36,484	45,605
6	45,392	64,195		26,136	39,204	52,272	65,340
8	96,112			45,785	68,677	91,570	114,462
10				74,860	112,291	149,721	187,151
12	184,257			108,722	163,084	217,445	271,806
14				133,085	199,628	266,171	332,713

(*Continued*)

100 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				177,185	265,777	354,369	442,961
18				227,584	341,376	455,168	568,959
20				284,283	426,424	568,566	710,707
22				347,282	520,923	694,564	868,205
24				416,581	624,871	833,161	1,041,452
26				492,179	738,269	984,359	1,230,449
28				574,078	861,117	1,148,156	1,435,195
30				662,277	993,415	1,324,553	1,655,692
32	Velocity these	governs pipe	with sizes	756,775	1,135,163	1,513,550	1,891,938
34				857,573	1,286,360	1,715,147	2,143,934
36				964,672	1,447,008	1,929,343	2,411,679
42				1,323,766	1,985,649	2,647,532	3,309,414
48				1,739,559	2,609,338	3,479,118	4,348,897
54				2,212,051	3,318,077	4,424,102	5,530,128
60				2,741,243	4,111,864	5,482,485	6,853,106
72				3,969,722	5,954,584	7,939,445	9,924,306
84				5,424,999	8,137,498	10,849,997	13,562,496
96				7,107,071	10,660,606	14,214,142	17,767,677
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	68	96	136				
3/4	167	236	333				
1	349	493	698		Pressure with these	drop pipe	
1–1/4	803	1,135	1,606	1,590			
1–1/2	1,269	1,795	2,539	2,191			governs sizes
2	2,631	3,721	5,262	3,661			
2–1/2	4,375	6,188	8,751	5,254	7,881		
3	8,126	11,492	16,252	8,188	12,282	28,505	
4	17,458	24,689	34,916	14,252	21,379		
5	32,652	46,177		22,554	33,832	45,109	56,386
6	53,085	75,073		32,314	48,471	64,628	80,786
8	112,400			56,608	84,912	113,216	141,520
10				92,557	138,835	185,113	231,392
12	215,482			134,423	201,635	268,846	336,058
14				164,545	246,818	329,090	411,363
16				219,069	328,603	438,138	547,672
18				281,382	422,073	562,764	703,455
20				351,484	527,226	702,968	878,710
22				429,375	644,063	858,750	1,073,438
24				515,055	772,583	1,030,111	1,287,639
26			with sizes	608,525	912,787	1,217,050	1,521,312
28				709,783	1,064,675	1,419,567	1,774,459
30		governs pipe		818,831	1,228,247	1,637,662	2,047,078
32	Velocity these			935,668	1,403,502	1,871,336	2,339,170
34				1,060,294	1,590,441	2,120,587	2,650,734
36				1,192,709	1,789,063	2,385,418	2,981,772
42				1,636,689	2,455,033	3,273,377	4,091,721
48				2,150,770	3,226,155	4,301,541	5,376,926
54				2,734,954	4,102,431	5,469,908	6,837,386
60				3,389,240	5,083,860	6,778,480	8,473,100
72				4,908,118	7,362,177	9,816,236	12,270,296
84				6,707,405	10,061,107	13,414,809	16,768,512
96				8,787,099	13,180,649	17,574,198	21,967,748

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	20	28	39				
3/4	48	68	96	92	Pressure	drop	
1	101	143	202	153	with these	pipe	governs
1–1/4	232	328	464	273	410		sizes
1–1/2	367	519	734	376	564	1,258	
2	761	1,076	1,521	629	943		
2–1/2	1,265	1,789		903	1,354	1,805	2,256
3	2,349	3,322		1,407	2,110	2,813	3,516
4	5,047			2,448	3,672	4,896	6,120
5				3,874	5,811	7,748	9,686
6	9,439			5,551	8,326	11,101	13,877
8				9,724	14,586	19,448	24,309
10				15,899	23,848	31,798	39,747
12				23,090	34,636	46,181	57,726
14				28,265	42,397	56,529	70,661
16				37,630	56,445	75,261	94,076
18				48,334	72,501	96,668	120,835
20				60,376	90,564	120,751	150,939
22				73,755	110,633	147,511	184,388
24			with	88,473	132,709	176,946	221,182
26		governs	sizes	104,529	156,793	209,057	261,321
28	Velocity	pipe		121,922	182,883	243,844	304,805
30	these			140,654	210,980	281,307	351,634
32				160,723	241,085	321,446	401,808
34				182,130	273,196	364,261	455,326
36				204,876	307,314	409,752	512,190
42				281,140	421,710	562,280	702,850
48				369,446	554,168	738,891	923,614
54				469,793	704,689	939,586	1,174,482
60				582,182	873,273	1,164,364	1,455,455
72				843,085	1,264,628	1,686,170	2,107,713
84				1,152,155	1,728,233	2,304,310	2,880,388
96				1,509,392	2,264,088	3,018,784	3,773,480
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	25	35	50		Pressure	drop	
3/4	61	87	122	223	with these	pipe	
1	128	181	256				governs
1–1/4	295	417	590	398	823		sizes
1–1/2	467	660	933	549	1,375	1,833	
2	967	1,368	1,934	917			
2–1/2	1,608	2,274		1,316	1,973	2,631	5,126
3	2,986	4,223	3,216	2,050	3,075	4,100	8,921
4	6,416			3,569	5,353	7,137	
5	12,000			5,647	8,471	11,295	14,118
6	19,509			8,091	12,137	16,182	20,228
8				14,174	21,261	28,348	35,435
10				23,175	34,762	46,350	57,937
12				33,658	50,486	67,315	84,144
14		governs	with	41,200	61,800	82,399	102,999
16	Velocity	pipe	sizes	54,852	82,278	109,703	137,129
18	these			70,454	105,681	140,908	176,135
20				88,006	132,010	176,013	220,016
22				107,509	161,264	215,019	268,773
24				128,962	193,444	257,925	322,406
26				152,366	228,549	304,732	380,914

(*Continued*)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				177,719	266,579	355,439	444,299
30				205,023	307,535	410,047	512,558
32				234,278	351,416	468,555	585,694
34				265,482	398,223	530,964	663,705
36				298,637	447,955	597,274	746,592
42				409,803	614,704	819,606	1,024,507
48				538,522	807,782	1,077,043	1,346,304
54				684,793	1,027,189	1,369,585	1,711,982
60				848,616	1,272,925	1,697,233	2,121,541
72				1,228,921	1,843,382	2,457,843	3,072,303
84				1,679,436	2,519,155	3,358,873	4,198,591
96				2,200,162	3,300,242	4,400,323	5,500,404
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	27	38	54				
3/4	67	94	133	254	Pressure with these	drop pipe	
1	139	197	279				governs sizes
1–1/4	321	454	642	453	937		
1–1/2	508	718	1,015	624	1,565	2,087	
2	1,052	1,488	2,105	1,043			
2–1/2	1,750	2,475		1,498	2,247	2,995	
3	3,250	4,596	3,500	2,334	3,501	4,668	5,835
4	6,982	9,874		4,063	6,094	8,126	10,157
5	13,058			6,429	9,644	12,859	16,073
6	21,230			9,211	13,817	18,423	23,029
8				16,137	24,205	32,273	40,342
10				26,384	39,576	52,768	65,960
12				38,319	57,478	76,637	95,797
14				46,905	70,358	93,810	117,263
16				62,448	93,672	124,896	156,119
18				80,211	120,316	160,421	200,527
20				100,194	150,291	200,388	250,485
22				122,398	183,596	244,795	305,994
24				146,822	220,232	293,643	367,054
26		governs	with	173,466	260,199	346,932	433,665
28		pipe	sizes	202,331	303,496	404,662	505,827
30	Velocity			233,416	350,124	466,832	583,540
32	these			266,721	400,082	533,443	666,804
34				302,247	453,371	604,494	755,618
36				339,993	509,990	679,987	849,984
42				466,554	699,831	933,109	1,166,386
48				613,098	919,648	1,226,197	1,532,746
54				779,626	1,169,439	1,559,252	1,949,065
60				966,137	1,449,205	1,932,273	2,415,341
72				1,399,108	2,098,662	2,798,216	3,497,769
84				1,912,012	2,868,018	3,824,024	4,780,031
96				2,504,850	3,757,275	5,009,700	6,262,124
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	31	43	61				
3/4	75	106	150	303	Pressure with these		
1	157	222	313			drop pipe	governs sizes
1–1/4	361	510	721	541	1,118		
1–1/2	570	807	1,141	745	1,868		
2	1,182	1,672	2,364	1,246			
2–1/2	1,966	2,780		1,788	2,682	3,575	
3	3,651	5,163	3,931	2,786	4,179	5,572	6,965
4	7,843	11,091		4,849	7,274	9,699	12,124
5	14,669			7,674	11,511	15,348	19,185
6	23,848			10,995	16,493	21,990	27,488
8				19,261	28,892	38,522	48,153

(*Continued*)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
10				31,493	47,239	62,985	78,732
12				45,738	68,607	91,476	114,345
14				55,987	83,981	111,974	139,968
16				74,539	111,808	149,078	186,347
18				95,741	143,612	191,482	239,353
20				119,594	179,390	239,187	298,984
22				146,096	219,144	292,193	365,241
24				175,249	262,874	350,499	438,123
26				207,053	310,579	414,105	517,631
28				241,506	362,259	483,012	603,765
30	Velocity these	governs pipe	with sizes	278,610	417,915	557,220	696,525
32				318,364	477,546	636,728	795,910
34				360,768	541,152	721,537	901,921
36				405,823	608,734	811,646	1,014,557
42				556,888	835,333	1,113,777	1,392,221
48				731,806	1,097,710	1,463,613	1,829,516
54				930,577	1,395,865	1,861,154	2,326,442
60				1,153,200	1,729,800	2,306,399	2,882,999
72				1,670,003	2,505,004	3,340,006	4,175,007
84				2,282,216	3,423,324	4,564,431	5,705,539
96				2,989,838	4,484,758	5,979,677	7,474,596
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	33	46	66				
3/4	80	114	161		Pressure with these		
1	168	238	337			drop pipe	governs sizes
1–1/4	388	549	776	603			
1–1/2	613	867	1,227	831	2,084		
2	1,271	1,798	2,542	1,389			
2–1/2	2,114	2,989		1,994	2,991	3,988	
3	3,926	5,552	4,228	3,107	4,661	6,215	7,768
4	8,434	11,928		5,409	8,113	10,817	13,521
5	15,775			8,559	12,839	17,118	21,398
6	25,646			12,263	18,394	24,526	30,657
8				21,482	32,223	42,964	53,705
10				35,124	52,686	70,248	87,810
12				51,012	76,517	102,023	127,529
14				62,443	93,664	124,885	156,106
16				83,134	124,700	166,267	207,834
18				106,780	160,171	213,561	266,951
20				133,383	200,075	266,766	333,458
22				162,942	244,413	325,883	407,354
24				195,456	293,184	390,912	488,640
26		governs pipe	with sizes	230,926	346,390	461,853	577,316
28				269,353	404,029	538,705	673,382
30	Velocity these			310,735	466,102	621,469	776,837
32				355,073	532,609	710,145	887,681
34				402,366	603,549	804,733	1,005,916
36				452,616	678,924	905,232	1,131,540
42				621,100	931,650	1,242,200	1,552,750
48				816,187	1,224,280	1,632,373	2,040,467
54				1,037,876	1,556,814	2,075,752	2,594,690
60				1,286,168	1,929,252	2,572,336	3,215,421
72				1,862,561	2,793,841	3,725,122	4,656,402
84				2,545,364	3,818,046	5,090,729	6,363,411
96				3,334,579	5,001,868	6,669,157	8,336,447
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	36	51	73				
3/4	89	126	178		Pressure with these		
1	187	264	373			drop pipe	governs sizes
1–1/4	430	608	860	703			
1–1/2	680	961	1,360	969	2,428		
2	1,409	1,992	2,818	1,618			

(*Continued*)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
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	15,753
4	9,348	13,220		6,301	9,452	12,602	
5	17,484			9,971	14,957	19,943	24,929
6	28,425	24,726		14,286	21,430	28,573	35,716
8	60,185			25,027	37,540	50,054	62,567
10				40,920	61,380	81,840	102,300
12				59,430	89,144	118,859	148,574
14				72,747	109,120	145,494	181,867
16				96,852	145,278	193,705	242,131
18				124,401	186,602	248,803	311,004
20				155,394	233,091	310,788	388,485
22				189,831	284,746	379,661	474,576
24				227,711	341,566	455,421	569,276
26			with	269,034	403,551	538,068	672,585
28	Velocity	governs	sizes	313,801	470,702	627,603	784,504
30	these	pipe		362,012	543,019	724,025	905,031
32				413,667	620,500	827,334	1,034,167
34				468,765	703,148	937,530	1,171,913
36				527,307	790,960	1,054,614	1,318,267
42				723,594	1,085,391	1,447,189	1,808,986
48				950,874	1,426,312	1,901,749	2,377,186
54				1,209,147	1,813,721	2,418,294	3,022,868
60				1,498,413	2,247,619	2,996,825	3,746,032
72				2,169,922	3,254,883	4,339,844	5,424,805
84				2,965,402	4,448,103	5,930,805	7,413,506
96				3,884,854	5,827,280	7,769,707	9,712,134
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	43	60	85		Pressure		
3/4	105	148	209		with these	drop	governs
1	219	310	438			pipe	sizes
1–1/4	504	713	1,008	887			
1–1/2	797	1,127	1,594	1,222	3,062		
2	1,652	2,337	3,305	2,042			
2–1/2	2,748	3,886	5,495	2,930	4,395	9,134	
3	5,103	7,217	10,206	4,567	6,850	15,898	19,872
4	10,964	15,505		7,949	11,923		
5	20,505			12,579	18,869	25,158	31,448
6	33,337	28,999		18,022	27,034	36,045	45,056
8	70,587			31,572	47,357	63,143	78,929
10				51,621	77,431	103,242	129,052
12				74,971	112,456	149,942	187,427
14				91,771	137,656	183,541	229,427
16				122,180	183,270	244,360	305,450
18				156,933	235,400	313,866	392,333
20				196,031	294,046	392,062	490,077
22				239,472	359,209	478,945	598,681
24			with	287,258	430,888	574,517	718,146
26	Velocity	governs	sizes	339,388	509,083	678,777	848,471
28	these	pipe		395,863	593,794	791,725	989,657
30				456,681	685,022	913,362	1,141,703
32				521,844	782,765	1,043,687	1,304,609
34				591,350	887,026	1,182,701	1,478,376
36				665,201	997,802	1,330,403	1,663,003
42				912,819	1,369,229	1,825,638	2,282,048
48				1,199,534	1,799,302	2,399,069	2,998,836
54				1,525,347	2,288,021	3,050,695	3,813,368
60				1,890,258	2,835,387	3,780,516	4,725,644

(*Continued*)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
72				2,737,371	4,106,057	5,474,743	6,843,428
84				3,740,875	5,611,312	7,481,750	9,352,187
96				4,900,769	7,351,153	9,801,538	12,251,922
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	49	70	99		Pressure		
3/4	121	171	243		with these	drop	governs
1	254	359	508			pipe	sizes
1–1/4	585	827	1,169	1,095			
1–1/2	924	1,307	1,849	1,509	3,782		
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	24,539
4	12,712	17,977		9,816	14,724		
5	23,775	33,622		15,533	23,300	31,067	38,833
6	38,652	54,662		22,255	33,383	44,510	55,638
8	81,840			38,986	58,479	77,973	97,466
10				63,744	95,616	127,489	159,361
12	156,896			92,578	138,867	185,156	231,445
14				113,323	169,985	226,646	283,308
16				150,874	226,311	301,748	377,185
18				193,789	290,684	387,579	484,474
20				242,069	363,104	484,138	605,173
22				295,713	443,570	591,427	739,283
24				354,722	532,083	709,444	886,805
26			with	419,095	628,642	838,190	1,047,737
28			sizes	488,832	733,248	977,664	1,222,080
30		governs		563,934	845,901	1,127,868	1,409,835
32	Velocity	pipe		644,400	966,600	1,288,800	1,611,000
34	these			730,231	1,095,346	1,460,461	1,825,577
36				821,426	1,232,139	1,642,852	2,053,564
42				1,127,197	1,690,796	2,254,395	2,817,993
48				1,481,249	2,221,873	2,962,497	3,703,122
54				1,883,580	2,825,369	3,767,159	4,708,949
60				2,334,190	3,501,285	4,668,381	5,835,476
72				3,380,251	5,070,376	6,760,502	8,450,627
84				4,619,430	6,929,146	9,238,861	11,548,576
96				6,051,729	9,077,593	12,103,457	15,129,322
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	57	80	114				
3/4	139	197	279				
1	292	413	584		Pressure	drop	
1–1/4	672	951	1,345	1,332	with these	pipe	governs
1–1/2	1,063	1,504	2,127	1,835			sizes
2	2,204	3,117	4,408	3,066			
2–1/2	3,665	5,183	7,329	4,401	6,601		
3	6,806	9,625	13,612	6,858	10,287	23,875	
4	14,622	20,679	29,244	11,937	17,906		
5	27,348	38,676		18,891	28,336	37,781	47,227
6	44,462	62,879		27,065	40,598	54,130	67,663
8	94,142			47,413	71,119	94,826	118,532
10				77,522	116,283	155,044	193,805
12	180,480			112,588	168,882	225,176	281,470
14			with	137,817	206,725	275,634	344,542
16		governs	sizes	183,484	275,226	366,968	458,710
18		pipe		235,675	353,513	471,350	589,188
20	Velocity			294,390	441,585	588,780	735,975
22	these			359,629	539,443	719,258	899,072
24				431,392	647,087	862,783	1,078,479
26				509,678	764,517	1,019,356	1,274,195

(*Continued*)

120 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				594,489	891,733	1,188,977	1,486,222
30				685,823	1,028,734	1,371,646	1,714,557
32				783,681	1,175,522	1,567,362	1,959,203
34				888,063	1,332,095	1,776,127	2,220,158
36				998,969	1,498,454	1,997,939	2,497,423
42				1,370,830	2,056,246	2,741,661	3,427,076
48				1,801,407	2,702,110	3,602,813	4,503,517
54				2,290,698	3,436,047	4,581,395	5,726,744
60				2,838,704	4,258,056	5,677,407	7,096,759
72				4,110,860	6,166,291	8,221,721	10,277,151
84				5,617,877	8,426,815	11,235,754	14,044,692
96				7,359,753	11,039,630	14,719,506	18,399,383
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	74	105	148				
3/4	182	257	363				
1	381	538	761		Pressure	drop	
1–1/4	876	1,239	1,752	2,626	with these	pipe	governs
1–1/2	1,385	1,959	2,770	4,387			sizes
2	2,871	4,060	5,742				
2–1/2	4,774	6,751	9,548	6,297	9,446		
3	8,866	12,539	17,733	9,814	14,721	34,163	
4	19,048	26,939	38,097	17,081	25,622		
5	35,627	50,384		27,031	40,547	54,063	67,578
6	57,921	81,913		38,729	58,093	77,457	96,821
8	122,639			67,845	101,767	135,689	169,611
10	235,113			110,929	166,393	221,858	277,322
12	383,762			161,106	241,659	322,212	402,765
14				197,207	295,810	394,414	493,017
16				262,554	393,830	525,107	656,384
18				337,236	505,853	674,471	843,089
20				421,253	631,879	842,506	1,053,132
22				514,605	771,908	1,029,210	1,286,513
24				617,293	925,939	1,234,586	1,543,232
26			with	729,316	1,093,974	1,458,631	1,823,289
28		governs	sizes	850,674	1,276,011	1,701,348	2,126,685
30		pipe		981,367	1,472,051	1,962,734	2,453,418
32	Velocity			1,121,396	1,682,094	2,242,792	2,803,490
34	these			1,270,760	1,906,140	2,541,519	3,176,899
36				1,429,459	2,144,188	2,858,918	3,573,647
42				1,961,568	2,942,351	3,923,135	4,903,919
48				2,577,693	3,866,540	5,155,387	6,444,234
54				3,277,837	4,916,755	6,555,673	8,194,591
60				4,061,997	6,092,995	8,123,994	10,154,992
72				5,882,369	8,823,553	11,764,738	14,705,922
84				8,038,810	12,058,214	16,077,619	20,097,024
96				10,531,319	15,796,979	21,062,638	26,328,298

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	19	27	38		Pressure	drop	
3/4	47	67	94	90	with these	pipe	
1	99	140	197	150			governs sizes
1–1/4	227	321	455	267	401		
1–1/2	359	508	719	369	553		
2	745	1,053	1,490	616	924	1,232	
2–1/2	1,239	1,752		884	1,326	1,768	2,210
3	2,300	3,253		1,377	2,066	2,755	3,443
4	4,942			2,397	3,596	4,795	5,994
5	9,243			3,794	5,691	7,588	9,485
6				5,436	8,153	10,871	13,589
8				9,522	14,283	19,044	23,805
10				15,569	23,354	31,138	38,923
12				22,612	33,917	45,223	56,529
14				27,679	41,518	55,357	69,196
16				36,850	55,275	73,700	92,125
18				47,332	70,998	94,664	118,330
20				59,124	88,686	118,248	147,810
22				72,226	108,339	144,452	180,565
24			with sizes	86,639	129,958	173,277	216,597
26		governs pipe		102,361	153,542	204,723	255,903
28	Velocity these			119,394	179,091	238,789	298,486
30				137,737	206,606	275,475	344,344
32				157,391	236,086	314,782	393,477
34				178,354	267,532	356,709	445,886
36				200,628	300,942	401,257	501,571
42				275,311	412,967	550,622	688,278
48				361,786	542,679	723,572	904,465
54				460,053	690,079	920,106	1,150,132
60				570,112	855,168	1,140,224	1,425,280
72				825,606	1,238,409	1,651,212	2,064,015
84				1,128,268	1,692,402	2,256,536	2,820,670
96				1,478,098	2,217,147	2,956,197	3,695,246
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	24	34	49		Pressure	drop	
3/4	60	85	120		with these	pipe	
1	125	177	250	218			governs sizes
1–1/4	288	408	576	389			
1–1/2	456	645	911	536	804		
2	945	1,336	1,889	895	1,343	1,791	
2–1/2	1,571	2,221	3,142	1,285	1,928	2,570	
3	2,917	4,126		2,003	3,004	4,005	5,007
4	6,267			3,486	5,229	6,972	8,715
5	11,722			5,516	8,275	11,033	13,791
6	19,057			7,904	11,855	15,807	19,759
8				13,845	20,768	27,691	34,614
10				22,638	33,957	45,276	56,595
12				32,878	49,317	65,756	82,195
14				40,245	60,368	80,491	100,613
16				53,581	80,371	107,162	133,952
18		governs pipe	with sizes	68,822	103,233	137,644	172,054
20	Velocity these			85,968	128,952	171,935	214,919
22				105,019	157,528	210,037	262,547
24				125,975	188,962	251,950	314,937
26				148,836	223,254	297,672	372,090
28				173,602	260,404	347,205	434,006
30				200,274	300,411	400,548	500,684
32				228,850	343,275	457,701	572,126

(*Continued*)

125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
34				259,332	388,998	518,664	648,330
36				291,719	437,578	583,437	729,297
42				400,309	600,464	800,619	1,000,774
48				526,046	789,069	1,052,092	1,315,115
54				668,929	1,003,393	1,337,858	1,672,322
60				828,957	1,243,436	1,657,915	2,072,393
72				1,200,452	1,800,678	2,400,904	3,001,130
84				1,640,531	2,460,796	3,281,061	4,101,326
96				2,149,193	3,223,789	4,298,385	5,372,982
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	27	37	53				
3/4	65	92	130	248	Pressure	drop	
1	136	192	272		with these	pipe	governs
1–1/4	313	443	627	442			sizes
1–1/2	495	701	991	609	914	2,037	
2	1,027	1,452	2,054	1,018	1,527		
2–1/2	1,708	2,415		1,462	2,192	2,923	
3	3,171	4,485	3,415	2,278	3,417	4,556	5,694
4	6,813	9,635		3,965	5,947	7,929	9,912
5	12,743			6,274	9,411	12,548	15,685
6	20,717			8,989	13,483	17,978	22,472
8				15,747	23,620	31,494	39,367
10				25,747	38,620	51,494	64,367
12				37,393	56,090	74,786	93,483
14				45,772	68,658	91,544	114,431
16				60,939	91,409	121,879	152,348
18				78,273	117,410	156,546	195,683
20				97,774	146,661	195,548	244,435
22				119,441	179,162	238,882	298,603
24				143,275	214,913	286,550	358,188
26		governs	with	169,276	253,914	338,552	423,190
28		pipe	sizes	197,444	296,165	394,887	493,609
30	Velocity			227,778	341,667	455,556	569,445
32	these			260,279	390,418	520,558	650,697
34				294,947	442,420	589,893	737,366
36				331,781	497,672	663,562	829,453
42				455,285	682,927	910,570	1,138,212
48				598,289	897,434	1,196,579	1,495,723
54				760,794	1,141,191	1,521,589	1,901,986
60				942,800	1,414,200	1,885,600	2,357,000
72				1,365,313	2,047,969	2,730,626	3,413,282
84				1,865,828	2,798,743	3,731,657	4,664,571
96				2,444,346	3,666,519	4,888,692	6,110,865
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	30	42	59				
3/4	73	103	146	296	Pressure		
1	153	216	305		with these	drop	governs
1–1/4	351	497	703	527		pipe	sizes
1–1/2	556	786	1,111	726	1,089		
2	1,152	1,629	2,304	1,214	1,820		
2–1/2	1,915	2,709		1,742	2,613	3,484	
3	3,557	5,030	3,830	2,715	4,072	5,429	6,787
4	7,642	10,807		4,725	7,088	9,450	11,813
5	14,293			7,478	11,216	14,955	18,694
6	23,237			10,713	16,070	21,427	26,783
8				18,768	28,151	37,535	46,919
10				30,686	46,029	61,372	76,715
12				44,566	66,849	89,132	111,415
14				54,553	81,829	109,105	136,382

(*Continued*)

125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				72,629	108,944	145,259	181,573
18				93,288	139,932	186,577	233,221
20				116,530	174,794	233,059	291,324
22				142,353	213,530	284,707	355,884
24				170,760	256,139	341,519	426,899
26				201,748	302,622	403,496	504,370
28				235,319	352,978	470,638	588,297
30				271,472	407,208	542,944	678,680
32	Velocity these	governs pipe	with sizes	310,208	465,312	620,416	775,519
34				351,526	527,289	703,051	878,814
36				395,426	593,139	790,852	988,565
42				542,621	813,932	1,085,243	1,356,554
48				713,058	1,069,587	1,426,116	1,782,645
54				906,736	1,360,104	1,813,473	2,266,841
60				1,123,656	1,685,484	2,247,312	2,809,139
72				1,627,219	2,440,828	3,254,438	4,068,047
84				2,223,747	3,335,621	4,447,495	5,559,368
96				2,913,241	4,369,862	5,826,483	7,283,103
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	32	45	64		Pressure with these		
3/4	78	111	157			drop pipe	governs sizes
1	164	232	328				
1–1/4	378	534	755	587			
1–1/2	597	844	1,194	809			
2	1,237	1,750	2,475	1,352	2,028		
2–1/2	2,058	2,910	4,115	1,941	2,911	3,882	
3	3,821	5,404		3,025	4,537	6,049	7,562
4	8,210	11,610		5,265	7,897	10,529	13,162
5	15,355			8,331	12,497	16,662	20,828
6	24,963			11,936	17,905	23,873	29,841
8				20,910	31,365	41,820	52,275
10				34,189	51,283	68,378	85,472
12				49,654	74,481	99,308	124,134
14				60,780	91,171	121,561	151,951
16				80,921	121,381	161,841	202,301
18				103,938	155,907	207,876	259,845
20				129,833	194,749	259,665	324,581
22				158,604	237,907	317,209	396,511
24				190,253	285,380	380,507	475,633
26		governs pipe	with sizes	224,779	337,169	449,559	561,948
28				262,183	393,274	524,365	655,457
30	Velocity these			302,463	453,695	604,926	756,158
32				345,621	518,431	691,242	864,052
34				391,656	587,483	783,311	979,139
36				440,568	660,851	881,135	1,101,419
42				604,567	906,850	1,209,133	1,511,417
48				794,460	1,191,690	1,588,921	1,986,151
54				1,010,248	1,515,373	2,020,497	2,525,621
60				1,251,931	1,877,897	2,503,863	3,129,828
72				1,812,981	2,719,471	3,625,961	4,532,452
84				2,477,608	3,716,412	4,955,217	6,194,021
96				3,245,814	4,868,722	6,491,629	8,114,536
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	35	50	71		Pressure with these		
3/4	87	123	173			drop pipe	governs sizes
1	181	257	363				
1–1/4	418	591	836	683			
1–1/2	661	934	1,321	941			
2	1,369	1,936	2,739	1,573	2,359		

(*Continued*)

125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	2,277	3,220	4,554	2,258	3,386	4,515	
3	4,229	5,980	8,457	3,518	5,277	7,036	
4	9,085	12,848		6,124	9,186	12,248	15,309
5	16,992	24,030		9,691	14,536	19,382	24,227
6	27,625			13,884	20,827	27,769	34,711
8	58,492			24,323	36,484	48,645	60,806
10				39,769	59,653	79,537	99,421
12				57,757	86,636	115,514	144,393
14				70,700	106,049	141,399	176,749
16				94,127	141,190	188,253	235,317
18				120,900	181,351	241,801	302,251
20				151,021	226,531	302,042	377,552
22				184,488	276,732	368,976	461,220
24				221,302	331,953	442,604	553,255
26				261,463	392,194	522,926	653,657
28	Velocity	governs	with	304,970	457,455	609,941	762,426
30	these	pipe	sizes	351,824	527,737	703,649	879,561
32				402,025	603,038	804,051	1,005,063
34				455,573	683,359	911,146	1,138,932
36				512,467	768,701	1,024,934	1,281,168
42				703,231	1,054,846	1,406,461	1,758,076
48				924,114	1,386,171	1,848,229	2,310,286
54				1,175,119	1,762,678	2,350,237	2,937,797
60				1,456,244	2,184,365	2,912,487	3,640,609
72				2,108,855	3,163,282	4,217,710	5,272,137
84				2,881,948	4,322,922	5,763,896	7,204,871
96				3,775,524	5,663,285	7,551,047	9,438,809
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	41	58	83		Pressure		
3/4	101	143	203		with these	drop	governs
1	212	300	425			pipe	sizes
1–1/4	489	691	977	860			
1–1/2	773	1,093	1,545	1,184	2,968		
2	1,602	2,265	3,203	1,979			
2–1/2	2,663	3,766	5,326	2,840	4,260		
3	4,946	6,995	9,892	4,426	6,639	8,852	
4	10,626	15,027		7,704	11,556	15,408	19,260
5	19,874	28,106		12,192	18,287	24,383	30,479
6	32,310			17,467	26,201	34,935	43,668
8	68,413			30,599	45,899	61,198	76,498
10				50,031	75,047	100,062	125,078
12				72,662	108,993	145,323	181,654
14				88,944	133,416	177,888	222,360
16				118,417	177,625	236,833	296,041
18				152,100	228,149	304,199	380,249
20				189,993	284,989	379,986	474,982
22				232,097	348,145	464,193	580,241
24				278,411	417,616	556,821	696,026
26				328,935	493,402	657,870	822,337
28	Velocity	governs	with	383,670	575,505	767,340	959,174
30	these	pipe	sizes	442,615	663,922	885,230	1,106,537
32				505,770	758,656	1,011,541	1,264,426
34				573,136	859,704	1,146,273	1,432,841
36				644,713	967,069	1,289,425	1,611,781
42				884,704	1,327,055	1,769,407	2,211,759
48				1,162,588	1,743,882	2,325,176	2,906,470
54				1,478,365	2,217,548	2,956,731	3,695,913
60				1,832,036	2,748,054	3,664,073	4,580,091
72				2,653,058	3,979,587	5,306,116	6,632,645
84				3,625,653	5,438,479	7,251,306	9,064,132
96				4,749,821	7,124,732	9,499,642	11,874,553

(*Continued*)

125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	48	68	96				
3/4	117	166	234		Pressure with these		
1	245	347	491			drop pipe	governs sizes
1–1/4	565	799	1,130	1,058			
1–1/2	893	1,263	1,786	1,458	3,654		
2	1,851	2,618	3,703	2,436			
2–1/2	3,079	4,354	6,157	3,497	5,245		
3	5,718	8,086	11,435	5,450	8,175	10,899	
4	12,284	17,372		9,486	14,228	18,971	23,714
5	22,975	32,491		15,011	22,516	30,022	37,527
6	37,352	52,824		21,507	32,260	43,013	53,766
8	79,088			37,675	56,513	75,350	94,188
10	151,620			61,600	92,401	123,201	154,001
12				89,464	134,197	178,929	223,661
14				109,512	164,268	219,024	273,780
16				145,800	218,700	291,600	364,500
18				187,272	280,908	374,544	468,180
20				233,928	350,892	467,856	584,820
22				285,768	428,652	571,536	714,419
24				342,792	514,188	685,583	856,979
26			with sizes	405,000	607,500	809,999	1,012,499
28		governs pipe		472,392	708,587	944,783	1,180,979
30				544,968	817,451	1,089,935	1,362,419
32	Velocity these			622,727	934,091	1,245,455	1,556,819
34				705,671	1,058,507	1,411,343	1,764,179
36				793,799	1,190,699	1,587,599	1,984,498
42				1,089,287	1,633,931	2,178,574	2,723,218
48				1,431,431	2,147,146	2,862,862	3,578,577
54				1,820,231	2,730,346	3,640,461	4,550,576
60				2,255,686	3,383,529	4,511,372	5,639,215
72				3,266,565	4,899,848	6,533,131	8,166,413
84				4,464,068	6,696,102	8,928,137	11,160,171
96				5,848,195	8,772,293	11,696,390	14,620,488
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	55	77	110				
3/4	134	190	269				
1	281	398	563				
1–1/4	648	916	1,295	1,283	Pressure with these	drop pipe	
1–1/2	1,024	1,449	2,049	1,768			governs sizes
2	2,123	3,002	4,246	2,954			
2–1/2	3,530	4,993	7,061	4,239	6,359		
3	6,556	9,272	13,113	6,607	9,910		
4	14,086	19,921	28,172	11,499	17,249	22,999	
5	26,345	37,258		18,198	27,297	36,396	45,495
6	42,831	60,573		26,073	39,109	52,145	65,182
8	90,689			45,674	68,511	91,348	114,185
10	173,861			74,679	112,018	149,358	186,697
12				108,459	162,688	216,918	271,147
14				132,763	199,144	265,525	331,906
16				176,755	265,132	353,510	441,887
18			with sizes	227,032	340,548	454,064	567,580
20		governs pipe		283,593	425,390	567,187	708,984
22				346,440	519,659	692,879	866,099
24	Velocity these			415,570	623,356	831,141	1,038,926
26				490,986	736,479	981,972	1,227,465
28				572,686	859,029	1,145,372	1,431,715
30				660,671	991,006	1,321,341	1,651,676
32				754,940	1,132,410	1,509,880	1,887,350

(*Continued*)

125 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				855,494	1,283,241	1,710,987	2,138,734
36				962,332	1,443,498	1,924,665	2,405,831
42				1,320,556	1,980,833	2,641,111	3,301,389
48				1,735,340	2,603,011	3,470,681	4,338,351
54				2,206,687	3,310,030	4,413,374	5,516,717
60				2,734,595	4,101,892	5,469,189	6,836,487
72				3,960,095	5,940,143	7,920,191	9,900,239
84				5,411,842	8,117,764	10,823,685	13,529,606
96				7,089,836	10,634,753	14,179,671	17,724,589
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	71	100	142				
3/4	174	246	348				
1	364	515	728		Pressure	drop	
1–1/4	838	1,185	1,675		with these	pipe	
1–1/2	1,325	1,873	2,649	2,511			governs
2	2,746	3,883	5,491	4,196			sizes
2–1/2	4,566	6,457	9,132	6,022	9,034		
3	8,480	11,992	16,959	9,386	14,079	32,673	
4	18,218	25,764	36,436	16,337	24,505		
5	34,073	48,187		25,853	38,779	51,705	64,632
6	55,395	78,341		37,040	55,560	74,080	92,600
8	117,291			64,886	97,329	129,773	162,216
10	224,861			106,092	159,138	212,184	265,230
12	367,028			154,081	231,121	308,162	385,202
14				188,608	282,912	377,216	471,520
16				251,105	376,658	502,210	627,763
18				322,531	483,796	645,061	806,326
20				402,884	604,326	805,768	1,007,210
22				492,166	738,249	984,332	1,230,415
24				590,376	885,564	1,180,752	1,475,940
26			with	697,514	1,046,271	1,395,028	1,743,785
28		governs	sizes	813,581	1,220,371	1,627,161	2,033,951
30		pipe		938,575	1,407,863	1,877,150	2,346,438
32	Velocity			1,072,498	1,608,747	2,144,996	2,681,244
34	these			1,215,349	1,823,023	2,430,697	3,038,372
36				1,367,128	2,050,692	2,734,256	3,417,819
42				1,876,034	2,814,051	3,752,068	4,690,085
48				2,465,294	3,697,941	4,930,588	6,163,235
54				3,134,908	4,702,361	6,269,815	7,837,269
60				3,884,875	5,827,312	7,769,750	9,712,187
72				5,625,870	8,438,805	11,251,740	14,064,676
84				7,688,280	11,532,420	15,376,560	19,220,700
96				10,072,105	15,108,157	20,144,209	25,180,261

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	18	25	35				
3/4	43	61	86	82	Pressure	drop	
1	90	128	180	137	with these	pipe	governs
1–1/4	208	294	415	244	367		sizes
1–1/2	328	464	657	337	505	1,125	
2	680	962	1,361	563	844		

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	1,131	1,600		807	1,211	1,615	2,018
3	2,101	2,972		1,258	1,887	2,516	3,146
4	4,515			2,190	3,285	4,380	5,475
5				3,466	5,199	6,932	8,664
6	8,444			4,966	7,448	9,931	12,414
8				8,699	13,048	17,397	21,746
10				14,223	21,334	28,445	35,556
12				20,656	30,984	41,312	51,640
14				25,285	37,927	50,569	63,212
16				33,663	50,494	67,326	84,157
18				43,238	64,857	86,476	108,095
20				54,010	81,015	108,021	135,026
22				65,979	98,969	131,959	164,948
24			with	79,145	118,718	158,291	197,863
26		governs	sizes	93,508	140,262	187,016	233,770
28		pipe		109,068	163,602	218,136	272,670
30	Velocity			125,825	188,737	251,649	314,561
32	these			143,778	215,667	287,556	359,445
34				162,929	244,393	325,857	407,322
36				183,276	274,914	366,552	458,190
42				251,500	377,249	502,999	628,749
48				330,495	495,743	660,990	826,238
54				420,263	630,395	840,526	1,050,658
60				520,803	781,204	1,041,606	1,302,007
72				754,199	1,131,299	1,508,399	1,885,498
84				1,030,684	1,546,026	2,061,368	2,576,711
96				1,350,258	2,025,387	2,700,515	3,375,644
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	22	31	44		Pressure	drop	
3/4	54	76	108	197	with these	pipe	
1	113	160	226				governs
1–1/4	261	369	521	352	727		sizes
1–1/2	412	583	824	485	1,215	1,619	
2	854	1,208	1,708	810			
2–1/2	1,420	2,009		1,162	1,743	2,324	4,528
3	2,638	3,731	2,841	1,811	2,717	3,622	7,881
4	5,668			3,152	4,729	6,305	
5	10,601			4,989	7,483	9,977	12,472
6	17,234			7,147	10,721	14,295	17,869
8				12,521	18,781	25,042	31,302
10				20,472	30,708	40,944	51,180
12				29,732	44,599	59,465	74,331
14				36,395	54,592	72,790	90,987
16				48,455	72,682	96,910	121,137
18				62,238	93,356	124,475	155,594
20				77,743	116,615	155,486	194,358
22				94,972	142,457	189,943	237,429
24				113,923	170,884	227,846	284,807
26		governs	with	134,597	201,895	269,194	336,492
28		pipe	sizes	156,994	235,491	313,988	392,484
30	Velocity			181,114	271,670	362,227	452,784
32	these			206,956	310,434	413,912	517,390
34				234,522	351,782	469,043	586,304
36				263,810	395,715	527,620	659,525
42				362,012	543,018	724,023	905,029
48				475,719	713,579	951,438	1,189,298
54				604,932	907,398	1,209,864	1,512,330
60				749,651	1,124,476	1,499,301	1,874,127
72				1,085,604	1,628,407	2,171,209	2,714,011
84				1,483,580	2,225,370	2,967,161	3,708,951
96				1,943,579	2,915,368	3,887,157	4,858,946

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	24	34	48				
3/4	59	83	117	223	Pressure with these	drop pipe	
1	123	173	245				governs sizes
1–1/4	282	399	564	398			
1–1/2	446	631	892	549	823	1,834	
2	925	1,308	1,850	917	1,376		
2–1/2	1,538	2,175		1,316	1,975	2,633	
3	2,856	4,039	3,076	2,051	3,077	4,103	5,129
4	6,136	8,678		3,571	5,356	7,142	8,927
5	11,477			5,651	8,476	11,301	14,127
6	18,659			8,096	12,144	16,192	20,240
8				14,182	21,274	28,365	35,456
10				23,189	34,784	46,378	57,973
12				33,678	50,517	67,356	84,195
14				41,225	61,837	82,450	103,062
16				54,885	82,328	109,770	137,213
18				70,497	105,746	140,994	176,243
20				88,060	132,090	176,121	220,151
22				107,575	161,363	215,150	268,938
24				129,041	193,562	258,082	322,603
26				152,459	228,688	304,918	381,147
28		governs pipe	with sizes	177,828	266,742	355,656	444,570
30	Velocity these			205,149	307,723	410,297	512,872
32				234,421	351,631	468,842	586,052
34				265,644	398,467	531,289	664,111
36				298,819	448,229	597,639	747,049
42				410,054	615,080	820,107	1,025,134
48				538,851	808,276	1,077,702	1,347,127
54				685,211	1,027,817	1,370,423	1,713,028
60				849,135	1,273,703	1,698,270	2,122,838
72				1,229,673	1,844,509	2,459,345	3,074,182
84				1,680,463	2,520,695	3,360,926	4,201,158
96				2,201,507	3,302,260	4,403,014	5,503,767
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	27	38	53				
3/4	65	92	131	265	Pressure with these		
1	137	193	273			drop pipe	governs sizes
1–1/4	315	445	629	472			
1–1/2	497	704	995	650	975		
2	1,031	1,458	2,062	1,087	1,630		
2–1/2	1,715	2,425		1,559	2,339	3,119	
3	3,184	4,503	3,429	2,430	3,646	4,861	6,076
4	6,841	9,675		4,230	6,345	8,461	10,576
5	12,796			6,694	10,042	13,389	16,736
6	20,803			9,591	14,387	19,182	23,978
8				16,802	25,203	33,604	42,005
10				27,472	41,208	54,944	68,680
12				39,898	59,847	79,797	99,746
14				48,839	73,258	97,678	122,097
16				65,022	97,533	130,044	162,555
18		governs pipe	with sizes	83,517	125,276	167,035	208,793
20				104,324	156,486	208,649	260,811
22	Velocity these			127,443	191,165	254,887	318,608
24				152,874	229,311	305,748	382,185
26				180,617	270,925	361,234	451,542
28				210,672	316,007	421,343	526,679
30				243,038	364,557	486,076	607,595
32				277,717	416,575	555,433	694,291

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				314,707	472,060	629,414	786,767
36				354,009	531,014	708,018	885,023
42				485,787	728,681	971,575	1,214,468
48				638,372	957,559	1,276,745	1,595,931
54				811,765	1,217,647	1,623,529	2,029,412
60				1,005,964	1,508,946	2,011,928	2,514,910
72				1,456,784	2,185,176	2,913,568	3,641,960
84				1,990,832	2,986,248	3,981,664	4,977,080
96				2,608,108	3,912,162	5,216,217	6,520,271
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	28	40	57		Pressure		
3/4	70	99	140		with these	drop	governs
1	146	207	292			pipe	sizes
1–1/4	337	476	673	524			
1–1/2	532	753	1,065	721	1,808		
2	1,103	1,560	2,206	1,206			
2–1/2	1,835	2,594		1,730	2,596	3,461	6,742
3	3,407	4,818	3,669	2,697	4,045	5,394	11,735
4	7,320	10,352		4,694	7,041	9,388	
5	13,691			7,428	11,142	14,856	18,571
6	22,258			10,643	15,964	21,285	26,607
8				18,644	27,966	37,287	46,609
10				30,483	45,725	60,967	76,208
12				44,272	66,408	88,544	110,680
14				54,193	81,289	108,385	135,482
16				72,150	108,225	144,300	180,375
18				92,673	139,009	185,345	231,681
20				115,761	173,641	231,521	289,401
22				141,414	212,121	282,828	353,535
24				169,632	254,449	339,265	424,081
26		governs	with	200,416	300,625	400,833	501,041
28		pipe	sizes	233,766	350,649	467,531	584,414
30	Velocity			269,680	404,521	539,361	674,201
32	these			308,160	462,240	616,321	770,401
34				349,206	523,808	698,411	873,014
36				392,816	589,224	785,632	982,041
42				539,040	808,560	1,078,080	1,347,600
48				708,352	1,062,528	1,416,704	1,770,880
54				900,752	1,351,127	1,801,503	2,251,879
60				1,116,239	1,674,359	2,232,479	2,790,598
72				1,616,479	2,424,718	3,232,958	4,041,197
84				2,209,070	3,313,605	4,418,140	5,522,675
96				2,894,013	4,341,020	5,788,027	7,235,033
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	31	44	63		Pressure		
3/4	77	109	154		with these	drop	governs
1	161	227	322			pipe	sizes
1–1/4	370	524	740	605			
1–1/2	585	828	1,171	834	2,091		
2	1,213	1,716	2,427	1,394			
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	13,566
4	8,050	11,385		5,426	8,140	10,853	
5	15,057			8,587	12,881	17,174	21,468
6	24,479	21,293		12,303	18,455	24,606	30,758
8	51,830			21,553	32,329	43,105	53,882
10				35,240	52,859	70,479	88,099
12				51,180	76,769	102,359	127,949
14				62,648	93,972	125,296	156,620

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
16 18 20	Velocity these	governs pipe	with sizes	83,407 107,132 133,822	125,111 160,698 200,734	166,815 214,264 267,645	208,518 267,830 334,556
22 24 26				163,478 196,100 231,687	245,217 294,150 347,530	326,957 392,200 463,374	408,696 490,250 579,217
28 30 32				270,240 311,758 356,242	405,359 467,637 534,363	540,479 623,516 712,484	675,599 779,395 890,605
34 36 42				403,691 454,106 623,145	605,537 681,160 934,718	807,383 908,213 1,246,290	1,009,228 1,135,266 1,557,863
48 54 60				818,874 1,041,294 1,290,404	1,228,312 1,561,941 1,935,605	1,637,749 2,082,588 2,580,807	2,047,186 2,603,235 3,226,009
72 84 96				1,868,694 2,553,746 3,345,560	2,803,041 3,830,619 5,018,339	3,737,389 5,107,493 6,691,119	4,671,736 6,384,366 8,363,899
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2 3/4 1	36 89 186	51 126 263	72 178 372		Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	428 677 1,404	606 958 1,986	857 1,355 2,808	754 1,038 1,735	2,602		
2–1/2 3 4	2,335 4,336 9,316	3,302 6,132 13,174	4,669 8,672	2,490 3,880 6,754	3,735 5,821 10,131	7,761 13,508	16,885
5 6 8	17,423 28,326 59,977	24,640	with sizes	10,688 15,313 26,826	16,032 22,970 40,239	21,377 30,627 53,652	26,721 38,283 67,065
10 12 14	Velocity these	governs pipe		43,862 63,702 77,976	65,792 95,552 116,964	87,723 127,403 155,952	109,654 159,254 194,940
16 18 20				103,814 133,344 166,564	155,722 200,016 249,847	207,629 266,688 333,129	259,536 333,359 416,411
22 24 26				203,476 244,079 288,373	305,214 366,119 432,560	406,952 488,158 576,746	508,690 610,198 720,933
28 30 32				336,359 388,035 443,403	504,538 582,053 665,104	672,717 776,070 886,805	840,896 970,088 1,108,507
34 36 42				502,462 565,212 775,609	753,692 847,817 1,163,413	1,004,923 1,130,423 1,551,217	1,256,154 1,413,029 1,939,022
48 54 60				1,019,226 1,296,065 1,606,124	1,528,840 1,944,097 2,409,185	2,038,453 2,592,129 3,212,247	2,548,066 3,240,162 4,015,309
72 84 96				2,325,903 3,178,565 4,164,110	3,488,855 4,767,848 6,246,164	4,651,806 6,357,130 8,328,219	5,814,758 7,946,413 10,410,274
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2 3/4 1	41 102 213	59 144 301	83 203 425		Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	490 774 1,605	692 1,095 2,270	979 1,549 3,210	917 1,264 2,112	3,168		

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2 3 4	2,669 4,956 10,649	3,774 7,009 15,059	5,338 9,913	3,031 4,724 8,223	4,547 7,086 12,334	9,448 16,445	20,557
5 6 8	19,916 32,379 68,558	28,166 45,791		13,012 18,643 32,659	19,519 27,965 48,989	26,025 37,286 65,318	32,531 46,608 81,648
10 12 14	131,433			53,399 77,553 94,932	80,099 116,330 142,397	106,798 155,106 189,863	133,498 193,883 237,329
16 18 20				126,388 162,339 202,783	189,582 243,508 304,174	252,776 324,677 405,566	315,971 405,847 506,957
22 24 26				247,721 297,153 351,078	371,581 445,729 526,618	495,442 594,306 702,157	619,302 742,882 877,696
28 30 32	Velocity these	governs pipe	with sizes	409,498 472,411 539,818	614,247 708,617 809,727	818,996 944,822 1,079,636	1,023,745 1,181,028 1,349,545
34 36 42				611,719 688,114 944,261	917,579 1,032,171 1,416,391	1,223,438 1,376,227 1,888,521	1,529,298 1,720,284 2,360,651
48 54 60				1,240,852 1,577,887 1,955,366	1,861,277 2,366,830 2,933,050	2,481,703 3,155,774 3,910,733	3,102,129 3,944,717 4,888,416
72 84 96				2,831,658 3,869,727 5,069,573	4,247,487 5,804,590 7,604,359	5,663,316 7,739,454 10,139,145	7,079,145 9,674,317 12,673,931
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2 3/4 1	47 115 241	66 163 341	94 230 482		Pressure with these	drop pipe	
1–1/4 1–1/2 2	555 877 1,818	785 1,241 2,572	1,110 1,755 3,637	1,099 1,514 2,530			governs sizes
2–1/2 3 4	3,024 5,616 12,065	4,276 7,942 17,063	6,048 11,232 24,131	3,631 5,659 9,850	5,447 8,488 14,775	19,700	
5 6 8	22,566 36,687 77,679	31,913 51,883		15,587 22,332 39,122	23,381 33,499 58,683	31,175 44,665 78,244	38,968 55,831 97,804
10 12 14	148,920			63,966 92,900 113,717	95,949 139,350 170,576	127,932 185,800 227,434	159,915 232,249 284,293
16 18 20				151,398 194,463 242,910	227,098 291,694 364,366	302,797 388,926 485,821	378,496 486,157 607,276
22 24 26				296,741 355,955 420,551	445,111 533,932 630,827	593,482 711,909 841,102	741,852 889,886 1,051,378
28 30 32	Velocity these	governs pipe	with sizes	490,531 565,894 646,640	735,796 848,841 969,959	981,062 1,131,787 1,293,279	1,226,327 1,414,734 1,616,599
34 36 42				732,768 824,280 1,131,115	1,099,153 1,236,421 1,696,672	1,465,537 1,648,561 2,262,229	1,831,921 2,060,701 2,827,786
48 54 60				1,486,396 1,890,125 2,342,302	2,229,594 2,835,188 3,513,453	2,972,792 3,780,251 4,684,604	3,715,991 4,725,314 5,855,755
72 84 96				3,391,998 4,635,484 6,072,760	5,087,997 6,953,226 9,109,140	6,783,996 9,270,968 12,145,519	8,479,995 11,588,710 15,181,899

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	59	84	118				
3/4	145	205	290				
1	304	429	607		Pressure	drop	
1–1/4	699	988	1,397		with these	pipe	
1–1/2	1,105	1,562	2,209	2,094			governs
2	2,290	3,238	4,580	3,499			sizes
2–1/2	3,808	5,385	7,615	5,022	7,534		
3	7,072	10,001	14,143	7,827	11,741		
4	15,193	21,486	30,385	13,624	20,436	27,248	
5	28,415	40,185		21,560	32,339	43,119	53,899
6	46,196	65,331		30,889	46,333	61,778	77,222
8	97,814			54,111	81,167	108,222	135,278
10	187,520			88,474	132,711	176,948	221,186
12	306,079			128,494	192,741	256,988	321,235
14				157,287	235,931	314,575	393,219
16				209,406	314,110	418,813	523,516
18				268,971	403,456	537,942	672,427
20				335,981	503,971	671,962	839,952
22				410,437	615,655	820,873	1,026,092
24				492,338	738,507	984,676	1,230,844
26			with	581,685	872,527	1,163,369	1,454,211
28		governs	sizes	678,477	1,017,715	1,356,954	1,696,192
30		pipe		782,715	1,174,072	1,565,429	1,956,787
32	Velocity			894,398	1,341,597	1,788,796	2,235,995
34	these			1,013,527	1,520,291	2,027,054	2,533,818
36				1,140,102	1,710,153	2,280,203	2,850,254
42				1,564,499	2,346,748	3,128,997	3,911,247
48				2,055,906	3,083,859	4,111,812	5,139,765
54				2,614,323	3,921,484	5,228,646	6,535,807
60				3,239,750	4,859,625	6,479,500	8,099,376
72				4,691,635	7,037,452	9,383,270	11,729,087
84				6,411,560	9,617,339	12,823,119	16,028,899
96				8,399,525	12,599,287	16,799,049	20,998,812
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2	74	104	147				
3/4	180	255	361				
1	378	534	755		Pressure	drop	
1–1/4	869	1,229	1,738		with these	pipe	
1–1/2	1,374	1,944	2,749				governs
2	2,849	4,029	5,697	4,715			sizes
2–1/2	4,737	6,699	9,474	6,767			
3	8,797	12,441	17,595	10,546	15,819		
4	18,900	26,729	37,801	18,357	27,535	36,713	
5	35,350	49,992	70,699	29,049	43,574	58,099	
6	57,471	81,276		41,620	62,430	83,240	104,050
8	121,686	172,090		72,910	109,364	145,819	182,274
10	233,285			119,210	178,816	238,421	298,026
12	380,779			173,133	259,700	346,266	432,833
14	495,895			211,930	317,894	423,859	529,824
16				282,155	423,232	564,309	705,387
18				362,412	543,618	724,824	906,030
20		governs	with	452,701	679,052	905,403	1,131,754
22	Velocity	pipe	sizes	553,023	829,535	1,106,046	1,382,558
24	these			663,377	995,065	1,326,754	1,658,442
26				783,763	1,175,644	1,567,526	1,959,407
28				914,181	1,371,272	1,828,362	2,285,453
30				1,054,631	1,581,947	2,109,263	2,636,579
32				1,205,114	1,807,671	2,410,228	3,012,785

(*Continued*)

150 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				1,365,629	2,048,443	2,731,257	3,414,072
36				1,536,175	2,304,263	3,072,351	3,840,439
42				2,108,009	3,162,013	4,216,018	5,270,022
48				2,770,132	4,155,198	5,540,264	6,925,330
54				3,522,544	5,283,816	7,045,089	8,806,361
60				4,365,246	6,547,869	8,730,493	10,913,116
72				6,321,519	9,482,278	12,643,037	15,803,797
84				8,638,949	12,958,423	17,277,898	21,597,372
96				11,317,537	16,976,306	22,635,075	28,293,843

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	16	23	33				
3/4	40	57	80	76	Pressure	drop	
1	84	118	167	127	with these	pipe	governs
1–1/4	193	272	385	227	340		sizes
1–1/2	305	431	609	312	469		
2	631	893	1,263	522	783	1,044	
2–1/2	1,050	1,485		749	1,124	1,498	1,873
3	1,950	2,758		1,168	1,751	2,335	2,919
4	4,189			2,032	3,048	4,065	5,081
5	7,835			3,216	4,824	6,432	8,040
6				4,608	6,912	9,215	11,519
8				8,072	12,108	16,144	20,180
10				13,198	19,797	26,396	32,994
12				19,168	28,751	38,335	47,919
14				23,463	35,194	46,925	58,657
16				31,237	46,856	62,475	78,093
18				40,123	60,184	80,245	100,306
20				50,119	75,178	100,237	125,296
22			with	61,225	91,838	122,450	153,063
24			sizes	73,442	110,164	146,885	183,606
26		governs		86,770	130,155	173,541	216,926
28		pipe		101,209	151,813	202,418	253,022
30	Velocity			116,758	175,137	233,516	291,895
32	these			133,418	200,127	266,836	333,545
34				151,189	226,783	302,377	377,971
36				170,070	255,105	340,140	425,174
42				233,377	350,066	466,755	583,444
48				306,681	460,021	613,362	766,702
54				389,980	584,971	779,961	974,951
60				483,276	724,914	966,552	1,208,190
72				699,855	1,049,782	1,399,709	1,749,636
84				956,417	1,434,626	1,912,834	2,391,043
96				1,252,963	1,879,445	2,505,926	3,132,408
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	20	29	41				
3/4	50	70	100		Pressure	drop	
1	104	147	209	182	with these	pipe	governs
1–1/4	240	339	480	324			sizes
1–1/2	380	537	759	446	669		
2	787	1,113	1,573	746	1,118	1,491	

(*Continued*)

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2 3 4	1,308 2,429 5,219	1,850 3,436	2,616	1,070 1,668 2,903	1,605 2,502 4,355	2,140 3,336 5,806	4,170 7,258
5 6 8	9,762 15,871			4,594 6,582 11,530	6,891 9,873 17,296	9,188 13,164 23,061	11,485 16,455 28,826
10 12 14				18,853 27,381 33,516	28,279 41,071 50,274	37,706 54,761 67,032	47,132 68,452 83,790
16 18 20				44,622 57,315 71,594	66,933 85,972 107,391	89,244 114,629 143,187	111,555 143,287 178,984
22 24 26		governs pipe	with sizes	87,459 104,912 123,950	131,189 157,367 185,925	174,919 209,823 247,901	218,648 262,279 309,876
28 30 32	Velocity these			144,576 166,787 190,586	216,863 250,181 285,879	289,151 333,575 381,172	361,439 416,969 476,465
34 36 42				215,971 242,943 333,377	323,956 364,414 500,065	431,942 485,885 666,753	539,927 607,356 833,442
48 54 60				438,090 557,082 690,353	657,135 835,623 1,035,530	876,180 1,114,164 1,380,707	1,095,225 1,392,705 1,725,884
72 84 96				999,733 1,366,230 1,789,842	1,499,600 2,049,344 2,684,763	1,999,467 2,732,459 3,579,684	2,499,333 3,415,574 4,474,605
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2 3/4 1	22 54 113	31 76 159	44 107 225	205	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	259 410 849	366 579 1,201	518 819 1,698	366 504 842	756 1,263	1,684	
2–1/2 3 4	1,412 2,622 5,634	1,997 3,709 7,968	2,824	1,209 1,883 3,278	1,813 2,825 4,918	2,417 3,767 6,557	4,709 8,196
5 6 8	10,537 17,131			5,188 7,433 13,021	7,782 11,149 19,532	10,376 14,866 26,042	12,970 18,582 32,553
10 12 14				21,290 30,920 37,849	31,935 46,380 56,773	42,580 61,840 75,698	53,225 77,301 94,622
16 18 20				50,391 64,724 80,849	75,586 97,086 121,273	100,781 129,448 161,698	125,977 161,810 202,122
22 24 26		governs pipe	with sizes	98,766 118,474 139,974	148,148 177,711 209,961	197,531 236,948 279,948	246,914 296,185 349,935
28 30 32	Velocity these			163,266 188,349 215,224	244,898 282,523 322,836	326,531 376,698 430,448	408,164 470,872 538,060
34 36 42				243,891 274,349 376,474	365,836 411,523 564,711	487,781 548,698 752,948	609,726 685,872 941,185
48 54 60				494,724 629,099 779,599	742,086 943,648 1,169,398	989,448 1,258,198 1,559,198	1,236,810 1,572,747 1,948,997
72 84 96				1,128,974 1,542,849 2,021,224	1,693,461 2,314,273 3,031,835	2,257,948 3,085,697 4,042,447	2,822,434 3,857,122 5,053,059

(*Continued*)

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	24	34	49		Pressure		
3/4	60	84	119	242	with these		
1	125	177	250			drop	governs
1–1/4	288	407	575	431		pipe	sizes
1–1/2	455	643	909	594	891		
2	942	1,333	1,885	993	1,490		
2–1/2	1,567	2,216		1,425	2,138	2,851	5,554
3	2,911	4,116	3,135	2,221	3,332	4,443	9,667
4	6,253	8,844		3,867	5,800	7,733	
5	11,696			6,119	9,178	12,238	15,297
6	19,015			8,767	13,150	17,534	21,917
8				15,358	23,037	30,715	38,394
10				25,111	37,666	50,221	62,776
12				36,469	54,703	72,938	91,172
14				44,641	66,961	89,282	111,602
16				59,433	89,150	118,866	148,583
18				76,339	114,508	152,677	190,847
20				95,357	143,036	190,715	238,393
22				116,489	174,734	232,978	291,223
24				139,734	209,601	279,468	349,335
26		governs	with	165,092	247,638	330,184	412,730
28	Velocity	pipe	sizes	192,564	288,845	385,127	481,409
30	these			222,148	333,222	444,296	555,370
32				253,846	380,769	507,692	634,614
34				287,657	431,485	575,313	719,142
36				323,581	485,371	647,161	808,952
42				444,032	666,048	888,064	1,110,080
48				583,502	875,253	1,167,004	1,458,755
54				741,990	1,112,986	1,483,981	1,854,976
60				919,497	1,379,246	1,838,995	2,298,744
72				1,331,568	1,997,351	2,663,135	3,328,919
84				1,819,712	2,729,568	3,639,424	4,549,280
96				2,383,931	3,575,897	4,767,863	5,959,828
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	26	37	52		Pressure		
3/4	64	90	127		with these		
1	133	188	267			drop	governs
1–1/4	307	434	614	477		pipe	sizes
1–1/2	485	686	970	658	1,648		
2	1,005	1,422	2,011	1,099			
2–1/2	1,672	2,364		1,577	2,365	3,154	6,144
3	3,105	4,391	3,344	2,458	3,686	4,915	10,694
4	6,671	9,434		4,278	6,417	8,555	
5	12,476			6,769	10,154	13,539	16,924
6	20,284			9,699	14,548	19,398	24,247
8				16,990	25,486	33,981	42,476
10				27,780	41,670	55,560	69,450
12				40,346	60,519	80,692	100,865
14				49,387	74,080	98,774	123,467
16				65,752	98,627	131,503	164,379
18		governs	with	84,454	126,681	168,909	211,136
20	Velocity	pipe	sizes	105,495	158,242	210,990	263,737
22	these			128,873	193,310	257,746	322,183
24				154,589	231,884	309,179	386,473
26				182,643	273,965	365,287	456,608
28				213,035	319,553	426,070	532,588
30				245,765	368,647	491,530	614,412
32				280,832	421,249	561,665	702,081

(*Continued*)

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				318,238	477,357	636,476	795,595
36				357,981	536,972	715,962	894,953
42				491,238	736,856	982,475	1,228,094
48				645,535	968,302	1,291,070	1,613,837
54				820,872	1,231,309	1,641,745	2,052,181
60				1,017,251	1,525,876	2,034,501	2,543,126
72				1,473,128	2,209,693	2,946,257	3,682,821
84				2,013,168	3,019,753	4,026,337	5,032,921
96				2,637,370	3,956,056	5,274,741	6,593,426
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	28	40	57		Pressure		
3/4	70	99	139		with these	drop	governs
1	146	206	292			pipe	sizes
1–1/4	336	475	672	549			
1–1/2	531	751	1,062	757	1,897		
2	1,101	1,557	2,202	1,264			
2–1/2	1,830	2,589	3,661	1,815	2,722	3,630	
3	3,400	4,808	6,799	2,828	4,243	5,657	12,308
4	7,304	10,329		4,923	7,385	9,846	
5	13,660			7,791	11,686	15,581	19,477
6	22,208	19,318		11,162	16,743	22,324	27,905
8	47,023			19,553	29,330	39,107	48,884
10				31,971	47,956	63,942	79,927
12				46,432	69,648	92,864	116,081
14				56,837	85,255	113,674	142,092
16				75,670	113,506	151,341	189,176
18				97,194	145,792	194,389	242,986
20				121,409	182,113	242,818	303,522
22				148,314	222,471	296,628	370,785
24				177,910	266,864	355,819	444,774
26			with	210,196	315,293	420,391	525,489
28			sizes	245,172	367,758	490,344	612,930
30	Velocity	governs		282,839	424,259	565,678	707,098
32	these	pipe		323,197	484,795	646,394	807,992
34				366,245	549,367	732,490	915,612
36				411,983	617,975	823,967	1,029,959
42				565,342	848,013	1,130,684	1,413,355
48				742,915	1,114,373	1,485,831	1,857,289
54				944,703	1,417,055	1,889,406	2,361,758
60				1,170,706	1,756,058	2,341,411	2,926,764
72				1,695,354	2,543,031	3,390,708	4,238,385
84				2,316,860	3,475,290	4,633,721	5,792,151
96				3,035,225	4,552,837	6,070,450	7,588,062
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	33	46	65		Pressure		
3/4	80	113	160		with these	drop	governs
1	168	237	335			pipe	sizes
1–1/4	386	545	771	678			
1–1/2	610	862	1,220	935	2,343		
2	1,264	1,788	2,528	1,562			
2–1/2	2,102	2,973	4,204	2,242	3,363		
3	3,904	5,521	7,808	3,494	5,240	6,987	15,202
4	8,387	11,861		6,081	9,121	12,162	
5	15,687			9,623	14,434	19,246	24,057
6	25,503	22,184		13,787	20,680	27,574	34,467
8	53,998			24,152	36,228	48,304	60,380
10				39,490	59,234	78,979	98,724
12				57,352	86,028	114,704	143,380
14				70,204	105,306	140,408	175,509

(*Continued*)

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				93,467	140,200	186,933	233,666
18				120,053	180,079	240,105	300,132
20				149,962	224,943	299,924	374,905
22				183,195	274,792	366,389	457,986
24				219,750	329,625	439,501	549,376
26				259,629	389,444	519,259	649,073
28				302,832	454,248	605,663	757,079
30				349,357	524,036	698,715	873,393
32	Velocity these	governs pipe	with sizes	399,206	598,809	798,412	998,015
34				452,378	678,567	904,757	1,130,946
36				508,874	763,310	1,017,747	1,272,184
42				698,299	1,047,449	1,396,598	1,745,748
48				917,634	1,376,451	1,835,268	2,294,085
54				1,166,878	1,750,318	2,333,757	2,917,196
60				1,446,032	2,169,048	2,892,064	3,615,080
72				2,094,067	3,141,100	4,188,134	5,235,167
84				2,861,739	4,292,609	5,723,478	7,154,348
96				3,749,048	5,623,573	7,498,097	9,372,621
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	37	52	74		Pressure with these		
3/4	91	128	181			drop pipe	governs sizes
1	190	269	380				
1–1/4	437	619	875	819			
1–1/2	692	978	1,383	1,129	2,830		
2	1,434	2,027	2,867	1,886			
2–1/2	2,384	3,371	4,768	2,708	4,061	8,439	
3	4,427	6,261	8,854	4,220	6,330	14,689	18,362
4	9,512	13,451		7,345	11,017		
5	17,790	25,158		11,623	17,435	23,246	29,058
6	28,922	40,902		16,653	24,979	33,305	41,632
8	61,238			29,172	43,758	58,344	72,930
10				47,698	71,546	95,395	119,244
12	117,400			69,273	103,909	138,546	173,182
14				84,796	127,194	169,591	211,989
16				112,894	169,340	225,787	282,234
18				145,006	217,508	290,011	362,514
20				181,132	271,697	362,263	452,829
22				221,272	331,907	442,543	553,179
24				265,426	398,138	530,851	663,564
26			with sizes	313,593	470,390	627,187	783,984
28				365,775	548,663	731,551	914,439
30		governs pipe		421,971	632,957	843,943	1,054,929
32	Velocity these			482,181	723,272	964,363	1,205,453
34				546,405	819,608	1,092,811	1,366,013
36				614,643	921,965	1,229,286	1,536,608
42				843,441	1,265,162	1,686,882	2,108,603
48				1,108,365	1,662,547	2,216,730	2,770,912
54				1,409,415	2,114,122	2,818,829	3,523,536
60				1,746,590	2,619,885	3,493,181	4,366,476
72				2,529,320	3,793,980	5,058,639	6,323,299
84				3,456,553	5,184,829	6,913,106	8,641,382
96				4,528,290	6,792,435	9,056,580	11,320,725
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	42	59	83				
3/4	102	144	204				
1	214	302	427		Pressure with these	drop pipe	
1–1/4	492	695	983	974			
1–1/2	777	1,099	1,554	1,341			governs sizes
2	1,611	2,278	3,222	2,241			
2–1/2	2,679	3,788	5,358	3,217	4,825		
3	4,975	7,036	9,950	5,013	7,520	17,452	
4	10,689	15,116	21,377	8,726	13,089		

(*Continued*)

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5	19,991	28,272		13,809	20,713	27,618	34,522
6	32,501	45,963		19,784	29,676	39,568	49,461
8	68,816			34,658	51,987	69,316	86,645
10				56,667	85,001	113,335	141,668
12	131,928			82,300	123,450	164,600	205,750
14				100,742	151,113	201,484	251,855
16				134,124	201,186	268,248	335,310
18				172,275	258,412	344,549	430,687
20				215,194	322,791	430,389	537,986
22				262,883	394,324	525,765	657,207
24				315,340	473,010	630,680	788,350
26			with	372,566	558,849	745,133	931,416
28			sizes	434,561	651,842	869,123	1,086,403
30		governs		501,325	751,988	1,002,650	1,253,313
32	Velocity	pipe		572,858	859,287	1,145,716	1,432,145
34	these			649,159	973,739	1,298,319	1,622,899
36				730,230	1,095,345	1,460,460	1,825,575
42				1,002,054	1,503,081	2,004,108	2,505,135
48				1,316,798	1,975,197	2,633,596	3,291,995
54				1,674,462	2,511,693	3,348,924	4,186,154
60				2,075,045	3,112,567	4,150,090	5,187,612
72				3,004,970	4,507,456	6,009,941	7,512,426
84				4,106,574	6,159,861	8,213,148	10,266,436
96				5,379,857	8,069,785	10,759,713	13,449,642
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	51	73	103				
3/4	126	178	252		Pressure	drop	
1	264	374	528		with these	pipe	
1–1/4	608	860	1,216				governs
1–1/2	961	1,360	1,923	1,822			sizes
2	1,993	2,818	3,985	3,045			
2–1/2	3,314	4,686	6,627	4,371	6,556		
3	6,154	8,703	12,308	6,812	10,217	23,712	
4	13,221	18,698	26,443	11,856	17,784		
5	24,728	34,971		18,762	28,143	37,524	46,906
6	40,202	56,855		26,881	40,322	53,762	67,203
8	85,123			47,090	70,636	94,181	117,726
10	163,190			76,995	115,492	153,990	192,487
12	266,367			111,822	167,734	223,645	279,556
14				136,880	205,320	273,760	342,200
16				182,237	273,355	364,473	455,592
18				234,073	351,109	468,146	585,182
20				292,389	438,583	584,777	730,971
22				357,184	535,776	714,368	892,959
24				428,459	642,688	856,917	1,071,146
26			with	506,213	759,319	1,012,426	1,265,532
28			sizes	590,447	885,670	1,180,893	1,476,117
30		governs		681,160	1,021,740	1,362,320	1,702,900
32	Velocity	pipe		778,353	1,167,529	1,556,706	1,945,882
34	these			882,025	1,323,038	1,764,050	2,205,063
36				992,177	1,488,266	1,984,354	2,480,443
42				1,361,510	2,042,265	2,723,020	3,403,775
48				1,789,159	2,683,738	3,578,317	4,472,896
54				2,275,123	3,412,684	4,550,246	5,687,807
60				2,819,403	4,229,104	5,638,806	7,048,507
72				4,082,910	6,124,365	8,165,820	10,207,275
84				5,579,680	8,369,520	11,159,360	13,949,200
96				7,309,713	10,964,569	14,619,426	18,274,282

(*Continued*)

175 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2	63	89	125				
3/4	154	217	307				
1	322	455	644		Pressure with these	drop pipe	
1–1/4	741	1,048	1,482				governs sizes
1–1/2	1,172	1,657	2,344	4,020			
2	2,429	3,435	4,858				
2–1/2	4,039	5,712	8,078	5,770			
3	7,501	10,609	15,003	8,993	13,489	31,305	
4	16,116	22,792	32,233	15,653	23,479		
5	30,143	42,628		24,770	37,155	49,540	
6	49,005	69,303	60,285	35,489	53,234	70,978	88,723
8	103,761	146,740		62,170	93,254	124,339	155,424
10	198,921			101,650	152,475	203,300	254,125
12	324,688			147,630	221,445	295,260	369,074
14	422,847			180,711	271,067	361,422	451,778
16				240,592	360,888	481,184	601,479
18				309,027	463,540	618,054	772,567
20				386,016	579,024	772,032	965,040
22				471,560	707,340	943,120	1,178,900
24				565,658	848,487	1,131,316	1,414,145
26				668,310	1,002,466	1,336,621	1,670,776
28				779,517	1,169,276	1,559,035	1,948,793
30		governs pipe	with sizes	899,279	1,348,918	1,798,557	2,248,196
32	Velocity these			1,027,594	1,541,391	2,055,188	2,568,985
34				1,164,464	1,746,696	2,328,928	2,911,160
36				1,309,889	1,964,833	2,619,777	3,274,721
42				1,797,488	2,696,232	3,594,976	4,493,720
48				2,362,077	3,543,115	4,724,153	5,905,191
54				3,003,655	4,505,482	6,007,309	7,509,136
60				3,722,222	5,583,333	7,444,444	9,305,555
72				5,390,325	8,085,487	10,780,650	13,475,812
84				7,366,385	11,049,578	14,732,771	18,415,963
96				9,650,403	14,475,605	19,300,806	24,126,008

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 3.

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	15	22	31				
3/4	38	53	75	72	Pressure with these	drop pipe	
1	79	111	157	119			governs sizes
1–1/4	181	256	362	213	319		
1–1/2	286	404	572	293	440	980	
2	593	838	1,185	490	735		
2–1/2	985	1,393		703	1,055	1,406	1,758
3	1,830	2,588		1,096	1,644	2,191	2,739
4	3,931			1,907	2,861	3,814	4,768
5				3,018	4,527	6,036	7,545
6	7,353			4,324	6,486	8,648	10,810
8				7,575	11,362	15,150	18,937
10				12,385	18,578	24,770	30,963
12				17,987	26,981	35,975	44,968
14				22,018	33,027	44,036	55,045

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				29,314	43,971	58,628	73,285
18				37,652	56,478	75,304	94,130
20				47,033	70,549	94,065	117,582
22				57,455	86,183	114,911	143,638
24				68,920	103,381	137,841	172,301
26				81,428	122,141	162,855	203,569
28				94,977	142,466	189,954	237,443
30				109,569	164,354	219,138	273,923
32	Velocity these	governs pipe	with sizes	125,203	187,805	250,406	313,008
34				141,880	212,819	283,759	354,699
36				159,598	239,397	319,196	398,996
42				219,008	328,512	438,016	547,520
48				287,798	431,697	575,596	719,495
54				365,968	548,953	731,937	914,921
60				453,519	680,279	907,039	1,133,799
72				656,763	985,144	1,313,526	1,641,907
84				897,528	1,346,292	1,795,056	2,243,821
96				1,175,815	1,763,723	2,351,631	2,939,538
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	19	27	38				
3/4	46	66	93	169	Pressure with these	drop pipe	
1	97	138	195				governs sizes
1–1/4	224	317	448	302	624		
1–1/2	354	501	708	416	1,043	1,391	
2	734	1,038	1,468	696			
2–1/2	1,220	1,726		998	1,497	1,997	3,890
3	2,266	3,205	2,440	1,556	2,334	3,112	6,770
4	4,869			2,708	4,062	5,416	
5	9,106			4,285	6,428	8,571	10,714
6	14,805			6,140	9,210	12,280	15,350
8				10,756	16,134	21,512	26,889
10				17,586	26,379	35,172	43,965
12				25,541	38,312	51,082	63,853
14				31,264	46,896	62,529	78,161
16				41,624	62,436	83,248	104,060
18				53,464	80,196	106,928	133,660
20				66,784	100,175	133,567	166,959
22				81,583	122,375	163,166	203,958
24				97,863	146,794	195,726	244,657
26		governs pipe	with sizes	115,622	173,434	231,245	289,056
28				134,862	202,293	269,724	337,155
30	Velocity these			155,582	233,372	311,163	388,954
32				177,781	266,672	355,562	444,453
34				201,461	302,191	402,921	503,652
36				226,620	339,930	453,240	566,550
42				310,978	466,467	621,956	777,446
48				408,656	612,984	817,312	1,021,640
54				519,654	779,481	1,039,307	1,299,134
60				643,971	965,957	1,287,942	1,609,928
72				932,565	1,398,847	1,865,129	2,331,412
84				1,274,437	1,911,656	2,548,875	3,186,093
96				1,669,589	2,504,383	3,339,177	4,173,972
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	20	29	41				
3/4	50	71	100	191	Pressure with these	drop pipe	
1	105	148	209				governs sizes
1–1/4	241	341	482	340	703		
1–1/2	381	539	762	469	1,175	1,567	
2	790	1,118	1,580	784			

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2 3 4	1,314 2,440 5,243	1,858 3,451 7,415	2,628	1,125 1,753 3,051	1,687 2,629 4,576	2,249 3,506 6,102	4,382 7,627
5 6 8	9,806 15,942			4,828 6,917 12,118	7,242 10,376 18,176	9,656 13,834 24,235	12,070 17,293 30,294
10 12 14				19,813 28,775 35,223	29,719 43,162 52,834	39,625 57,549 70,445	49,532 71,937 88,056
16 18 20				46,894 60,233 75,239	70,341 90,349 112,858	93,788 120,465 150,477	117,235 150,581 188,097
22 24 26		governs pipe	with sizes	91,912 110,253 130,261	137,868 165,379 195,391	183,824 220,505 260,522	229,780 275,632 325,652
28 30 32	Velocity these			151,936 175,279 200,289	227,904 262,918 300,433	303,872 350,558 400,578	379,840 438,197 500,722
34 36 42				226,966 255,311 350,349	340,450 382,967 525,524	453,933 510,622 700,699	567,416 638,278 875,873
48 54 60				460,394 585,444 725,500	690,590 878,166 1,088,250	920,787 1,170,888 1,451,001	1,150,984 1,463,610 1,813,751
72 84 96				1,050,631 1,435,786 1,880,965	1,575,947 2,153,679 2,821,448	2,101,262 2,871,572 3,761,931	2,626,578 3,589,465 4,702,413
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2 3/4 1	23 55 116	32 78 164	45 111 232	224	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	267 422 874	377 596 1,236	533 843 1,748	400 551 921	827 1,382		
2–1/2 3 4	1,453 2,699 5,800	2,056 3,818 8,202	2,907	1,322 2,060 3,586	1,983 3,090 5,379	2,644 4,120 7,172	5,151 8,965
5 6 8	10,847 17,635			5,675 8,130 14,243	8,512 12,196 21,364	11,350 16,261 28,486	14,187 20,326 35,607
10 12 14				23,288 33,822 41,401	34,932 50,733 62,101	46,576 67,643 82,801	58,220 84,554 103,502
16 18 20				55,119 70,798 88,436	82,679 106,196 132,653	110,238 141,595 176,871	137,798 176,994 221,089
22 24 26	Velocity these	governs pipe	with sizes	108,034 129,591 153,109	162,050 194,387 229,663	216,067 259,183 306,218	270,084 323,978 382,772
28 30 32				178,586 206,023 235,420	267,879 309,035 353,130	357,172 412,046 470,840	446,465 515,058 588,550
34 36 42				266,777 300,093 411,802	400,165 450,140 617,702	533,554 600,187 823,603	666,942 750,233 1,029,504
48 54 60				541,148 688,132 852,755	811,722 1,032,199 1,279,132	1,082,296 1,376,265 1,705,510	1,352,870 1,720,331 2,131,887

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
72				1,234,915	1,852,372	2,469,829	3,087,286
84				1,687,627	2,531,440	3,375,254	4,219,067
96				2,210,892	3,316,337	4,421,783	5,527,229
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	24	34	48		Pressure with these		
3/4	59	83	118			drop pipe	governs sizes
1	123	174	247				
1–1/4	284	401	568	442			
1–1/2	449	635	898	608			
2	930	1,316	1,861	1,017	1,525		
2–1/2	1,547	2,188	3,094	1,459	2,189	2,918	
3	2,873	4,063		2,274	3,411	4,548	5,685
4	6,172	8,729		3,958	5,937	7,916	9,895
5	11,544			6,264	9,396	12,527	15,659
6	18,768			8,974	13,461	17,948	22,435
8				15,721	23,581	31,442	39,302
10				25,704	38,557	51,409	64,261
12				37,331	55,997	74,663	93,329
14				45,697	68,545	91,394	114,242
16				60,839	91,258	121,678	152,097
18				78,144	117,216	156,288	195,360
20				97,613	146,419	195,225	244,032
22				119,244	178,866	238,488	298,111
24				143,039	214,558	286,078	357,597
26		governs pipe	with sizes	168,997	253,495	337,994	422,492
28				197,118	295,677	394,236	492,795
30	Velocity these			227,402	341,103	454,804	568,506
32				259,850	389,774	519,699	649,624
34				294,460	441,690	588,920	736,151
36				331,234	496,851	662,468	828,085
42				454,534	681,801	909,068	1,136,335
48				597,303	895,954	1,194,605	1,493,257
54				759,540	1,139,310	1,519,079	1,898,849
60				941,245	1,411,868	1,882,490	2,353,113
72				1,363,061	2,044,592	2,726,123	3,407,654
84				1,862,752	2,794,127	3,725,503	4,656,879
96				2,440,315	3,660,473	4,880,631	6,100,789
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	26	37	52		Pressure with these		
3/4	64	91	128			drop pipe	governs sizes
1	135	190	269				
1–1/4	310	438	619	507			
1–1/2	490	693	979	698			
2	1,015	1,435	2,030	1,166	1,749		
2–1/2	1,688	2,387	3,376	1,674	2,510	3,347	
3	3,135	4,433	6,269	2,608	3,912	5,216	
4	6,735	9,524		4,540	6,809	9,079	11,349
5	12,596	17,814		7,184	10,776	14,368	17,960
6	20,478			10,293	15,439	20,585	25,731
8	43,360			18,031	27,046	36,061	45,076
10				29,481	44,221	58,961	73,702
12				42,816	64,224	85,632	107,039
14			with sizes	52,410	78,615	104,820	131,025
16				69,777	104,665	139,554	174,442
18	Velocity these	governs pipe		89,624	134,437	179,249	224,061
20				111,953	167,929	223,906	279,882
22				136,762	205,144	273,525	341,906
24				164,053	246,079	328,106	410,132
26				193,824	290,737	387,649	484,561

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				226,077	339,115	452,153	565,192
30				260,810	391,215	521,620	652,025
32				298,024	447,036	596,049	745,061
34				337,720	506,579	675,439	844,299
36				379,896	569,844	759,791	949,739
42				521,310	781,965	1,042,620	1,303,275
48				685,053	1,027,579	1,370,106	1,712,632
54				871,124	1,306,686	1,742,248	2,177,810
60				1,079,524	1,619,286	2,159,048	2,698,810
72				1,563,310	2,344,964	3,126,619	3,908,274
84				2,136,409	3,204,614	4,272,819	5,341,024
96				2,798,824	4,198,235	5,597,647	6,997,059
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	30	42	60		Pressure		
3/4	73	104	147		with these	drop	governs
1	154	217	307			pipe	sizes
1–1/4	354	500	707	622			
1–1/2	559	791	1,118	857	2,148		
2	1,159	1,639	2,318	1,432			
2–1/2	1,927	2,725	3,854	2,055	3,083	6,406	
3	3,579	5,061	7,158	3,203	4,804	11,150	13,937
4	7,689	10,874		5,575	8,362		
5	14,381			8,822	13,233	17,644	22,055
6	23,381	20,338		12,640	18,960	25,280	31,599
8	49,505			22,142	33,214	44,285	55,356
10				36,204	54,306	72,407	90,509
12				52,580	78,870	105,160	131,450
14				64,362	96,543	128,724	160,905
16				85,689	128,534	171,379	214,223
18				110,063	165,095	220,126	275,158
20				137,484	206,226	274,967	343,709
22				167,951	251,926	335,902	419,877
24				201,465	302,198	402,930	503,663
26			with	238,026	357,039	476,052	595,064
28			sizes	277,633	416,450	555,266	694,083
30	Velocity	governs		320,287	480,431	640,575	800,719
32	these	pipe		365,988	548,983	731,977	914,971
34				414,736	622,104	829,472	1,036,840
36				466,530	699,796	933,061	1,166,326
42				640,194	960,291	1,280,388	1,600,485
48				841,278	1,261,917	1,682,556	2,103,196
54				1,069,783	1,604,674	2,139,566	2,674,457
60				1,325,708	1,988,562	2,651,417	3,314,271
72				1,919,821	2,879,731	3,839,641	4,799,551
84				2,623,615	3,935,423	5,247,230	6,559,038
96				3,437,092	5,155,638	6,874,184	8,592,730
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	34	48	67		Pressure		
3/4	83	117	165		with these	drop	governs
1	173	245	346			pipe	sizes
1–1/4	399	564	797	747			
1–1/2	630	891	1,261	1,029	2,579		
2	1,307	1,848	2,613	1,719			
2–1/2	2,173	3,072	4,345	2,468	3,702	7,692	
3	4,035	5,706	8,070	3,846	5,769	13,388	16,735
4	8,669	12,259		6,694	10,041		
5	16,213	22,929		10,593	15,890	21,186	26,483
6	26,359	37,278		15,177	22,766	30,354	37,943
8	55,812			26,587	39,881	53,174	66,468
10				43,471	65,207	86,942	108,678
12	106,997			63,135	94,702	126,269	157,837
14				77,282	115,923	154,564	193,205

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				102,890	154,336	205,781	257,226
18				132,157	198,236	264,314	330,393
20				165,082	247,623	330,164	412,705
22				201,665	302,498	403,330	504,163
24				241,907	362,860	483,814	604,767
26				285,807	428,710	571,613	714,517
28				333,365	500,047	666,730	833,412
30				384,582	576,872	769,163	961,454
32	Velocity	governs	with	439,456	659,185	878,913	1,098,641
34	these	pipe	sizes	497,990	746,984	995,979	1,244,974
36				560,181	840,272	1,120,362	1,400,453
42				768,706	1,153,059	1,537,412	1,921,764
48				1,010,155	1,515,233	2,020,311	2,525,388
54				1,284,530	1,926,795	2,569,060	3,211,324
60				1,591,829	2,387,744	3,183,658	3,979,573
72				2,305,203	3,457,804	4,610,405	5,763,007
84				3,150,276	4,725,414	6,300,552	7,875,690
96				4,127,049	6,190,574	8,254,098	10,317,623
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	38	53	75				
3/4	92	131	185				
1	193	274	387		Pressure	drop	
1–1/4	445	630	891	882	with these	pipe	
1–1/2	704	996	1,408	1,215			governs
2	1,459	2,064	2,919	2,030			sizes
2–1/2	2,427	3,432	4,853	2,914	4,371		
3	4,507	6,374	9,014	4,541	6,812	15,809	
4	9,683	13,693	19,365	7,905	11,857		
5	18,110	25,611		12,509	18,764	25,018	31,273
6	29,442	41,637		17,922	26,883	35,844	44,805
8	62,339			31,396	47,094	62,792	78,490
10				51,334	77,001	102,668	128,335
12	119,511			74,554	111,831	149,108	186,385
14				91,260	136,890	182,521	228,151
16				121,500	182,251	243,001	303,751
18				156,061	234,091	312,121	390,151
20				194,941	292,411	389,881	487,352
22				238,141	357,211	476,282	595,352
24				285,661	428,492	571,322	714,153
26			with	337,501	506,252	675,002	843,753
28		governs	sizes	393,661	590,492	787,323	984,153
30		pipe		454,142	681,212	908,283	1,135,354
32	Velocity			518,942	778,413	1,037,884	1,297,355
34	these			588,062	882,093	1,176,124	1,470,155
36				661,502	992,254	1,323,005	1,653,756
42				907,743	1,361,615	1,815,486	2,269,358
48				1,192,864	1,789,296	2,385,728	2,982,161
54				1,516,865	2,275,298	3,033,731	3,792,163
60				1,879,747	2,819,620	3,759,493	4,699,367
72				2,722,150	4,083,224	5,444,299	6,805,374
84				3,720,073	5,580,110	7,440,146	9,300,183
96				4,873,517	7,310,276	9,747,034	12,183,793
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	46	65	92				
3/4	113	160	226				
1	236	334	472		Pressure	drop	
1–1/4	544	769	1,087		with these	pipe	
1–1/2	860	1,216	1,720	1,630			governs
2	1,782	2,520	3,564	2,723			sizes
2–1/2	2,963	4,191	5,927	3,909	5,863		
3	5,504	7,784	11,008	6,092	9,138	21,207	
4	11,824	16,722	23,649	10,603	15,905		

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5	22,115	31,276		16,780	25,170	33,560	41,950
6	35,955	50,848		24,041	36,061	48,082	60,102
8	76,129			42,115	63,172	84,230	105,287
10	145,947			68,860	103,289	137,719	172,149
12	238,222			100,007	150,011	200,014	250,018
14				122,417	183,626	244,834	306,043
16				162,981	244,472	325,963	407,454
18				209,341	314,011	418,681	523,351
20				261,495	392,242	522,989	653,737
22				319,444	479,165	638,887	798,609
24				383,187	574,781	766,375	957,969
26			with	452,726	679,089	905,452	1,131,815
28		governs	sizes	528,060	792,090	1,056,120	1,320,150
30		pipe		609,188	913,783	1,218,377	1,522,971
32	Velocity			696,112	1,044,168	1,392,224	1,740,279
34	these			788,830	1,183,245	1,577,660	1,972,075
36				887,343	1,331,015	1,774,687	2,218,358
42				1,217,652	1,826,478	2,435,305	3,044,131
48				1,600,115	2,400,173	3,200,231	4,000,288
54				2,034,733	3,052,099	4,069,465	5,086,831
60				2,521,504	3,782,256	5,043,007	6,303,759
72				3,651,508	5,477,262	7,303,016	9,128,771
84				4,990,129	7,485,193	9,980,258	12,475,322
96				6,537,366	9,806,049	13,074,732	16,343,415
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2	55	78	111				
3/4	136	192	271				
1	284	401	568		Pressure	drop	
1–1/4	653	924	1,307		with these	pipe	governs
1–1/2	1,033	1,461	2,067				sizes
2	2,142	3,029	4,283	3,545			
2–1/2	3,561	5,037	7,123	5,088			
3	6,614	9,354	13,229	7,929	11,894		
4	14,210	20,096	28,420	13,801	20,702	27,603	
5	26,578	37,586	53,155	21,841	32,761	43,681	
6	43,209	61,107		31,292	46,938	62,584	78,229
8	91,489	129,385		54,817	82,225	109,634	137,042
10	175,395			89,628	134,442	179,256	224,070
12	286,288			130,170	195,255	260,340	325,425
14	372,838			159,339	239,008	318,678	398,347
16				212,137	318,206	424,275	530,344
18				272,479	408,718	544,957	681,197
20				340,363	510,544	680,725	850,907
22				415,789	623,684	831,579	1,039,473
24				498,759	748,138	997,517	1,246,897
26				589,271	883,906	1,178,541	1,473,176
28		governs	with	687,325	1,030,988	1,374,650	1,718,313
30		pipe	sizes	792,922	1,189,384	1,585,845	1,982,306
32	Velocity			906,062	1,359,094	1,812,125	2,265,156
34	these			1,026,745	1,540,118	2,053,490	2,566,863
36				1,154,970	1,732,455	2,309,941	2,887,426
42				1,584,902	2,377,353	3,169,804	3,962,255
48				2,082,718	3,124,077	4,165,436	5,206,795
54				2,648,418	3,972,627	5,296,835	6,621,044
60				3,282,001	4,923,002	6,564,003	8,205,004
72				4,752,821	7,129,231	9,505,642	11,882,052
84				6,495,176	9,742,764	12,990,352	16,237,940
96				8,509,067	12,763,601	17,018,134	21,272,668

(*Continued*)

200 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 60 psig Back Pressure							
1/2	66	93	131				
3/4	161	227	321				
1	337	476	673		Pressure with these		
1–1/4	775	1,096	1,549			drop pipe	governs sizes
1–1/2	1,225	1,733	2,450	4,497			
2	2,539	3,591	5,078				
2–1/2	4,222	5,971	8,445	6,454	15,088		
3	7,842	11,090	15,684	10,059	26,262		
4	16,848	23,826	33,695	17,508			
5	31,510	44,562		27,706	41,560	55,413	99,239
6	51,229	72,448	63,021	39,696	59,544	79,392	173,847
8	108,469	153,399		69,539	104,308	139,078	
10	207,948			113,699	170,549	227,399	284,248
12	339,422			165,129	247,694	330,259	412,823
14	442,035			202,132	303,198	404,264	505,330
16				269,111	403,666	538,221	672,777
18				345,658	518,487	691,316	864,144
20				431,773	647,660	863,546	1,079,433
22				527,457	791,186	1,054,914	1,318,643
24				632,709	949,064	1,265,419	1,581,773
26				747,530	1,121,295	1,495,060	1,868,825
28		governs pipe	with sizes	871,919	1,307,878	1,743,838	2,179,797
30				1,005,876	1,508,814	2,011,752	2,514,690
32	Velocity these			1,149,402	1,724,103	2,298,804	2,873,505
34				1,302,496	1,953,744	2,604,992	3,256,240
36				1,465,158	2,197,738	2,930,317	3,662,896
42				2,010,556	3,015,834	4,021,113	5,026,391
48				2,642,069	3,963,104	5,284,139	6,605,174
54				3,359,698	5,039,547	6,719,396	8,399,245
60				4,163,442	6,245,163	8,326,884	10,408,605
72				6,029,277	9,043,915	12,058,553	15,073,192
84				8,239,573	12,359,359	16,479,146	20,598,932
96				10,794,331	16,191,496	21,588,662	26,985,827

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back							
1/2	14	20	29	68	Pressure	drop	
3/4	36	50	71	113	with these	pipe	
1	74	105	149				governs
1–1/4	171	242	342	201	302		sizes
1–1/2	271	383	541	278	416	928	
2	561	793	1,122	464	696		
2–1/2	933	1,319		666	999	1,331	1,664
3	1,733	2,450		1,038	1,556	2,075	2,594
4	3,723			1,806	2,709	3,612	4,515
5				2,858	4,287	5,716	7,144
6	6,962			4,094	6,142	8,189	10,236
8				7,173	10,759	14,345	17,932
10				11,728	17,591	23,455	29,319
12				17,032	25,548	34,065	42,581
14				20,849	31,273	41,698	52,122

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
16				27,757	41,636	55,515	69,394
18				35,653	53,479	71,306	89,132
20				44,535	66,803	89,071	111,338
22				54,405	81,607	108,809	136,012
24				65,261	97,891	130,522	163,152
26				77,104	115,656	154,208	192,760
28				89,934	134,901	179,868	224,835
30				103,751	155,627	207,502	259,378
32	Velocity these	governs pipe	with sizes	118,555	177,833	237,110	296,388
34				134,346	201,519	268,692	335,865
36				151,124	226,686	302,248	377,810
42				207,379	311,069	414,758	518,448
48				272,517	408,775	545,033	681,292
54				346,537	519,805	693,073	866,341
60				429,439	644,158	858,878	1,073,597
72				621,891	932,836	1,243,781	1,554,726
84				849,872	1,274,808	1,699,744	2,124,680
96				1,113,383	1,670,074	2,226,765	2,783,457
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	18	25	36				
3/4	44	62	88	160	Pressure with these	drop pipe	
1	92	130	183				governs sizes
1–1/4	211	298	422	285			
1–1/2	334	472	667	392	588 983	1,311	
2	691	978	1,383	655			
2–1/2	1,150			941	1,411	1,881	
3	2,136	1,626 3,020	2,300	1,466	2,199	2,932	3,665 6,380
4	4,588			2,552	3,828	5,104	
5				4,038	6,057	8,077	10,096
6	8,581 13,951			5,786	8,679	11,572	14,465
8				10,136	15,203	20,271	25,339
10				16,572	24,858	33,144	41,430
12				24,068	36,102	48,137	60,171
14				29,462	44,192	58,923	73,654
16				39,224	58,836	78,448	98,060
18				50,381	75,572	100,762	125,953
20				62,933	94,399	125,866	157,332
22				76,879	115,319	153,758	192,198
24				92,220	138,330	184,440	230,550
26		governs pipe	with sizes	108,956	163,434	217,911	272,389
28				127,086	190,629	254,172	317,715
30	Velocity these			146,611	219,916	293,222	366,527
32				167,530	251,295	335,061	418,826
34				189,844	284,767	379,689	474,611
36				213,553	320,330	427,106	533,883
42				293,047	439,571	586,095	732,618
48				385,093	577,640	770,186	962,733
54				489,691	734,536	979,381	1,224,227
60				606,840	910,260	1,213,680	1,517,100
72				878,793	1,318,190	1,757,587	2,196,983
84				1,200,954	1,801,430	2,401,907	3,002,384
96				1,573,321	2,359,981	3,146,642	3,933,302
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	19	27	38				
3/4	47	67	94	180	Pressure with these	drop pipe	
1	99	139	197				governs sizes
1–1/4	227	321	454	320			
1–1/2	359	507	717	441	662 1,106	1,474	
2	743	1,051	1,486	737			

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	1,236	1,748	2,472	1,058	1,587	2,116	
3	2,295	3,246		1,649	2,473	3,297	4,122
4	4,931	6,974		2,870	4,304	5,739	7,174
5	9,223			4,541	6,812	9,082	11,353
6	14,995			6,506	9,759	13,012	16,265
8				11,397	17,096	22,794	28,493
10				18,635	27,952	37,270	46,587
12				27,064	40,596	54,128	67,661
14				33,129	49,693	66,258	82,822
16				44,106	66,160	88,213	110,266
18				56,652	84,978	113,305	141,631
20				70,766	106,150	141,533	176,916
22				86,449	129,673	172,897	216,122
24				103,699	155,549	207,398	259,248
26		governs	with	122,518	183,777	245,036	306,295
28		pipe	sizes	142,905	214,357	285,810	357,262
30	Velocity			164,860	247,290	329,720	412,150
32	these			188,384	282,575	376,767	470,959
34				213,475	320,213	426,951	533,688
36				240,135	360,203	480,270	600,338
42				329,524	494,287	659,049	823,811
48				433,028	649,541	866,055	1,082,569
54				550,645	825,967	1,101,290	1,376,612
60				682,376	1,023,564	1,364,752	1,705,940
72				988,181	1,482,272	1,976,362	2,470,453
84				1,350,442	2,025,663	2,700,884	3,376,105
96				1,769,160	2,653,739	3,538,319	4,422,899
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	21	30	42		Pressure		
3/4	52	73	104	210	with these		
1	109	154	217			drop	governs
1–1/4	250	354	500	375		pipe	sizes
1–1/2	396	559	791	517	776		
2	820	1,159	1,640	864	1,296		
2–1/2	1,363	1,928	2,727	1,240	1,860	2,480	
3	2,532	3,581		1,932	2,899	3,865	4,831
4	5,440	7,693		3,364	5,045	6,727	8,409
5	10,174			5,323	7,984	10,646	13,307
6	16,541			7,626	11,440	15,253	19,066
8				13,360	20,040	26,720	33,399
10				21,844	32,766	43,688	54,610
12				31,725	47,587	63,449	79,311
14				38,834	58,250	77,667	97,084
16				51,701	77,552	103,403	129,254
18				66,408	99,611	132,815	166,019
20				82,952	124,428	165,904	207,380
22				101,335	152,002	202,670	253,337
24				121,556	182,334	243,112	303,890
26		governs	with	143,615	215,423	287,230	359,038
28		pipe	sizes	167,513	251,269	335,025	418,782
30	Velocity			193,249	289,873	386,497	483,121
32	these			220,823	331,234	441,645	552,057
34				250,235	375,353	500,470	625,588
36				281,486	422,229	562,971	703,714
42				386,267	579,401	772,535	965,668
48				507,593	761,390	1,015,187	1,268,983
54				645,464	968,196	1,290,928	1,613,660
60				799,879	1,199,818	1,599,758	1,999,697
72				1,158,342	1,737,514	2,316,685	2,895,856
84				1,582,984	2,374,476	3,165,967	3,957,459
96				2,073,803	3,110,704	4,147,606	5,184,507

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	22	32	45		Pressure		
3/4	55	78	110		with these	drop	governs
1	115	163	231			pipe	sizes
1–1/4	266	376	532	413			
1–1/2	420	594	840	570	1,428		
2	871	1,232	1,742	952			
2–1/2	1,448	2,048		1,366	2,049	2,732	
3	2,690	3,804	2,897	2,129	3,194	4,258	5,323
4	5,779	8,173		3,706	5,559	7,412	9,265
5	10,809			5,865	8,797	11,729	14,662
6	17,573			8,402	12,604	16,805	21,006
8				14,719	22,079	29,439	36,798
10				24,067	36,100	48,134	60,167
12				34,953	52,430	69,906	87,383
14				42,785	64,178	85,571	106,964
16				56,963	85,444	113,926	142,407
18				73,166	109,748	146,331	182,914
20				91,394	137,091	182,787	228,484
22				111,647	167,471	223,294	279,118
24				133,926	200,889	267,852	334,815
26		governs pipe	with sizes	158,230	237,345	316,460	395,575
28	Velocity these			184,560	276,839	369,119	461,399
30				212,914	319,372	425,829	532,286
32				243,295	364,942	486,589	608,236
34				275,700	413,550	551,400	689,250
36				310,131	465,196	620,262	775,327
42				425,576	638,363	851,151	1,063,939
48				559,248	838,873	1,118,497	1,398,121
54				711,149	1,066,724	1,422,299	1,777,873
60				881,278	1,321,917	1,762,557	2,203,196
72				1,276,221	1,914,331	2,552,441	3,190,551
84				1,744,075	2,616,113	3,488,151	4,360,188
96				2,284,842	3,427,264	4,569,685	5,712,106
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	24	35	49		Pressure		
3/4	60	85	120		with these	drop	governs
1	126	178	251			pipe	sizes
1–1/4	289	409	578	473			
1–1/2	457	647	915	652	1,633		
2	948	1,340	1,896	1,089			
2–1/2	1,576	2,229	3,152	1,563	2,344	3,125	
3	2,927	4,140	5,854	2,435	3,653	4,871	10,597
4	6,289	8,894		4,239	6,358	8,478	
5	11,762			6,708	10,062	13,416	16,770
6	19,122	16,634		9,611	14,416	19,222	24,027
8	40,488			16,836	25,254	33,673	42,091
10				27,528	41,292	55,056	68,820
12				39,980	59,970	79,960	99,950
14				48,939	73,408	97,878	122,347
16				65,155	97,733	130,310	162,888
18			with sizes	83,688	125,532	167,376	209,221
20				104,538	156,807	209,076	261,345
22	Velocity these	governs pipe		127,704	191,556	255,408	319,260
24				153,187	229,781	306,374	382,968
26				180,987	271,480	361,973	452,467
28				211,103	316,654	422,206	527,757
30				243,536	365,303	487,071	608,839
32				278,285	417,428	556,570	695,713
34				315,351	473,027	630,702	788,378
36				354,734	532,101	709,468	886,834
42				486,782	730,172	973,563	1,216,954

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
48				639,679	959,519	1,279,358	1,599,198
54				813,426	1,220,139	1,626,853	2,033,566
60				1,008,023	1,512,035	2,016,046	2,520,058
72				1,459,766	2,189,649	2,919,531	3,649,414
84				1,994,907	2,992,361	3,989,814	4,987,268
96				2,613,447	3,920,170	5,226,894	6,533,617
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	28	39	56		Pressure		
3/4	68	96	136		with these		
1	143	202	286			drop	governs
1–1/4	329	465	657	578		pipe	sizes
1–1/2	520	735	1,039	797	1,996		
2	1,077	1,523	2,155	1,331			
2–1/2	1,791	2,533	3,583	1,910	2,866	5,955	
3	3,327	4,705	6,654	2,977	4,466	10,364	12,955
4	7,148	10,108		5,182	7,773		
5	13,368			8,201	12,301	16,401	20,502
6	21,734	18,905		11,749	17,624	23,499	29,374
8	46,018			20,583	30,874	41,165	51,456
10				33,653	50,480	67,307	84,134
12				48,876	73,314	97,752	122,190
14				59,828	89,743	119,657	149,571
16				79,653	119,480	159,306	199,133
18				102,310	153,465	204,620	255,775
20				127,799	191,699	255,598	319,498
22				156,120	234,180	312,240	390,300
24				187,273	280,910	374,547	468,184
26			with	221,259	331,888	442,518	553,147
28	Velocity	governs	sizes	258,076	387,114	516,152	645,191
30	these	pipe		297,726	446,589	595,452	744,314
32				340,207	510,311	680,415	850,519
34				385,521	578,282	771,043	963,803
36				433,667	650,501	867,334	1,084,168
42				595,098	892,646	1,190,195	1,487,744
48				782,017	1,173,025	1,564,034	1,955,042
54				994,425	1,491,638	1,988,851	2,486,063
60				1,232,323	1,848,484	2,464,645	3,080,807
72				1,784,585	2,676,877	3,569,169	4,461,461
84				2,438,802	3,658,204	4,877,605	6,097,006
96				3,194,976	4,792,465	6,389,953	7,987,441
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	31	44	62		Pressure		
3/4	77	108	153		with these		
1	160	227	320			drop	governs
1–1/4	369	522	738	691		pipe	sizes
1–1/2	583	825	1,167	952	2,386		
2	1,209	1,710	2,418	1,591			
2–1/2	2,010	2,843	4,021	2,283	3,425	7,117	
3	3,734	5,280	7,467	3,559	5,338	12,388	15,485
4	8,021	11,344		6,194	9,291		
5	15,003	21,217		9,802	14,703	19,604	24,505
6	24,391	34,494		14,044	21,066	28,088	35,109
8	51,644			24,602	36,903	49,204	61,505
10				40,225	60,338	80,450	100,563
12	99,008			58,420	87,631	116,841	146,051
14				71,511	107,267	143,023	178,779
16				95,208	142,811	190,415	238,019
18				122,289	183,433	244,578	305,722
20				152,755	229,133	305,510	381,888
22				186,607	279,910	373,214	466,517
24				223,843	335,765	447,687	559,609
26				264,465	396,698	528,931	661,163

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				308,472	462,709	616,945	771,181
30				355,865	533,797	711,729	889,662
32				406,642	609,963	813,284	1,016,605
34				460,804	691,207	921,609	1,152,011
36				518,352	777,528	1,036,704	1,295,880
42	Velocity these	governs pipe	with sizes	711,306	1,066,959	1,422,612	1,778,265
48				934,726	1,402,090	1,869,453	2,336,816
54				1,188,613	1,782,920	2,377,226	2,971,533
60				1,472,966	2,209,450	2,945,933	3,682,416
72				2,133,072	3,199,608	4,266,144	5,332,680
84				2,915,043	4,372,565	5,830,086	7,287,608
96				3,818,880	5,728,320	7,637,760	9,547,200
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	35	49	69				
3/4	85	120	170				
1	178	252	356		Pressure with these	drop pipe	
1–1/4	410	580	820	812			
1–1/2	648	917	1,297	1,119			governs sizes
2	1,344	1,901	2,688	1,870			
2–1/2	2,235	3,161	4,470	2,684	4,026		
3	4,151	5,870	8,302	4,183	6,274	14,561	
4	8,918	12,612	17,836	7,281	10,921		
5	16,680	23,589		11,522	17,282	23,043	28,804
6	27,118	38,350		16,507	24,761	33,015	41,268
8	57,418			28,917	43,376	57,835	72,294
10				47,281	70,922	94,563	118,203
12	110,076			68,668	103,002	137,336	171,670
14				84,056	126,083	168,111	210,139
16				111,908	167,862	223,817	279,771
18				143,740	215,610	287,480	359,350
20				179,551	269,326	359,101	448,877
22				219,340	329,010	438,680	548,351
24				263,109	394,663	526,218	657,772
26				310,856	466,285	621,713	777,141
28			with sizes	362,583	543,874	725,166	906,457
30		governs pipe		418,288	627,432	836,577	1,045,721
32	Velocity these			477,973	716,959	955,945	1,194,932
34				541,636	812,454	1,083,272	1,354,090
36				609,278	913,918	1,218,557	1,523,196
42				836,079	1,254,119	1,672,159	2,090,198
48				1,098,691	1,648,036	2,197,381	2,746,727
54				1,397,113	2,095,669	2,794,226	3,492,782
60				1,731,346	2,597,018	3,462,691	4,328,364
72				2,507,243	3,760,865	5,014,486	6,268,108
84				3,426,383	5,139,575	6,852,766	8,565,958
96				4,488,766	6,733,149	8,977,532	11,221,915
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	42	59	84				
3/4	103	146	206				
1	215	305	431		Pressure with these	drop pipe	
1–1/4	496	701	992	1,487			governs sizes
1–1/2	784	1,109	1,569	2,484			
2	1,626	2,299	3,251				
2–1/2	2,703	3,823	5,407	3,566	5,349		
3	5,021	7,100	10,041	5,557	8,336	19,345	
4	10,786	15,254	21,573	9,673	14,509		
5	20,174	28,531		15,307	22,960	30,614	38,267
6	32,799	46,384		21,931	32,896	43,861	54,827
8	69,446			38,418	57,627	76,836	96,045
10	133,136			62,815	94,223	125,630	157,038
12	217,311			91,229	136,843	182,457	228,072
14				111,671	167,507	223,343	279,179

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	Pressure Drop psig/100 ft. 0.25	Pressure Drop psig/100 ft. 0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
16				148,675	223,012	297,350	371,687
18				190,965	286,447	381,929	477,412
20				238,541	357,811	477,081	596,352
22				291,403	437,104	582,806	728,507
24				349,551	524,327	699,103	873,878
26				412,986	619,479	825,972	1,032,465
28				481,707	722,560	963,414	1,204,267
30				555,714	833,571	1,111,428	1,389,285
32	Velocity these	governs pipe	with sizes	635,007	952,511	1,270,015	1,587,518
34				719,587	1,079,380	1,439,174	1,798,967
36				809,453	1,214,179	1,618,905	2,023,631
42				1,110,767	1,666,151	2,221,534	2,776,918
48				1,459,658	2,189,487	2,919,316	3,649,144
54				1,856,124	2,784,186	3,712,249	4,640,311
60				2,300,167	3,450,250	4,600,334	5,750,417
72				3,330,980	4,996,470	6,661,960	8,327,450
84				4,552,097	6,828,145	9,104,194	11,380,242
96				5,963,518	8,945,277	11,927,036	14,908,795
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2	50	71	100				
3/4	122	173	245				
1	256	362	513		Pressure with these	drop pipe	governs sizes
1–1/4	590	834	1,180				
1–1/2	933	1,319	1,866				
2	1,933	2,734	3,867	3,200			
2–1/2	3,215	4,547	6,430	4,593			
3	5,971	8,444	11,942	7,158	10,737		
4	12,828	18,142	25,657	12,459	18,689	24,919	
5	23,993	33,932	47,987	19,717	29,576	39,434	
6	39,008	55,165		28,249	42,374	56,498	70,623
8	82,593	116,805		49,487	74,230	98,973	123,717
10	158,340			80,913	121,370	161,826	202,283
12	258,451			117,513	176,269	235,025	293,782
14	336,585			143,845	215,768	287,691	359,613
16				191,510	287,265	383,020	478,775
18				245,984	368,976	491,968	614,960
20				307,267	460,901	614,535	768,168
22				375,360	563,040	750,720	938,400
24				450,262	675,392	900,523	1,125,654
26				531,973	797,959	1,063,945	1,329,931
28		governs pipe	with sizes	620,493	930,739	1,240,986	1,551,232
30				715,822	1,073,733	1,431,645	1,789,556
32	Velocity these			817,961	1,226,942	1,635,922	2,044,903
34				926,909	1,390,364	1,853,818	2,317,273
36				1,042,666	1,563,999	2,085,333	2,606,666
42				1,430,793	2,146,190	2,861,587	3,576,984
48				1,880,204	2,820,306	3,760,408	4,700,510
54				2,390,898	3,586,346	4,781,795	5,977,244
60				2,962,874	4,444,312	5,925,749	7,407,186
72				4,290,678	6,436,017	8,581,356	10,726,695
84				5,863,615	8,795,422	11,727,229	14,659,036
96				7,681,684	11,522,526	15,363,368	19,204,210
Steam Condensate Flow lbs./hr. 60 psig Back Pressure							
1/2	58	83	117				
3/4	143	203	287				
1	300	425	601		Pressure with these		
1–1/4	692	978	1,383				
1–1/2	1,094	1,547	2,187			drop pipe	governs sizes
2	2,267	3,205	4,533	4,014			
2–1/2	3,769	5,330	7,538	5,761			
3	7,000	9,899	14,000	8,979	13,468		
4	15,039	21,268	30,077	15,628	23,442		

(*Continued*)

225 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5	28,127	39,778		24,732	37,097	49,463	
6	45,728	64,670	56,254	35,434	53,151	70,867	88,584
8	96,823	136,929		62,073	93,109	124,145	155,182
10	185,621			101,492	152,237	202,983	253,729
12	302,979			147,400	221,099	294,799	368,499
14	394,575			180,429	270,644	360,859	451,074
16				240,217	360,325	480,433	600,542
18	572,625			308,545	462,818	617,090	771,363
20				385,414	578,122	770,829	963,536
22				470,825	706,237	941,650	1,177,062
24				564,776	847,164	1,129,553	1,411,941
26				667,269	1,000,903	1,334,537	1,668,172
28		governs	with	778,302	1,167,453	1,556,605	1,945,756
30		pipe	sizes	897,877	1,346,815	1,795,754	2,244,692
32				1,025,992	1,538,989	2,051,985	2,564,981
34	Velocity			1,162,649	1,743,974	2,325,298	2,906,623
36	these			1,307,847	1,961,770	2,615,693	3,269,617
42				1,794,686	2,692,029	3,589,372	4,486,715
48				2,358,395	3,537,592	4,716,789	5,895,987
54				2,998,973	4,498,459	5,997,945	7,497,432
60				3,716,420	5,574,630	7,432,840	9,291,050
72				5,381,923	8,072,884	10,763,845	13,454,807
84				7,354,903	11,032,354	14,709,806	18,387,257
96				9,635,361	14,453,041	19,270,721	24,088,402
Steam Condensate Flow lbs./hr. 75 psig Back Pressure							
1/2	73	104	147				
3/4	180	254	359				
1	376	532	753		Pressure		
1–1/4	866	1,225	1,732		with these	drop	governs
1–1/2	1,370	1,937	2,739	5,481		pipe	sizes
2	2,839	4,015	5,678				
2–1/2	4,721	6,676	9,441	7,867			
3	8,767	12,399	17,535	12,260	32,009		
4	18,836	26,638	37,672	21,339			
5	35,229	49,822		33,769	50,654	67,538	
6	57,275	80,999	70,459	48,382	72,573	96,764	211,889
8	121,271	171,504	114,550	84,756	127,133	169,511	
10	232,491			138,579	207,869	277,158	346,448
12	379,483	328,792		201,263	301,895	402,527	503,158
14	494,206			246,363	369,544	492,726	615,907
16				327,998	491,997	655,996	819,995
18	717,216			421,295	631,943	842,591	1,053,238
20	992,077			526,255	789,382	1,052,509	1,315,637
22				642,876	964,314	1,285,752	1,607,191
24				771,160	1,156,740	1,542,320	1,927,900
26				911,106	1,366,659	1,822,211	2,277,764
28				1,062,714	1,594,071	2,125,427	2,656,784
30			with	1,225,984	1,838,976	2,451,968	3,064,960
32		governs	sizes	1,400,916	2,101,374	2,801,832	3,502,290
34	Velocity	pipe		1,587,511	2,381,266	3,175,021	3,968,777
36	these			1,785,767	2,678,651	3,571,534	4,464,418
42				2,450,510	3,675,765	4,901,020	6,126,275
48				3,220,212	4,830,318	6,440,424	8,050,530
54				4,094,874	6,142,310	8,189,747	10,237,184
60				5,074,495	7,611,742	10,148,989	12,686,236
72				7,348,614	11,022,922	14,697,229	18,371,536
84				10,042,572	15,063,858	20,085,144	25,106,430
96				13,156,367	19,734,550	26,312,734	32,890,917

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	14	20	28	65	Pressure	drop	
3/4	34	48	68	108	with these	pipe	
1	71	100	142				governs
1–1/4	163	231	326	192	288		sizes
1–1/2	258	365	516	265	397	884	
2	535	756	1,070	442	663		
2–1/2	889	1,258		635	952	1,269	1,587
3	1,652	2,336		989	1,484	1,978	2,473
4	3,549			1,722	2,582	3,443	4,304
5				2,724	4,087	5,449	6,811
6	6,638			3,903	5,855	7,807	9,759
8				6,838	10,257	13,676	17,095
10				11,180	16,771	22,361	27,951
12				16,238	24,357	32,475	40,594
14				19,876	29,815	39,753	49,691
16				26,463	39,694	52,925	66,156
18				33,990	50,985	67,979	84,974
20				42,458	63,687	84,915	106,144
22			with	51,867	77,800	103,733	129,667
24			sizes	62,216	93,325	124,433	155,541
26		governs		73,507	110,261	147,014	183,768
28	Velocity	pipe		85,739	128,608	171,477	214,347
30	these			98,911	148,367	197,822	247,278
32				113,025	169,537	226,049	282,561
34				128,079	192,118	256,158	320,197
36				144,074	216,111	288,148	360,185
42				197,705	296,557	395,410	494,262
48				259,804	389,706	519,607	649,509
54				330,371	495,556	660,741	825,926
60				409,405	614,108	818,811	1,023,514
72				592,879	889,319	1,185,759	1,482,198
84				810,225	1,215,338	1,620,450	2,025,563
96				1,061,443	1,592,165	2,122,887	2,653,608
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	17	24	34		Pressure	drop	
3/4	42	59	83	152	with these	pipe	
1	87	123	174				governs
1–1/4	200	283	401	270	559		sizes
1–1/2	317	448	634	372	934	1,245	
2	657	929	1,313	622			
2–1/2	1,092	1,544		893	1,340	1,787	3,480
3	2,028	2,868	2,184	1,392	2,088	2,784	6,058
4	4,357			2,423	3,635	4,846	
5	8,148			3,835	5,752	7,669	9,586
6	13,247			5,494	8,241	10,988	13,735
8				9,624	14,436	19,248	24,061
10				15,736	23,604	31,472	39,340
12				22,854	34,281	45,708	57,135
14				27,975	41,963	55,950	69,938
16				37,245	55,867	74,490	93,112
18				47,839	71,759	95,678	119,598
20		governs	with	59,757	89,636	119,515	149,394
22		pipe	sizes	73,000	109,500	146,000	182,500
24	Velocity			87,567	131,351	175,134	218,918
26	these			103,458	155,187	206,916	258,646
28				120,674	181,011	241,347	301,684
30				139,213	208,820	278,427	348,033
32				159,077	238,616	318,155	397,693
34				180,266	270,398	360,531	450,664
36				202,778	304,167	405,556	506,945
42				278,261	417,392	556,523	695,653

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
48				365,663	548,494	731,326	914,157
54				464,983	697,474	929,965	1,162,457
60				576,221	864,331	1,152,442	1,440,552
72				834,453	1,251,679	1,668,905	2,086,132
84				1,140,358	1,710,537	2,280,716	2,850,895
96				1,493,937	2,240,905	2,987,874	3,734,842
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	18	26	36				
3/4	45	63	89		Pressure with these	drop pipe	
1	93	132	187	170			governs sizes
1–1/4	215	304	430	304			
1–1/2	340	481	680	418	627		
2	705	996	1,409	699	1,048	1,397	
2–1/2	1,172	1,657	2,343	1,003	1,504	2,006	
3	2,176	3,077		1,563	2,344	3,126	3,907
4	4,675	6,612		2,720	4,081	5,441	6,801
5	8,744			4,305	6,458	8,610	10,763
6	14,216			6,168	9,252	12,336	15,420
8				10,805	16,208	21,611	27,013
10				17,667	26,501	35,334	44,168
12				25,659	38,488	51,317	64,147
14				31,408	47,113	62,817	78,521
16				41,816	62,724	83,632	104,540
18				53,710	80,565	107,420	134,275
20				67,091	100,637	134,182	167,728
22				81,959	122,939	163,918	204,898
24				98,314	147,471	196,627	245,784
26		governs pipe	with sizes	116,155	174,233	232,310	290,388
28				135,483	203,225	270,967	338,708
30	Velocity these			156,298	234,448	312,597	390,746
32				178,600	267,900	357,200	446,500
34				202,389	303,583	404,778	505,972
36				227,664	341,496	455,328	569,160
42				312,411	468,616	624,822	781,027
48				410,539	615,808	821,078	1,026,347
54				522,048	783,072	1,044,096	1,305,119
60				646,938	970,407	1,293,876	1,617,345
72				936,861	1,405,292	1,873,722	2,342,153
84				1,280,309	1,920,463	2,560,617	3,200,772
96				1,677,281	2,515,921	3,354,561	4,193,202
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	20	28	40				
3/4	49	69	98		Pressure with these		
1	103	145	206	199		drop pipe	governs sizes
1–1/4	237	335	473	355			
1–1/2	374	529	748	489	734		
2	776	1,097	1,551	817	1,226		
2–1/2	1,290	1,824	2,579	1,173	1,759	2,346	
3	2,395	3,387		1,828	2,742	3,656	4,570
4	5,146	7,277		3,182	4,773	6,364	7,955
5	9,624			5,035	7,553	10,070	12,588
6	15,647			7,214	10,821	14,428	18,035
8				12,638	18,956	25,275	31,594
10				20,663	30,995	41,326	51,658
12		governs pipe	with sizes	30,010	45,015	60,019	75,024
14	Velocity these			36,734	55,102	73,469	91,836
16				48,907	73,360	97,814	122,267
18				62,818	94,227	125,636	157,045
20				78,468	117,702	156,936	196,171

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
22				95,857	143,786	191,715	239,643
24				114,985	172,478	229,971	287,463
26				135,852	203,778	271,704	339,630
28				158,458	237,687	316,916	396,145
30				182,803	274,204	365,605	457,007
32				208,886	313,329	417,773	522,216
34				236,709	355,063	473,418	591,772
36				266,270	399,405	532,541	665,676
42				365,388	548,082	730,776	913,470
48				480,156	720,234	960,312	1,200,390
54				610,574	915,861	1,221,148	1,526,435
60				756,642	1,134,963	1,513,285	1,891,606
72				1,095,729	1,643,594	2,191,459	2,739,323
84				1,497,417	2,246,125	2,994,834	3,743,542
96				1,961,705	2,942,558	3,923,411	4,904,263
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	21	30	42		Pressure		
3/4	52	74	104		with these		governs
1	109	154	218			drop	sizes
1–1/4	251	355	502	391		pipe	
1–1/2	397	561	794	538	1,349		
2	823	1,163	1,645	899			
2–1/2	1,368	1,935		1,290	1,936	2,581	
3	2,541	3,593	2,736	2,011	3,017	4,022	5,028
4	5,459	7,720		3,500	5,251	7,001	8,751
5	10,209			5,539	8,309	11,079	13,848
6	16,598			7,936	11,905	15,873	19,841
8				13,903	20,855	27,806	34,758
10				22,732	34,098	45,464	56,830
12				33,015	49,522	66,029	82,537
14				40,413	60,619	80,825	101,032
16				53,804	80,706	107,608	134,510
18				69,108	103,662	138,216	172,770
20				86,325	129,488	172,651	215,813
22				105,456	158,183	210,911	263,639
24				126,499	189,748	252,998	316,247
26		governs	with	149,455	224,183	298,910	373,638
28		pipe	sizes	174,324	261,487	348,649	435,811
30	Velocity			201,107	301,660	402,214	502,767
32	these			229,802	344,703	459,604	574,505
34				260,411	390,616	520,821	651,026
36				292,932	439,398	585,864	732,330
42				401,974	602,962	803,949	1,004,936
48				528,234	792,351	1,056,468	1,320,585
54				671,711	1,007,566	1,343,422	1,679,277
60				832,405	1,248,608	1,664,810	2,081,013
72				1,205,445	1,808,167	2,410,890	3,013,612
84				1,647,354	2,471,031	3,294,707	4,118,384
96				2,158,131	3,237,197	4,316,263	5,395,329
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	23	33	46		Pressure		
3/4	57	80	113		with these		governs
1	118	167	237			drop	sizes
1–1/4	273	385	545	446		pipe	
1–1/2	431	610	862	614	1,539		
2	893	1,263	1,787	1,026			
2–1/2	1,485	2,101		1,473	2,209	2,946	
3	2,759	3,901	2,971	2,295	3,443	4,591	9,988
4	5,927	8,382	5,517	3,995	5,993	7,990	

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5	11,085			6,322	9,483	12,644	15,805
6	18,022	15,677		9,058	13,587	18,116	22,645
8	38,159			15,868	23,802	31,735	39,669
10				25,944	38,917	51,889	64,861
12				37,680	56,520	75,360	94,200
14				46,123	69,185	92,247	115,309
16				61,407	92,110	122,814	153,517
18				78,874	118,311	157,748	197,185
20				98,524	147,786	197,048	246,310
22				120,358	180,536	240,715	300,894
24				144,375	216,562	288,749	360,937
26				170,575	255,862	341,150	426,437
28			with sizes	198,959	298,438	397,917	497,396
30	Velocity these	governs pipe		229,526	344,288	459,051	573,814
32				262,276	393,414	524,552	655,690
34				297,210	445,815	594,419	743,024
36				334,327	501,490	668,654	835,817
42				458,778	688,167	917,557	1,146,946
48				602,880	904,320	1,205,760	1,507,200
54				766,632	1,149,948	1,533,264	1,916,580
60				950,034	1,425,051	1,900,068	2,375,085
72				1,375,789	2,063,684	2,751,578	3,439,473
84				1,880,145	2,820,217	3,760,290	4,700,362
96				2,463,102	3,694,653	4,926,203	6,157,754
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	26	37	52				
3/4	64	91	128		Pressure with these		
1	134	190	268			drop pipe	governs sizes
1–1/4	309	436	617	543			
1–1/2	488	690	976	748	1,875		
2	1,012	1,431	2,023	1,250			
2–1/2	1,682	2,379		1,794	2,691		
3	3,124	4,418	3,364	2,796	4,194	5,592	12,166
4	6,712	9,492	6,248	4,866	7,299	9,733	
5	12,553			7,701	11,551	15,402	19,252
6	20,409	17,753		11,033	16,550	22,066	27,583
8	43,213			19,328	28,992	38,656	48,320
10				31,602	47,403	63,204	79,005
12				45,897	68,845	91,793	114,741
14				56,181	84,272	112,362	140,453
16				74,798	112,196	149,595	186,994
18				96,073	144,110	192,146	240,183
20				120,008	180,013	240,017	300,021
22				146,603	219,905	293,206	366,508
24				175,857	263,786	351,715	439,643
26				207,771	311,656	415,542	519,427
28			with sizes	242,344	363,516	484,688	605,860
30	Velocity these	governs pipe		279,576	419,365	559,153	698,941
32				319,468	479,203	638,937	798,671
34				362,020	543,030	724,040	905,050
36				407,231	610,846	814,462	1,018,077
42				558,821	838,231	1,117,641	1,397,051
48				734,345	1,101,518	1,468,691	1,835,863
54				933,805	1,400,708	1,867,611	2,334,513
60				1,157,201	1,735,801	2,314,401	2,893,002
72				1,675,797	2,513,695	3,351,593	4,189,492
84				2,290,134	3,435,200	4,580,267	5,725,334
96				3,000,211	4,500,317	6,000,423	7,500,528

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	29	41	58				
3/4	72	101	143		Pressure with these		
1	150	212	300			drop pipe	governs sizes
1–1/4	345	488	690	647			
1–1/2	546	772	1,091	891	2,233		
2	1,131	1,600	2,262	1,488			
2–1/2	1,881	2,660	3,762	2,136	3,205	6,659	
3	3,493	4,940	6,987	3,330	4,994	11,591	14,488
4	7,505	10,614		5,795	8,693		
5	14,037	19,851		9,171	13,757	18,342	22,928
6	22,821	32,273		13,140	19,709	26,279	32,849
8	48,319			23,018	34,527	46,036	57,545
10				37,635	56,453	75,271	94,088
12	92,633			54,659	81,989	109,318	136,648
14				66,907	100,361	133,815	167,268
16				89,078	133,617	178,155	222,694
18				114,415	171,623	228,831	286,039
20				142,920	214,380	285,841	357,301
22				174,592	261,889	349,185	436,481
24				209,432	314,147	418,863	523,579
26			with sizes	247,438	371,157	494,876	618,595
28		governs pipe		288,612	432,918	577,224	721,530
30				332,953	499,429	665,906	832,382
32	Velocity these			380,461	570,691	760,922	951,152
34				431,136	646,704	862,272	1,077,841
36				484,979	727,468	969,958	1,212,447
42				665,510	998,264	1,331,019	1,663,774
48				874,545	1,311,818	1,749,091	2,186,364
54				1,112,086	1,668,129	2,224,172	2,780,215
60				1,378,132	2,067,197	2,756,263	3,445,329
72				1,995,737	2,993,606	3,991,474	4,989,343
84				2,727,362	4,091,043	5,454,725	6,818,406
96				3,573,007	5,359,510	7,146,014	8,932,517
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	32	46	65				
3/4	79	112	159				
1	166	235	332		Pressure with these	drop pipe	
1–1/4	382	541	765	757			
1–1/2	605	855	1,209	1,043			governs sizes
2	1,253	1,772	2,506	1,743			
2–1/2	2,084	2,947	4,167	2,502	3,753		
3	3,870	5,472	7,739	3,899	5,849	13,574	
4	8,313	11,757	16,627	6,787	10,180		
5	15,549	21,989		10,740	16,110	21,480	26,850
6	25,279	35,749		15,388	23,082	30,775	38,469
8	53,524			26,956	40,434	53,912	67,391
10	102,611			44,075	66,112	88,149	110,186
12	167,486			64,011	96,017	128,022	160,028
14				78,355	117,532	156,710	195,887
16				104,319	156,478	208,637	260,796
18				133,991	200,987	267,983	334,978
20			with sizes	167,373	251,060	334,747	418,433
22				204,464	306,697	408,929	511,161
24		governs pipe		245,265	367,897	490,529	613,161
26	Velocity these			289,774	434,661	579,548	724,434
28				337,992	506,988	675,984	844,980
30				389,920	584,879	779,839	974,799
32				445,556	668,334	891,112	1,113,890
34				504,902	757,353	1,009,804	1,262,254
36				567,957	851,935	1,135,913	1,419,891
42				779,375	1,169,063	1,558,751	1,948,439

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
48				1,024,176	1,536,265	2,048,353	2,560,441
54				1,302,359	1,953,539	2,604,718	3,255,898
60				1,613,924	2,420,886	3,227,848	4,034,810
72				2,337,199	3,505,799	4,674,398	5,842,998
84				3,194,002	4,791,003	6,388,004	7,985,005
96				4,184,333	6,276,499	8,368,666	10,460,832
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	39	55	78				
3/4	95	135	190				
1	199	282	399		Pressure with these	drop pipe	
1–1/4	459	649	918				governs sizes
1–1/2	726	1,026	1,451	1,375			
2	1,504	2,127	3,008	2,298			
2–1/2	2,501	3,537	5,002	3,299	4,948		
3	4,645	6,569	9,290	5,141	7,712		
4	9,979	14,113	19,958	8,949	13,423	17,897	
5	18,664	26,395		14,161	21,242	28,323	35,403
6	30,344	42,913		20,289	30,434	40,579	50,723
8	64,249			35,543	53,314	71,086	88,857
10	123,172			58,114	87,171	116,228	145,285
12	201,047			84,401	126,601	168,802	211,002
14				103,314	154,971	206,628	258,285
16				137,548	206,322	275,096	343,870
18				176,673	265,009	353,346	441,682
20				220,688	331,032	441,376	551,720
22				269,594	404,391	539,188	673,985
24				323,391	485,086	646,781	808,477
26			with sizes	382,078	573,117	764,156	955,195
28		governs pipe		445,656	668,483	891,311	1,114,139
30	Velocity these			514,124	771,186	1,028,248	1,285,310
32				587,483	881,224	1,174,966	1,468,707
34				665,732	998,599	1,331,465	1,664,331
36				748,873	1,123,309	1,497,745	1,872,181
42				1,027,637	1,541,455	2,055,273	2,569,091
48				1,350,416	2,025,624	2,700,832	3,376,040
54				1,717,211	2,575,816	3,434,421	4,293,026
60				2,128,021	3,192,031	4,256,041	5,320,052
72				3,081,687	4,622,530	6,163,374	7,704,217
84				4,211,415	6,317,122	8,422,829	10,528,536
96				5,517,204	8,275,806	11,034,407	13,793,009
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2	46	65	92				
3/4	112	159	225				
1	235	333	470		Pressure with these	drop pipe	
1–1/4	541	766	1,083				governs sizes
1–1/2	856	1,211	1,712				
2	1,774	2,509	3,549	2,937			
2–1/2	2,951	4,173	5,901	4,215			
3	5,480	7,750	10,960	6,570	9,854		
4	11,773	16,650	23,547	11,435	17,152	22,870	
5	22,020	31,141	44,040	18,095	27,143	36,191	
6	35,800	50,629		25,926	38,889	51,852	64,815
8	75,801	107,199		45,417	68,125	90,834	113,542
10	145,319			74,259	111,388	148,518	185,647
12	237,196			107,849	161,773	215,697	269,621
14	308,904			132,016	198,023	264,031	330,039
16				175,760	263,641	351,521	439,401
18				225,754	338,632	451,509	564,386
20				281,998	422,997	563,996	704,994

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
22				344,490	516,736	688,981	861,226
24				413,232	619,848	826,464	1,033,081
26				488,223	732,335	976,447	1,220,558
28				569,464	854,195	1,138,927	1,423,659
30				656,953	985,430	1,313,907	1,642,383
32				750,692	1,126,038	1,501,384	1,876,730
34	Velocity	governs	with	850,680	1,276,020	1,701,361	2,126,701
36	these	pipe	sizes	956,918	1,435,377	1,913,835	2,392,294
42				1,313,125	1,969,688	2,626,251	3,282,813
48				1,725,576	2,588,365	3,451,153	4,313,941
54				2,194,271	3,291,406	4,388,542	5,485,677
60				2,719,209	4,078,813	5,438,417	6,798,021
72				3,937,814	5,906,721	7,875,628	9,844,535
84				5,381,393	8,072,089	10,762,785	13,453,481
96				7,049,945	10,574,917	14,099,889	17,624,861
Steam Condensate Flow lbs./hr. 60 psig Back Pressure							
1/2	53	75	106				
3/4	131	185	261				
1	273	387	547		Pressure		
1–1/4	629	890	1,259		with these	drop	governs
1–1/2	995	1,407	1,990			pipe	sizes
2	2,063	2,917	4,125	3,653			
2–1/2	3,430	4,850	6,859	5,243			
3	6,370	9,008	12,739	8,170	12,256		
4	13,685	19,353	27,369	14,221	21,332		
5	25,595	36,196	51,189	22,505	33,757	45,010	
6	41,611	58,847		32,243	48,365	64,487	80,608
8	88,105	124,600		56,484	84,726	112,968	141,209
10	168,908			92,353	138,530	184,707	230,884
12	275,699			134,128	201,192	268,256	335,320
14	359,048			164,184	246,276	328,368	410,460
16	521,067			218,588	327,882	437,176	546,470
18				280,764	421,146	561,528	701,910
20				350,712	526,069	701,425	876,781
22				428,433	642,649	856,865	1,071,081
24				513,925	770,887	1,027,850	1,284,812
26				607,189	910,783	1,214,378	1,517,972
28		governs	with	708,225	1,062,338	1,416,450	1,770,563
30		pipe	sizes	817,034	1,225,550	1,634,067	2,042,584
32				933,614	1,400,421	1,867,228	2,334,034
34	Velocity			1,057,966	1,586,949	2,115,932	2,644,915
36	these			1,190,090	1,785,136	2,380,181	2,975,226
42				1,633,096	2,449,643	3,266,191	4,082,739
48				2,146,049	3,219,073	4,292,098	5,365,122
54				2,728,950	4,093,425	5,457,900	6,822,375
60				3,381,800	5,072,700	6,763,600	8,454,499
72				4,897,343	7,346,015	9,794,687	12,243,359
84				6,692,680	10,039,020	13,385,360	16,731,700
96				8,767,809	13,151,713	17,535,618	21,919,522
Steam Condensate Flow lbs./hr. 75 psig Back Pressure							
1/2	66	93	131				
3/4	161	228	322				
1	338	477	675		Pressure		
1–1/4	777	1,099	1,554		with these	drop	governs
1–1/2	1,229	1,737	2,457			pipe	sizes
2	2,546	3,601	5,093	4,916			
2–1/2	4,234	5,988	8,468	7,056			
3	7,864	11,121	15,727	10,996			
4	16,895	23,893	33,789	19,140	28,710		

(*Continued*)

250 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
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	190,050
8	108,772	153,827		76,020	114,030	152,040	
10	208,528			124,296	186,444	248,592	310,740
12	340,369	294,903		180,519	270,779	361,038	451,298
14	443,268			220,970	331,455	441,941	552,426
16	643,292			294,191	441,287	588,382	735,478
18	889,824			377,872	566,808	755,745	944,681
20				472,014	708,020	944,027	1,180,034
22				576,615	864,922	1,153,230	1,441,537
24				691,676	1,037,514	1,383,353	1,729,191
26				817,198	1,225,797	1,634,396	2,042,995
28			with	953,180	1,429,769	1,906,359	2,382,949
30			sizes	1,099,622	1,649,432	2,199,243	2,749,054
32		governs		1,256,524	1,884,785	2,513,047	3,141,309
34	Velocity	pipe		1,423,886	2,135,828	2,847,771	3,559,714
36	these			1,601,708	2,402,562	3,203,416	4,004,270
42				2,197,935	3,296,903	4,395,871	5,494,839
48				2,888,304	4,332,456	5,776,609	7,220,761
54				3,672,814	5,509,221	7,345,629	9,182,036
60				4,551,465	6,827,198	9,102,931	11,378,664
72				6,591,191	9,886,787	13,182,383	16,477,979
84				9,007,482	13,511,223	18,014,964	22,518,706
96				11,800,338	17,700,507	23,600,676	29,500,845

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 3.

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2	13	19	26	62	Pressure	drop	
3/4	32	46	65	103	with these	pipe	
1	68	96	136				governs
1–1/4	156	221	313	184	276		sizes
1–1/2	247	350	494	253	380	847	
2	512	724	1,025	423	635		
2–1/2	852	1,205		608	912	1,216	1,520
3	1,582	2,237		947	1,421	1,895	2,368
4	3,399			1,649	2,473	3,298	4,122
5				2,609	3,914	5,218	6,523
6	6,357			3,738	5,607	7,477	9,346
8				6,549	9,823	13,098	16,372
10				10,708	16,061	21,415	26,769
12				15,551	23,326	31,102	38,877
14			with	19,036	28,553	38,071	47,589
16			sizes	25,343	38,015	50,686	63,358
18		governs		32,552	48,828	65,104	81,380
20	Velocity	pipe		40,662	60,993	81,324	101,654
22	these			49,673	74,509	99,345	124,182
24				59,585	89,377	119,169	148,962
26				70,398	105,597	140,796	175,994
28				82,112	123,168	164,224	205,280
30				94,727	142,091	189,454	236,818
32				108,244	162,365	216,487	270,609

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
34				122,661	183,992	245,322	306,653
36				137,980	206,969	275,959	344,949
42				189,342	284,013	378,684	473,355
48				248,814	373,221	497,628	622,035
54				316,396	474,594	632,791	790,989
60				392,087	588,131	784,175	980,219
72				567,800	851,700	1,135,601	1,419,501
84				775,952	1,163,929	1,551,905	1,939,881
96				1,016,544	1,524,816	2,033,088	2,541,360
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	16	23	32	145	Pressure with these	drop pipe	governs sizes
3/4	40	56	79				
1	83	117	166				
1–1/4	191	270	382	258	533	1,188	
1–1/2	302	428	605	355	891		
2	627	886	1,253	594			
2–1/2	1,042	1,474	2,084	853	1,279	1,705	3,322
3	1,935	2,737		1,329	1,993	2,657	5,782
4	4,158			2,313	3,469	4,625	
5	7,777			3,660	5,490	7,319	9,149
6	12,643			5,243	7,865	10,487	13,109
8				9,185	13,778	18,371	22,963
10	Velocity these	governs pipe	with sizes	15,019	22,528	30,037	37,546
12				21,812	32,718	43,624	54,530
14				26,700	40,049	53,399	66,749
16				35,547	53,320	71,094	88,867
18				45,658	68,487	91,316	114,145
20				57,033	85,549	114,066	142,582
22				69,672	104,508	139,343	174,179
24				83,574	125,362	167,149	208,936
26				98,741	148,112	197,482	246,853
28				115,172	172,757	230,343	287,929
30				132,866	199,299	265,732	332,165
32				151,824	227,737	303,649	379,561
34				172,047	258,070	344,093	430,116
36				193,533	290,299	387,065	483,832
42				265,574	398,361	531,148	663,935
48				348,991	523,486	697,981	872,477
54				443,782	665,673	887,564	1,109,455
60				549,949	824,923	1,099,897	1,374,872
72				796,406	1,194,610	1,592,813	1,991,016
84				1,088,364	1,632,546	2,176,728	2,720,911
96				1,425,822	2,138,733	2,851,644	3,564,555
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	17	25	35	162	Pressure with these	drop pipe	governs sizes
3/4	43	60	85				
1	89	126	178				
1–1/4	205	290	410	289	598	1,332	
1–1/2	324	458	648	399	999		
2	672	950	1,343	666			
2–1/2	1,117	1,579	2,234	956	1,434	1,912	3,724
3	2,074	2,933		1,490	2,235	2,979	6,482
4	4,456	6,302		2,593	3,889	5,186	
5	8,334			4,103	6,155	8,207	10,259
6	13,550			5,879	8,819	11,758	14,698
8				10,299	15,448	20,598	25,747
10				16,839	25,259	33,678	42,098
12				24,456	36,684	48,912	61,140
14				29,936	44,905	59,873	74,841

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				39,856	59,784	79,712	99,640
18				51,193	76,789	102,386	127,982
20				63,947	95,920	127,894	159,867
22				78,118	117,177	156,236	195,295
24				93,706	140,559	187,412	234,265
26				110,711	166,067	221,423	276,778
28				129,134	193,701	258,267	322,834
30				148,973	223,460	297,946	372,433
32	Velocity these	governs pipe	with sizes	170,230	255,345	340,460	425,574
34				192,903	289,355	385,807	482,259
36				216,994	325,491	433,988	542,486
42				297,769	446,654	595,538	744,423
48				391,298	586,947	782,596	978,245
54				497,581	746,372	995,162	1,243,953
60				616,618	924,927	1,233,236	1,541,545
72				892,953	1,339,430	1,785,907	2,232,384
84				1,220,305	1,830,457	2,440,610	3,050,762
96				1,598,672	2,398,008	3,197,344	3,996,680
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2	19	27	38		Pressure with these		
3/4	47	66	93	189		drop pipe	governs sizes
1	98	138	196				
1–1/4	225	318	450	338	698		
1–1/2	356	503	712	465	1,166		
2	738	1,043	1,476	777			
2–1/2	1,227	1,735		1,116	1,674	2,232	4,348
3	2,279	3,222	2,454	1,739	2,609	3,478	7,567
4	4,895	6,923		3,027	4,540	6,054	
5	9,156			4,790	7,185	9,580	11,975
6	14,885			6,863	10,294	13,726	17,157
8				12,022	18,034	24,045	30,056
10				19,657	29,486	39,314	49,143
12				28,549	42,823	57,097	71,372
14				34,946	52,419	69,892	87,365
16				46,526	69,788	93,051	116,314
18				59,760	89,639	119,519	149,399
20				74,648	111,972	149,296	186,620
22				91,190	136,785	182,381	227,976
24				109,387	164,080	218,774	273,467
26				129,238	193,857	258,476	323,095
28		governs pipe	with sizes	150,743	226,115	301,486	376,858
30	Velocity these			173,903	260,854	347,805	434,756
32				198,716	298,074	397,432	496,791
34				225,184	337,776	450,368	562,960
36				253,306	379,960	506,613	633,266
42				347,598	521,397	695,197	868,996
48				456,779	685,168	913,557	1,141,946
54				580,847	871,270	1,161,694	1,452,117
60				719,804	1,079,705	1,439,607	1,799,509
72				1,042,381	1,563,572	2,084,763	2,605,954
84				1,424,512	2,136,768	2,849,024	3,561,280
96				1,866,196	2,799,293	3,732,391	4,665,489
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2	20	29	40		Pressure with these		
3/4	49	70	99			drop pipe	governs sizes
1	104	147	207				
1–1/4	238	337	477	371			
1–1/2	377	533	754	511	1,281		
2	782	1,105	1,563	854			

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2	1,300	1,838		1,226	1,839	2,452	
3	2,414	3,414	2,600	1,911	2,866	3,821	4,777
4	5,186	7,335		3,326	4,989	6,652	8,314
5	9,700			5,263	7,895	10,526	13,158
6	15,770			7,541	11,311	15,081	18,851
8				13,209	19,814	26,419	33,024
10				21,598	32,397	43,196	53,995
12				31,368	47,051	62,735	78,419
14				38,397	57,595	76,793	95,991
16				51,120	76,680	102,239	127,799
18				65,660	98,491	131,321	164,151
20				82,019	123,028	164,037	205,047
22				100,195	150,292	200,389	250,486
24				120,188	180,282	240,376	300,470
26				141,999	212,999	283,998	354,998
28		governs pipe	with sizes	165,628	248,442	331,255	414,069
30	Velocity these			191,074	286,611	382,148	477,685
32				218,338	327,507	436,676	545,844
34				247,419	371,129	494,838	618,548
36				278,318	417,477	556,636	695,796
42				381,921	572,881	763,841	954,802
48				501,882	752,822	1,003,763	1,254,704
54				638,201	957,301	1,276,401	1,595,502
60				790,878	1,186,317	1,581,756	1,977,195
72				1,145,308	1,717,962	2,290,616	2,863,270
84				1,565,171	2,347,756	3,130,341	3,912,927
96				2,050,467	3,075,700	4,100,934	5,126,167
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2	22	31	44		Pressure with the		
3/4	54	76	107			drop pipe	governs sizes
1	112	159	225				
1–1/4	258	366	517	423			
1–1/2	409	578	817	582	1,460		
2	847	1,198	1,694	973			
2–1/2	1,409	1,992	2,817	1,397	2,095	2,793	
3	2,616	3,700	5,232	2,177	3,265	4,353	9,472
4	5,621	7,949		3,789	5,683	7,577	
5	10,513			5,996	8,993	11,991	14,989
6	17,091	14,867		8,590	12,885	17,180	21,475
8	36,188			15,048	22,572	30,096	37,620
10				24,604	36,906	49,209	61,511
12				35,734	53,601	71,467	89,334
14				43,741	65,611	87,482	109,352
16				58,235	87,353	116,470	145,588
18				74,800	112,200	149,599	186,999
20				93,435	140,152	186,870	233,587
22				114,141	171,211	228,281	285,352
24				136,917	205,376	273,834	342,293
26			with sizes	161,764	242,646	323,528	404,410
28	Velocity these	governs pipe		188,682	283,022	377,363	471,704
30				217,670	326,504	435,339	544,174
32				248,728	373,093	497,457	621,821
34				281,858	422,786	563,715	704,644
36				317,057	475,586	634,115	792,644
42				435,081	652,621	870,161	1,087,701
48				571,739	857,608	1,143,478	1,429,347
54				727,032	1,090,548	1,454,064	1,817,581
60				900,961	1,351,441	1,801,922	2,252,402
72				1,304,724	1,957,086	2,609,448	3,261,810
84				1,783,028	2,674,542	3,566,055	4,457,569
96				2,335,872	3,503,809	4,671,745	5,839,681

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	25	35	49		Pressure with these	drop pipe	governs sizes
3/4	61	86	121				
1	127	179	254				
1–1/4	292	413	584	513			
1–1/2	461	653	923	707	1,772		
2	956	1,353	1,913	1,182			
2–1/2	1,590	2,249	3,181	1,696	2,544	5,286	11,502
3	2,954	4,177	5,907	2,643	3,965	9,201	
4	6,346	8,974		4,601	6,901		
5	11,868	16,784	with sizes	7,281	10,921	14,561	18,201
6	19,295			10,431	15,647	20,862	26,078
8	40,855			18,273	27,410	36,546	45,683
10	Velocity these	governs pipe		29,878	44,816	59,755	74,694
12				43,392	65,088	86,784	108,480
14				53,116	79,673	106,231	132,789
16				70,716	106,074	141,432	176,790
18				90,831	136,246	181,661	227,077
20				113,460	170,190	226,920	283,650
22				138,603	207,905	277,207	346,508
24				166,261	249,392	332,522	415,653
26				196,433	294,650	392,867	491,083
28				229,120	343,680	458,240	572,799
30				264,321	396,481	528,641	660,802
32				302,036	453,054	604,072	755,090
34				342,265	513,398	684,531	855,663
36				385,009	577,514	770,018	962,523
42				528,327	792,490	1,056,654	1,320,817
48				694,274	1,041,411	1,388,548	1,735,684
54				882,850	1,324,275	1,765,699	2,207,124
60				1,094,055	1,641,082	2,188,110	2,735,137
72				1,584,352	2,376,528	3,168,704	3,960,881
84				2,165,166	3,247,749	4,330,332	5,412,915
96				2,836,497	4,254,745	5,672,993	7,091,241
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	28	39	55		Pressure with these	drop pipe	governs sizes
3/4	67	95	135				
1	141	200	283				
1–1/4	325	460	651	609			
1–1/2	514	727	1,029	840	2,104		
2	1,066	1,508	2,132	1,403			
2–1/2	1,773	2,507	3,546	2,014	3,020	6,276	13,656
3	3,293	4,656	6,585	3,138	4,707	10,925	
4	7,074	10,004		5,462	8,193		
5	13,230	18,710	with sizes	8,644	12,966	17,288	21,610
6	21,509	30,419		12,385	18,577	24,769	30,962
8	45,543			21,695	32,543	43,391	54,239
10	87,311	governs pipe		35,473	53,209	70,946	88,682
12				51,519	77,278	103,037	128,796
14				63,063	94,595	126,126	157,658
16	Velocity these			83,960	125,939	167,919	209,899
18				107,842	161,762	215,683	269,604
20				134,709	202,063	269,417	336,771
22				164,561	246,841	329,122	411,402
24				197,398	296,098	394,797	493,496
26				233,221	349,832	466,442	583,053
28				272,029	408,044	544,059	680,073
30				313,823	470,734	627,645	784,556
32				358,601	537,901	717,202	896,502

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
34				406,365	609,547	812,729	1,015,912
36				457,114	685,670	914,227	1,142,784
42				627,272	940,908	1,254,544	1,568,180
48				824,297	1,236,446	1,648,594	2,060,743
54				1,048,190	1,572,284	2,096,379	2,620,474
60				1,298,949	1,948,424	2,597,898	3,247,373
72				1,881,069	2,821,604	3,762,138	4,702,673
84				2,570,658	3,855,987	5,141,316	6,426,645
96				3,367,715	5,051,572	6,735,429	8,419,287
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	30	43	61				
3/4	75	105	149				
1	156	221	312		Pressure with these	drop pipe	
1–1/4	359	508	718	712			governs sizes
1–1/2	568	803	1,136	980			
2	1,177	1,665	2,355	1,638			
2–1/2	1,958	2,769	3,916	2,351	3,526		
3	3,636	5,142	7,272	3,664	5,496	12,755	
4	7,812	11,047	15,623	6,377	9,566		
5	14,610	20,662		10,092	15,138	20,184	25,230
6	23,753	33,592		14,459	21,689	28,919	36,148
8	50,294			25,330	37,995	50,659	63,324
10				41,415	62,123	82,830	103,538
12	96,419			60,149	90,223	120,297	150,372
14				73,627	110,440	147,254	184,067
16				98,024	147,036	196,048	245,060
18				125,906	188,860	251,813	314,766
20				157,274	235,911	314,548	393,185
22				192,127	288,191	384,254	480,318
24				230,465	345,698	460,931	576,164
26			with sizes	272,289	408,434	544,578	680,723
28		governs pipe		317,598	476,397	635,196	793,995
30				366,392	549,588	732,784	915,981
32	Velocity these			418,672	628,008	837,343	1,046,679
34				474,437	711,655	948,873	1,186,091
36				533,687	800,530	1,067,373	1,334,217
42				732,349	1,098,523	1,464,698	1,830,872
48				962,379	1,443,568	1,924,757	2,405,946
54				1,223,776	1,835,664	2,447,552	3,059,440
60				1,516,541	2,274,812	3,033,083	3,791,353
72				2,196,175	3,294,262	4,392,350	5,490,437
84				3,001,279	4,501,919	6,002,559	7,503,198
96				3,931,855	5,897,782	7,863,709	9,829,636
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	36	51	72				
3/4	89	126	178				
1	186	263	372		Pressure with these	drop pipe	
1–1/4	429	606	857	1,284			governs sizes
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		
3	4,338	6,134	8,675	4,801	7,202	16,713	
4	9,319	13,179	18,638	8,357	12,535		
5	17,429	24,649		13,224	19,836	26,448	33,061
6	28,336	40,073		18,947	28,420	37,894	47,367
8	59,997			33,191	49,786	66,382	82,977
10	115,022			54,269	81,403	108,537	135,671
12	187,744			78,816	118,224	157,632	197,040
14				96,477	144,716	192,955	241,194

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

Pipe Size	Pressure Drop psig/100 ft. 0.125	0.25	0.5	Velocity FPM (mph) 2,000 (23)	3,000 (34)	4,000 (45)	5,000 (57)
16 18 20	Velocity these	governs pipe	with sizes	128,446 164,982 206,085	192,669 247,473 309,127	256,893 329,964 412,170	321,116 412,455 515,212
22 24 26				251,755 301,992 356,795	377,632 452,987 535,193	503,510 603,983 713,591	629,387 754,979 891,988
28 30 32				416,166 480,104 548,609	624,249 720,156 822,913	832,332 960,208 1,097,217	1,040,415 1,200,260 1,371,521
34 36 42				621,680 699,319 959,637	932,520 1,048,978 1,439,455	1,243,360 1,398,638 1,919,274	1,554,201 1,748,297 2,399,092
48 54 60				1,261,057 1,603,581 1,987,207	1,891,586 2,405,372 2,980,811	2,522,115 3,207,162 3,974,415	3,152,644 4,008,953 4,968,018
72 84 96				2,877,769 3,932,741 5,152,125	4,316,653 5,899,112 7,728,187	5,755,537 7,865,482 10,304,250	7,194,421 9,831,853 12,880,312
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2 3/4 1	42 104 218	60 147 309	85 208 436		Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	502 794 1,646	710 1,123 2,328	1,005 1,589 3,293	2,725			
2–1/2 3 4	2,738 5,084 10,923	3,871 7,190 15,447	5,475 10,168 21,846	3,911 6,095 10,609	9,142 15,913	21,217	
5 6 8	20,429 33,214 70,325	28,892 46,971 99,455	40,859	16,788 24,053 42,136	25,182 36,080 63,204	33,577 48,106 84,272	60,133 105,340
10 12 14	134,821 220,061 286,589	governs pipe	with sizes	68,894 100,058 122,479	103,341 150,086 183,718	137,789 200,115 244,957	172,236 250,144 306,197
16 18 20	Velocity these			163,063 209,446 261,626	244,595 314,169 392,439	326,127 418,892 523,252	407,659 523,615 654,065
22 24 26				319,604 383,380 452,954	479,406 575,070 679,431	639,209 766,760 905,908	799,011 958,451 1,132,385
28 30 32				528,325 609,495 696,462	792,488 914,242 1,044,693	1,056,651 1,218,990 1,392,924	1,320,814 1,523,737 1,741,155
34 36 42				789,227 887,790 1,218,265	1,183,840 1,331,685 1,827,397	1,578,454 1,775,579 2,436,530	1,973,067 2,219,474 3,045,662
48 54 60				1,600,920 2,035,756 2,522,772	2,401,381 3,053,634 3,784,158	3,201,841 4,071,512 5,045,544	4,002,301 5,089,390 6,306,930
72 84 96				3,653,345 4,992,639 6,540,655	5,480,018 7,488,959 9,810,982	7,306,690 9,985,279 13,081,309	9,133,363 12,481,598 16,351,637
Steam Condensate Flow lbs./hr. 60 psig Back Pressure							
1/2 3/4 1	49 120 252	69 170 356	98 241 504		Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	580 917 1,900	820 1,297 2,688	1,160 1,834 3,801	3,366			
2–1/2 3 4	3,160 5,869 12,610	4,469 8,300 17,833	6,321 11,739 25,219	4,831 7,529 13,104	11,293 19,656		

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5 6 8	23,584 38,342 81,185	33,353 54,224 114,812	47,168	20,737 29,711 52,047	31,106 44,566 78,070	41,474 59,421 104,094	74,276 130,117
10 12 14	155,640 254,042 330,844			85,099 123,592 151,287	127,648 185,388 226,930	170,198 247,184 302,574	212,747 308,980 378,217
16 18 20	480,136			201,417 258,709 323,163	302,126 388,064 484,745	402,835 517,419 646,326	503,543 646,774 807,908
22 24 26				394,778 473,555 559,493	592,167 710,332 839,239	789,556 947,109 1,118,986	986,945 1,183,887 1,398,732
28 30 32		governs pipe	with sizes	652,592 752,853 860,276	978,889 1,129,280 1,290,414	1,305,185 1,505,707 1,720,552	1,631,481 1,882,134 2,150,690
34 36 42	Velocity these			974,860 1,096,606 1,504,812	1,462,290 1,644,909 2,257,218	1,949,720 2,193,212 3,009,623	2,437,150 2,741,515 3,762,029
48 54 60				1,977,471 2,514,584 3,116,151	2,966,207 3,771,876 4,674,226	3,954,942 5,029,169 6,232,302	4,943,678 6,286,461 7,790,377
72 84 96				4,512,645 6,166,953 8,079,076	6,768,967 9,250,430 12,118,613	9,025,290 12,333,906 16,158,151	11,281,612 15,417,383 20,197,689
Steam Condensate Flow lbs./hr. 75 psig Back Pressure							
1/2 3/4 1	60 147 308	85 208 435	120 294 615		Pressure with these		
1–1/4 1–1/2 2	708 1,119 2,320	1,001 1,583 3,281	1,416 2,239 4,640	4,479		drop pipe	governs sizes
2–1/2 3 4	3,858 7,165 15,392	5,456 10,132 21,768	7,715 14,329 30,785	6,428 10,019 17,438	26,157		
5 6 8	28,789 46,804 99,101	40,714 66,191 140,150	57,578 93,608	27,596 39,537 69,261	41,393 59,306 103,891	55,191 79,074 138,522	173,152
10 12 14	189,987 310,107 403,857	268,683		113,245 164,469 201,324	169,867 246,703 301,985	226,489 328,938 402,647	283,111 411,172 503,309
16 18 20	586,096 810,709			268,034 344,275 430,046	402,052 516,413 645,069	536,069 688,551 860,093	670,086 860,688 1,075,116
22 24 26				525,347 630,179 744,540	788,021 945,268 1,116,810	1,050,695 1,260,357 1,489,080	1,313,368 1,575,447 1,861,350
28 30 32			with sizes	868,431 1,001,853 1,144,805	1,302,647 1,502,779 1,717,207	1,736,863 2,003,706 2,289,609	2,171,079 2,504,632 2,862,012
34 36 42	Velocity these	governs pipe		1,297,286 1,459,298 2,002,515	1,945,930 2,188,947 3,003,772	2,594,573 2,918,597 4,005,029	3,243,216 3,648,246 5,006,287
48 54 60				2,631,502 3,346,260 4,146,790	3,947,253 5,019,391 6,220,185	5,263,004 6,692,521 8,293,579	6,578,755 8,365,651 10,366,974
72 84 96				6,005,161 8,206,617 10,751,157	9,007,742 12,309,926 16,126,735	12,010,323 16,413,234 21,502,314	15,012,904 20,516,543 26,877,892

(*Continued*)

275 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 85 psig Back Pressure							
1/2 3/4 1	68 166 349	96 235 493	136 333 697		Pressure with these		
1–1/4 1–1/2 2	802 1,269 2,630	1,135 1,795 3,720	1,605 2,538 5,260			drop pipe	governs sizes
2–1/2 3 4	4,374 8,123 17,451	6,185 11,487 24,680	8,747 16,246 34,902	7,661 11,940 20,782	31,174		
5 6 8	32,639 53,064 112,355	46,159 75,044 158,894	65,278 106,128	32,888 47,120 82,544	49,332 70,680 123,817	94,240 165,089	206,361
10 12 14	215,397 351,582 457,871	304,618		134,964 196,012 239,935	202,446 294,019 359,903	269,927 392,025 479,871	337,409 490,031 599,839
16 18 20	664,484 919,137 1,225,107			319,441 410,304 512,525	479,161 615,456 768,787	638,881 820,608 1,025,050	798,602 1,025,760 1,281,312
22 24 26				626,104 751,041 887,335	939,156 1,126,561 1,331,003	1,252,207 1,502,081 1,774,670	1,565,259 1,877,601 2,218,338
28 30 32		governs pipe	with sizes	1,034,988 1,193,998 1,364,367	1,552,482 1,790,997 2,046,550	2,069,976 2,387,997 2,728,733	2,587,470 2,984,996 3,410,917
34 36 42	Velocity these			1,546,093 1,739,177 2,386,577	2,319,139 2,608,766 3,579,865	3,092,186 3,478,354 4,773,154	3,865,232 4,347,943 5,966,442
48 54 60				3,136,198 3,988,039 4,942,102	4,704,296 5,982,059 7,413,153	6,272,395 7,976,079 9,884,205	7,840,494 9,970,099 12,355,256
72 84 96				7,156,891 9,780,564 12,813,121	10,735,337 14,670,846 19,219,681	14,313,782 19,561,128 25,626,242	17,892,228 24,451,410 32,032,802

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 3.**

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)	5,000 (57)
Steam Condensate Flow lbs./hr. 0 psig Back Pressure							
1/2 3/4 1	13 31 65	18 44 92	25 62 131	60 99	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	150 238 493	213 336 697	301 476 986	177 244 407	265 366 611	815	
2–1/2 3 4	819 1,522 3,270	1,159 2,152		585 911 1,586	877 1,367 2,379	1,170 1,823 3,172	1,462 2,278 3,966
5 6 8	6,116			2,510 3,596 6,300	3,765 5,395 9,450	5,020 7,193 12,600	6,275 8,991 15,751
10 12 14				10,301 14,961 18,313	15,452 22,441 27,470	20,602 29,921 36,626	25,753 37,402 45,783

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				24,381	36,572	48,763	60,953
18				31,317	46,975	62,633	78,291
20				39,119	58,678	78,237	97,796
22				47,788	71,681	95,575	119,469
24				57,323	85,985	114,647	143,308
26				67,726	101,589	135,452	169,315
28				78,996	118,494	157,991	197,489
30				91,132	136,698	182,264	227,830
32	Velocity these	governs pipe	with sizes	104,136	156,203	208,271	260,339
34				118,006	177,009	236,012	295,015
36				132,743	199,115	265,486	331,858
42				182,156	273,234	364,312	455,390
48				239,371	359,057	478,742	598,428
54				304,388	456,582	608,776	760,970
60				377,207	565,811	754,414	943,018
72				546,251	819,377	1,092,503	1,365,628
84				746,504	1,119,756	1,493,008	1,866,260
96				977,964	1,466,947	1,955,929	2,444,911
Steam Condensate Flow lbs./hr. 5 psig Back Pressure							
1/2	16	22	31				
3/4	38	54	76	139	Pressure with these	drop pipe	
1	80	113	159				governs sizes
1–1/4	183	259	367	248	511		
1–1/2	290	410	580	341	855	1,140	
2	601	850	1,202	570			
2–1/2	1,000	1,414		818	1,227	1,636	3,186
3	1,856	2,625	1,999	1,274	1,912	2,549	5,546
4	3,988			2,218	3,327	4,437	
5	7,459			3,510	5,266	7,021	8,776
6	12,127			5,030	7,544	10,059	12,574
8				8,811	13,216	17,622	22,027
10				14,406	21,609	28,812	36,015
12				20,922	31,383	41,845	52,306
14				25,611	38,416	51,221	64,027
16				34,097	51,145	68,194	85,242
18				43,796	65,694	87,591	109,489
20				54,707	82,060	109,413	136,767
22				66,830	100,245	133,660	167,075
24				80,166	120,249	160,332	200,415
26		governs pipe	with sizes	94,714	142,071	189,428	236,785
28	Velocity these			110,474	165,711	220,948	276,186
30				127,447	191,170	254,894	318,617
32				145,632	218,448	291,264	364,080
34				165,029	247,544	330,059	412,574
36				185,639	278,459	371,278	464,098
42				254,742	382,114	509,485	636,856
48				334,757	502,135	669,513	836,892
54				425,682	638,523	851,364	1,064,205
60				527,518	791,277	1,055,037	1,318,796
72				763,924	1,145,886	1,527,848	1,909,810
84				1,043,974	1,565,961	2,087,948	2,609,935
96				1,367,668	2,051,502	2,735,336	3,419,170
Steam Condensate Flow lbs./hr. 7 psig Back Pressure							
1/2	17	23	33				
3/4	41	58	81	155	Pressure with these	drop pipe	
1	85	121	171				governs sizes
1–1/4	196	278	393	277	573		
1–1/2	310	439	621	382	957	1,276	
2	643	910	1,287	638			
2–1/2	1,070	1,513		916	1,374	1,832	3,568
3	1,987	2,810	2,140	1,427	2,141	2,855	6,211
4	4,269	6,038		2,484	3,727	4,969	

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5 6 8	7,985 12,982			3,932 5,633 9,868	5,897 8,449 14,801	7,863 11,266 19,735	9,829 14,082 24,669
10 12 14				16,134 23,432 28,683	24,201 35,148 43,024	32,268 46,864 57,365	40,335 58,580 71,707
16 18 20				38,187 49,049 61,269	57,281 73,574 91,903	76,374 98,098 122,538	95,468 122,623 153,172
22 24 26		governs pipe	with sizes	74,847 89,782 106,075	112,270 134,673 159,113	149,693 179,564 212,150	187,116 224,455 265,188
28 30 32	Velocity these			123,726 142,735 163,101	185,589 214,102 244,652	247,452 285,469 326,202	309,315 356,837 407,753
34 36 42				184,825 207,907 285,300	277,238 311,861 427,949	369,651 415,814 570,599	462,063 519,768 713,249
48 54 60				374,912 476,744 590,796	562,368 715,116 886,194	749,824 953,488 1,181,592	937,280 1,191,860 1,476,990
72 84 96				855,559 1,169,202 1,531,724	1,283,339 1,753,803 2,297,587	1,711,119 2,338,404 3,063,449	2,138,898 2,923,006 3,829,311
Steam Condensate Flow lbs./hr. 10 psig Back Pressure							
1/2 3/4 1	18 45 94	26 63 132	36 89 187	181	Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	215 341 706	305 482 998	431 681 1,412	323 445 744	668 1,116		
2–1/2 3 4	1,174 2,180 4,683	1,660 3,082 6,622	2,347	1,067 1,663 2,895	1,601 2,495 4,343	2,135 3,327 5,791	4,159 7,239
5 6 8	8,758 14,239			4,582 6,565 11,500	6,873 9,847 17,250	9,164 13,130 23,000	11,455 16,412 28,750
10 12 14				18,803 27,309 33,428	28,205 40,963 50,142	37,607 54,617 66,856	47,008 68,272 83,570
16 18 20				44,505 57,164 71,406	66,757 85,746 107,108	89,010 114,328 142,811	111,262 142,910 178,514
22 24 26		governs pipe	with sizes	87,230 104,636 123,625	130,844 156,954 185,437	174,459 209,272 247,250	218,074 261,590 309,062
28 30 32	Velocity these			144,196 166,349 190,085	216,294 249,524 285,128	288,392 332,699 380,171	360,490 415,874 475,214
34 36 42				215,404 242,305 332,501	323,106 363,457 498,752	430,808 484,609 665,002	538,509 605,761 831,253
48 54 60				436,939 555,619 688,540	655,409 833,429 1,032,811	873,879 1,111,238 1,377,081	1,092,348 1,389,048 1,721,351
72 84 96				997,108 1,362,642 1,785,142	1,495,662 2,043,962 2,677,712	1,994,216 2,725,283 3,570,283	2,492,770 3,406,604 4,462,854
Steam Condensate Flow lbs./hr. 12 psig Back Pressure							
1/2 3/4 1	19 47 99	27 67 140	39 95 198		Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	228 360 747	322 510 1,056	456 721 1,494	355 488 816	1,224		

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
2–1/2 3 4	1,242 2,307 4,956	1,756 3,262 7,008	2,484	1,172 1,826 3,178	1,757 2,739 4,767	2,343 3,652 6,356	4,564 7,945
5 6 8	9,269 15,069			5,029 7,205 12,622	7,544 10,808 18,933	10,058 14,411 25,244	12,573 18,013 31,556
10 12 14				20,638 29,973 36,690	30,957 44,960 55,034	41,276 59,946 73,379	51,595 74,933 91,724
16 18 20				48,847 62,741 78,372	73,271 94,112 117,559	97,694 125,483 156,745	122,118 156,853 195,931
22 24 26				95,740 114,845 135,686	143,610 172,267 203,529	191,481 229,690 271,373	239,351 287,112 339,216
28 30 32	Velocity these	governs pipe	with sizes	158,265 182,580 208,631	237,397 273,869 312,947	316,529 365,159 417,263	395,661 456,449 521,578
34 36 42				236,420 265,945 364,942	354,630 398,918 547,413	472,840 531,890 729,884	591,050 664,863 912,355
48 54 60				479,570 609,829 755,719	719,355 914,743 1,133,578	959,139 1,219,657 1,511,437	1,198,924 1,524,572 1,889,296
72 84 96				1,094,392 1,495,589 1,959,311	1,641,587 2,243,383 2,938,966	2,188,783 2,991,178 3,918,621	2,735,979 3,738,972 4,898,276
Steam Condensate Flow lbs./hr. 15 psig Back Pressure							
1/2 3/4 1	21 51 107	29 72 152	42 102 214		Pressure with these	drop pipe	governs sizes
1–1/4 1–1/2 2	247 390 808	349 551 1,143	493 780 1,616	403 556 928	1,393		
2–1/2 3 4	1,344 2,496 5,362	1,901 3,530 7,584	2,688 4,992	1,333 2,077 3,615	1,999 3,115 5,422	2,665 4,153 7,229	9,036
5 6 8	10,029 16,306 34,525	14,184		5,720 8,195 14,357	8,580 12,293 21,535	11,440 16,391 28,713	14,300 20,488 35,891
10 12 14				23,474 34,091 41,731	35,210 51,137 62,596	46,947 68,183 83,461	58,684 85,229 104,327
16 18 20				55,559 71,362 89,141	83,338 107,043 133,711	111,117 142,724 178,282	138,897 178,405 222,852
22 24 26			with sizes	108,895 130,625 154,330	163,343 195,937 231,495	217,790 261,249 308,659	272,238 326,562 385,824
28 30 32	Velocity these	governs pipe		180,010 207,666 237,297	270,015 311,499 355,946	360,020 415,332 474,595	450,025 519,165 593,243
34 36 42				268,904 302,486 415,085	403,356 453,729 622,628	537,808 604,972 830,170	672,260 756,215 1,037,713
48 54 60				545,463 693,619 859,555	818,194 1,040,429 1,289,332	1,090,926 1,387,239 1,719,109	1,363,657 1,734,048 2,148,886
72 84 96				1,244,761 1,701,083 2,228,521	1,867,142 2,551,625 3,342,781	2,489,523 3,402,167 4,457,041	3,111,904 4,252,709 5,571,302

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
Steam Condensate Flow lbs./hr. 20 psig Back Pressure							
1/2	23	33	47		Pressure		
3/4	58	81	115		with these		
1	121	171	241			drop	governs
1–1/4	278	393	555	488		pipe	sizes
1–1/2	439	621	878	673	1,687		
2	910	1,287	1,820	1,124			
2–1/2	1,513	2,140		1,614	2,421		
3	2,811	3,975	3,027	2,515	3,773	5,030	10,945
4	6,038	8,539	5,621	4,378	6,567	8,756	
5	11,294			6,928	10,392	13,856	17,320
6	18,361	15,972		9,926	14,889	19,852	24,815
8	38,876			17,388	26,082	34,777	43,471
10				28,431	42,646	56,861	71,077
12				41,291	61,936	82,582	103,227
14				50,543	75,815	101,087	126,359
16				67,292	100,937	134,583	168,229
18				86,432	129,648	172,865	216,081
20				107,966	161,948	215,931	269,914
22				131,891	197,837	263,783	329,729
24				158,210	237,315	316,420	395,525
26			with	186,921	280,382	373,842	467,303
28	Velocity	governs	sizes	218,025	327,037	436,049	545,062
30	these	pipe		251,521	377,281	503,042	628,802
32				287,410	431,115	574,820	718,525
34				325,691	488,537	651,382	814,228
36				366,365	549,548	732,731	915,913
42				502,743	754,114	1,005,486	1,256,857
48				660,654	990,981	1,321,307	1,651,634
54				840,098	1,260,147	1,680,196	2,100,245
60				1,041,075	1,561,613	2,082,151	2,602,689
72				1,507,630	2,261,446	3,015,261	3,769,076
84				2,060,319	3,090,478	4,120,637	5,150,796
96				2,699,140	4,048,710	5,398,280	6,747,850
Steam Condensate Flow lbs./hr. 25 psig Back Pressure							
1/2	26	37	52		Pressure		
3/4	64	91	128		with these		
1	134	190	268			drop	governs
1–1/4	309	437	617	578		pipe	sizes
1–1/2	488	690	976	797	1,997		
2	1,012	1,431	2,024	1,332			
2–1/2	1,683	2,380		1,911	2,867		
3	3,125	4,420	3,365	2,979	4,468	5,957	12,961
4	6,714	9,495	6,250	5,185	7,777	10,369	
5	12,557	17,759		8,204	12,307	16,409	20,511
6	20,415	28,872		11,755	17,632	23,510	29,387
8	43,227			20,592	30,888	41,184	51,480
10				33,669	50,503	67,338	84,172
12	82,870			48,898	73,348	97,797	122,246
14				59,856	89,784	119,712	149,639
16				79,690	119,534	159,379	199,224
18			with	102,357	153,535	204,714	255,892
20			sizes	127,858	191,786	255,715	319,644
22		governs		156,192	234,288	312,383	390,479
24		pipe		187,359	281,039	374,718	468,398
26	Velocity			221,360	332,040	442,720	553,400
28	these			258,194	387,292	516,389	645,486
30				297,862	446,793	595,724	744,655
32				340,363	510,545	680,727	850,908
34				385,698	578,547	771,396	964,245
36				433,866	650,799	867,732	1,084,665
42				595,370	893,055	1,190,740	1,488,425

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
48				782,375	1,173,563	1,564,750	1,955,938
54				994,881	1,492,321	1,989,762	2,487,202
60				1,232,887	1,849,331	2,465,775	3,082,218
72				1,785,402	2,678,103	3,570,804	4,463,505
84				2,439,920	3,659,880	4,879,839	6,099,799
96				3,196,440	4,794,660	6,392,880	7,991,100
Steam Condensate Flow lbs./hr. 30 psig Back Pressure							
1/2	29	41	58				
3/4	71	100	141				
1	148	209	295		Pressure	drop	
1–1/4	340	481	680	674	with these	pipe	governs
1–1/2	538	761	1,076	928			sizes
2	1,115	1,576	2,229	1,551			
2–1/2	1,853	2,621	3,707	2,226	3,339		
3	3,442	4,868	6,885	3,469	5,203	12,075	
4	7,396	10,459	14,791	6,038	9,056		
5	13,832	19,562		9,554	14,332	19,109	23,886
6	22,488	31,803		13,689	20,533	27,378	34,222
8	47,615			23,980	35,970	47,961	59,951
10				39,209	58,813	78,418	98,022
12	91,283			56,944	85,417	113,889	142,361
14				69,705	104,557	139,409	174,262
16				92,802	139,203	185,604	232,005
18				119,199	178,799	238,398	297,998
20				148,896	223,343	297,791	372,239
22				181,892	272,838	363,784	454,730
24				218,188	327,282	436,376	545,470
26				257,783	386,675	515,567	644,458
28		governs	with	300,678	451,018	601,357	751,696
30	Velocity	pipe	sizes	346,873	520,310	693,746	867,183
32	these			396,368	594,551	792,735	990,919
34				449,162	673,742	898,323	1,122,904
36				505,255	757,883	1,010,511	1,263,138
42				693,334	1,040,001	1,386,668	1,733,335
48				911,109	1,366,664	1,822,219	2,277,773
54				1,158,581	1,737,872	2,317,163	2,896,453
60				1,435,750	2,153,625	2,871,500	3,589,375
72				2,079,177	3,118,766	4,158,354	5,197,943
84				2,841,391	4,262,086	5,682,782	7,103,477
96				3,722,391	5,583,587	7,444,782	9,305,978
Steam Condensate Flow lbs./hr. 40 psig Back Pressure							
1/2	34	48	68				
3/4	84	118	167				
1	175	248	351		Pressure	drop	
1–1/4	404	571	807	1,210	with these	pipe	governs
1–1/2	638	903	1,276	2,022			sizes
2	1,323	1,871	2,646				
2–1/2	2,200	3,111	4,400	2,902	4,352		
3	4,085	5,778	8,171	4,522	6,783	15,742	
4	8,777	12,413	17,554	7,871	11,806		
5	16,416	23,216		12,456	18,683	24,911	31,139
6	26,689	37,744		17,846	26,768	35,691	44,614
8	56,510			31,262	46,893	62,523	78,154
10	108,336			51,114	76,671	102,229	127,786
12	176,832			74,235	111,353	148,470	185,588
14			with	90,870	136,305	181,740	227,175
16		governs	sizes	120,981	181,471	241,961	302,452
18		pipe		155,393	233,089	310,786	388,482
20	Velocity			194,107	291,160	388,213	485,267
22	these			237,122	355,683	474,244	592,805
24				284,439	426,658	568,878	711,097
26				336,057	504,086	672,114	840,143

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
28				391,977	587,966	783,954	979,943
30				452,199	678,298	904,397	1,130,497
32				516,722	775,082	1,033,443	1,291,804
34				585,546	878,319	1,171,092	1,463,865
36				658,672	988,008	1,317,344	1,646,680
42				903,860	1,355,789	1,807,719	2,259,649
48				1,187,761	1,781,641	2,375,521	2,969,402
54				1,510,376	2,265,564	3,020,751	3,775,939
60				1,871,704	2,807,557	3,743,409	4,679,261
72				2,710,503	4,065,755	5,421,007	6,776,258
84				3,704,157	5,556,236	7,408,315	9,260,393
96				4,852,667	7,279,000	9,705,333	12,131,666
Steam Condensate Flow lbs./hr. 50 psig Back Pressure							
1/2	40	56	80				
3/4	98	138	195				
1	204	289	409		Pressure with these	drop pipe	
1–1/4	471	666	941				governs sizes
1–1/2	744	1,052	1,488				
2	1,542	2,181	3,085	2,553			
2–1/2	2,565	3,627	5,129	3,664			
3	4,763	6,736	9,527	5,710	8,565		
4	10,234	14,472	20,467	9,939	14,909	19,878	
5	19,140	27,068	38,280	15,729	23,593	31,457	
6	31,117	44,006		22,535	33,802	45,070	56,337
8	65,886	93,177		39,477	59,215	78,953	98,691
10	126,311			64,546	96,819	129,092	161,365
12	206,171			93,742	140,613	187,484	234,355
14	268,500			114,748	172,122	229,496	286,870
16				152,771	229,157	305,542	381,928
18				196,226	294,339	392,452	490,565
20				245,113	367,669	490,226	612,782
22				299,432	449,147	598,863	748,579
24				359,182	538,773	718,364	897,955
26				424,364	636,547	848,729	1,060,911
28				494,979	742,468	989,957	1,237,447
30		governs pipe	with sizes	571,025	856,537	1,142,050	1,427,562
32	Velocity these			652,503	978,754	1,305,006	1,631,257
34				739,413	1,109,119	1,478,825	1,848,531
36				831,754	1,247,631	1,663,509	2,079,386
42				1,141,371	1,712,056	2,282,741	2,853,426
48				1,499,874	2,249,811	2,999,747	3,749,684
54				1,907,264	2,860,895	3,814,527	4,768,159
60				2,363,540	3,545,310	4,727,080	5,908,850
72				3,422,754	5,134,131	6,845,508	8,556,885
84				4,677,515	7,016,272	9,355,029	11,693,786
96				6,127,822	9,191,734	12,255,645	15,319,556
Steam Condensate Flow lbs./hr. 60 psig Back Pressure							
1/2	46	65	91				
3/4	112	158	224				
1	235	332	469		Pressure with these		
1–1/4	540	764	1,081			drop pipe	governs sizes
1–1/2	854	1,208	1,709				
2	1,771	2,504	3,542	3,136			
2–1/2	2,945	4,164	5,889	4,501			
3	5,469	7,734	10,937	7,015	10,522		
4	11,749	16,616	23,498	12,210	18,314		
5	21,974	31,076	43,949	19,322	28,982	38,643	
6	35,725	50,523		27,683	41,524	55,365	69,206
8	75,643	106,976		48,494	72,741	96,989	121,236
10	145,016			79,290	118,935	158,581	198,226
12	236,702			115,156	172,734	230,312	287,890
14	308,261			140,961	211,441	281,921	352,401

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
16				187,669	281,504	375,339	469,173
18	447,364			241,051	361,576	482,102	602,627
20				301,105	451,658	602,210	752,763
22				367,832	551,748	735,664	919,580
24				441,231	661,847	882,463	1,103,079
26				521,304	781,956	1,042,607	1,303,259
28				608,049	912,073	1,216,097	1,520,122
30				701,466	1,052,199	1,402,933	1,753,666
32		governs	with	801,557	1,202,335	1,603,113	2,003,891
34	Velocity	pipe	sizes	908,320	1,362,479	1,816,639	2,270,799
36	these			1,021,755	1,532,633	2,043,511	2,554,388
42				1,402,098	2,103,148	2,804,197	3,505,246
48				1,842,496	2,763,744	3,684,992	4,606,240
54				2,342,947	3,514,421	4,685,895	5,857,368
60				2,903,453	4,355,180	5,806,906	7,258,633
72				4,204,627	6,306,941	8,409,254	10,511,568
84				5,746,018	8,619,027	11,492,036	14,365,045
96				7,527,625	11,291,438	15,055,251	18,819,064
Steam Condensate Flow lbs./hr. 75 psig Back Pressure							
1/2	55	78	111				
3/4	136	192	271				
1	284	402	568		Pressure		
1–1/4	654	924	1,307		with these	drop	governs
1–1/2	1,034	1,462	2,067	4,136		pipe	sizes
2	2,142	3,030	4,285				
2–1/2	3,562	5,038	7,125	5,936			
3	6,616	9,356	13,232	9,251	24,154		
4	14,214	20,102	28,428	16,103			
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	159,894
8	91,513	129,419		63,958	95,936	127,915	
10	175,440			104,574	156,860	209,147	261,434
12	286,362	248,110		151,876	227,814	303,752	379,689
14	372,934			185,909	278,863	371,817	464,772
16	541,220			247,511	371,267	495,023	618,779
18	748,634			317,915	476,872	635,829	794,787
20				397,118	595,678	794,237	992,796
22				485,122	727,684	970,245	1,212,806
24				581,927	872,890	1,163,854	1,454,817
26				687,532	1,031,298	1,375,064	1,718,830
28			with	801,937	1,202,906	1,603,874	2,004,843
30		governs	sizes	925,143	1,387,714	1,850,286	2,312,857
32		pipe		1,057,149	1,585,723	2,114,298	2,642,872
34	Velocity			1,197,955	1,796,933	2,395,911	2,994,889
36	these			1,347,562	2,021,344	2,695,125	3,368,906
42				1,849,186	2,773,778	3,698,371	4,622,964
48				2,430,012	3,645,019	4,860,025	6,075,031
54				3,090,043	4,635,065	6,180,086	7,725,108
60				3,829,277	5,743,916	7,658,554	9,573,193
72				5,545,357	8,318,035	11,090,713	13,863,392
84				7,578,251	11,367,376	15,156,501	18,945,627
96				9,927,959	14,891,939	19,855,919	24,819,899
Steam Condensate Flow lbs./hr. 85 psig Back Pressure							
1/2	62	88	125				
3/4	153	216	305				
1	320	452	640		Pressure		
1–1/4	736	1,041	1,472		with these	drop	governs
1–1/2	1,164	1,646	2,328			pipe	sizes
2	2,413	3,412	4,826				
2–1/2	4,012	5,674	8,025	7,029			
3	7,452	10,539	14,904	10,954	28,599		
4	16,010	22,641	32,020	19,066			

(*Continued*)

300 PSIG STEAM CONDENSATE PIPING SYSTEMS—STEEL PIPE (*Continued*)

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 (57)
5 6 8	29,944 48,682 103,076	42,347 68,846 145,772	59,887 97,363	30,172 43,228 75,727	45,258 64,842 113,591	86,457 151,455	189,318
10 12 14	197,608 322,546 420,057	279,460		123,817 179,824 220,120	185,726 269,736 330,180	247,635 359,649 440,240	309,544 449,561 550,300
16 18 20	609,606 843,229 1,123,929			293,059 376,418 470,197	439,589 564,627 705,295	586,118 752,836 940,394	732,648 941,045 1,175,492
22 24 26				574,396 689,014 814,053	861,594 1,033,521 1,221,079	1,148,791 1,378,029 1,628,106	1,435,989 1,722,536 2,035,132
28 30 32		governs pipe	with sizes	949,511 1,095,389 1,251,688	1,424,267 1,643,084 1,877,531	1,899,022 2,190,779 2,503,375	2,373,778 2,738,474 3,129,219
34 36 42	Velocity these			1,418,406 1,595,544 2,189,476	2,127,608 2,393,315 3,284,215	2,836,811 3,191,087 4,378,953	3,546,014 3,988,859 5,473,691
48 54 60				2,877,188 3,658,679 4,533,949	4,315,782 5,488,019 6,800,923	5,754,377 7,317,358 9,067,897	7,192,971 9,146,698 11,334,872
72 84 96				6,565,824 8,972,816 11,754,923	9,848,737 13,459,224 17,632,384	13,131,649 17,945,632 23,509,846	16,414,561 22,432,040 29,387,307
Steam Condensate Flow lbs./hr. 100 psig Back Pressure							
1/2 3/4 1	74 181 379	104 256 536	148 362 758				
1–1/4 1–1/2 2	872 1,380 2,859	1,234 1,951 4,044	1,745 2,759 5,719		Pressure with these	drop pipe	governs sizes
2–1/2 3 4	4,755 8,830 18,971	6,724 12,488 26,829	9,509 17,660 37,942	8,900 13,871 24,144	36,215		
5 6 8	35,482 57,686 122,141	50,179 81,580 172,733	70,964 115,371	38,207 54,740 95,894	57,310 82,110 143,841	109,480 191,788	239,735
10 12 14	234,157 382,203 497,750	331,149 540,517		156,791 227,712 278,739	235,186 341,569 418,108	313,581 455,425 557,478	391,977 569,281 696,847
16 18 20	722,357 999,190 1,331,807			371,102 476,660 595,413	556,653 714,990 893,119	742,204 953,320 1,190,825	927,755 1,191,650 1,488,532
22 24 26	1,723,555 2,177,597			727,360 872,502 1,030,839	1,091,040 1,308,753 1,546,259	1,454,720 1,745,004 2,061,678	1,818,400 2,181,255 2,577,098
28 30 32		governs pipe	with sizes	1,202,371 1,387,097 1,585,018	1,803,556 2,080,646 2,377,527	2,404,741 2,774,194 3,170,036	3,005,927 3,467,743 3,962,545
34 36 42				1,796,134 2,020,445 2,772,545	2,694,201 3,030,667 4,158,817	3,592,268 4,040,889 5,545,089	4,490,335 5,051,111 6,931,362
48 54 60	Velocity these			3,643,397 4,633,003 5,741,361	5,465,096 6,949,504 8,612,042	7,286,795 9,266,006 11,482,722	9,108,494 11,582,507 14,353,403
72 84 96				8,314,335 11,362,320 14,885,316	12,471,503 17,043,480 22,327,974	16,628,671 22,724,640 29,770,631	20,785,838 28,405,801 37,213,289

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 3.

PART 23

AC Condensate Piping

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"

PART 24

Refrigerant Piping Systems

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. Assure proper refrigerant flow to feed evaporators.
   b. Size piping to limit excessive pressure drop and temperature rise and to minimize first cost.
   c. Assure 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, *ASTM B280,* hard drawn.
   Fittings: Wrought copper solder joint fittings, *ANSI/ASME B16.22.*
   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, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
      Fittings: Forged steel threaded fittings, 3,000 lbs.
      Joints: Pipe threads, general purpose (American) *ANSI/ASME B1.20.1*
      OR
      Pipe: Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
      Fittings: Forged steel socket weld, 150 lbs. *ANSI B16.11*.
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.
   b. 1-1/2":
      Pipe: Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
      Fittings: Forged steel socket weld, 150 lbs. *ANSI B16.11*.
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.
   c. 2" and larger:
      Pipe: Black steel pipe, *ASTM A53, Schedule 40*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 40*, Type S, Grade B.
      Fittings: Steel butt-welding fittings, 150 lbs., *ANSI/ASME B16.9*.
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*.

6. Recommended high pressure side piping requirements:
   a. 1-1/4" and smaller:
      Pipe: Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type S, Grade B.
      Fittings: Forged steel threaded fittings, 3,000 lbs.
      Joints: Pipe threads, general purpose (American) *ANSI/ASME B1.20.1*
      OR
      Pipe: Black steel pipe, *ASTM A53*, *Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type 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. 1-1/2":
      Pipe: Black steel pipe, *ASTM A53, Schedule 80*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 80*, Type 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*.
   c. 2" and larger:
      Pipe: Black steel pipe, *ASTM A53, Schedule 40*, Type E or S, Grade B or carbon steel pipe, *ASTM A106, Schedule 40*, Type 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*.

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 Btuhs/lbs., and ammonia absorbs 500–600 Btuhs/lbs.
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 depravation. 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 minutes is dangerous. Affects show up several days later—pulmonary edema (water in the lungs).
5,000 ppm and above	Immediate hazard to life due to suffocation. Full face respiratory protection is required, including eyes. Causes respiratory spasm, strangulation, and asphyxia—no exposure permissible.
15,000 ppm and above	Full body protection required. Ammonia reacts with body perspiration to form a caustic solution that attacks the skin causing burns and blisters.
160,000–270,000 ppm	Flammable in air at 68ºF.
15.5% by volume	Lower Flammability Limit (LFL); also referred to Lower Explosive Limit (LEL)

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 ºF	Freezing Point ºF	Critical		
No.	Name					Temp. ºF	Press. Psia	Volume ft.^{3}/lbs.
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

(*Continued*)

Refrigerant Physical Properties								
Refrigerant		ASHRAE Std. 15 Group No.	Molecular Mass	Boiling Point at 14.7 Psia ºF	Freezing Point ºF	Critical		
No.	Name					Temp. ºF	Press. Psia	Volume ft.^{3}/lbs.
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-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	Ehylene	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.				
	40ºF	20ºF	0ºF	–20ºF	–40ºF
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

PART 25

Air Handling Units

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 6 20 percent @ 20°F ΔT.

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 × Block Cooling Load.
5. Supplemental heater sizing:
   a. 0.75 × 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. 20–110°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.

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 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.
      2) Face and bypass dampers—internal. See Fig. 25.2.
      3) Integral face and bypass (IFB) coils. See Fig. 25.3.
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.

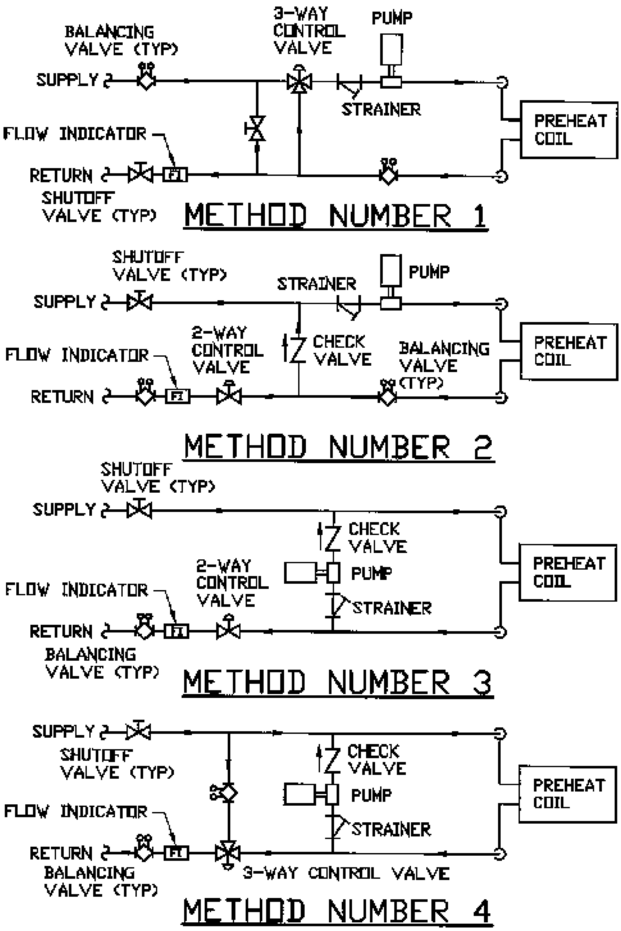


FIGURE 25.1 PREHEAT COIL PIPING DIAGRAMS.

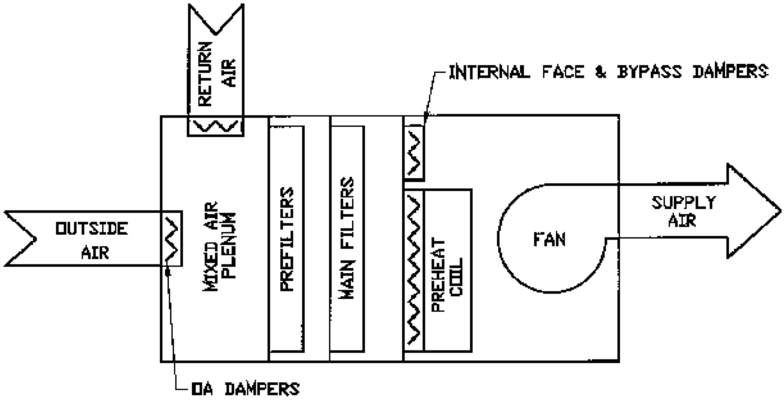


FIGURE 25.2 AIR HANDLING UNITS W/INTERNAL FACE AND BYPASS DAMPERS (PRHEAT COIL FREEZE PROTECTION).

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:

$$W_{WC} = W_{WT} + W_{WH}$$

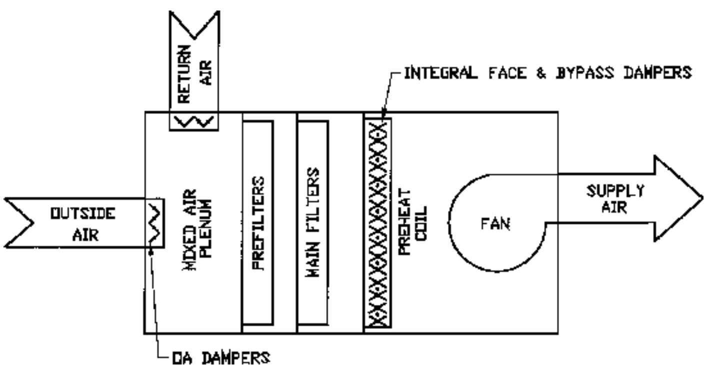


FIGURE 25.3 AIR HANDLING UNITS W/INTEGRAL FACE AND BYPASS DAMPERS (PRHEAT COIL FREEZE PROTECTION).

3. Total weight of water coils:

$$W_T = W_C + W_{WC}$$

4. Volume of water in coil:
   $V = W_{WC} \times 0.12$
   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

Notes:
1 Lower pressure drop is for 70 Fins/ft.
2 Higher pressure drop is for 170 Fins/ft.
3 Pressure drops in in. W.G.

2. Water pressure drop is given in the following table:
   a. Cooling coils:
      1) Range: 10–20 ft. H_2O.
      2) Recommended schedule value: 15 ft. H_2O.

b. Dehumidification/heat recovery coils:
   1) Range: 10–20 ft. H_2O.
   2) Recommended schedule value: 15 ft. H_2O.
c. Heating coils:
   1) Range: 1–5 ft. H_2O.
   2) Recommended schedule value: 2.5 ft. H_2O.

Finned Width	Finned Length											
	12	24	36	48	60	72	84	96	108	120	132	144
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	0.22 23.7	0.23 25.2
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	0.18 21.2	0.19 22.3
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	0.20 23.2	0.21 24.7
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	0.23 25.3	0.24 26.8
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	0.26 26.3	0.27 27.8
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	0.28 28.1	0.29 29.6
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	0.31 29.6	0.32 31.1
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	0.33 31.3	0.34 32.9

Notes:
1 Pressure drops in feet H_2O/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 fpm–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 fpm–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.

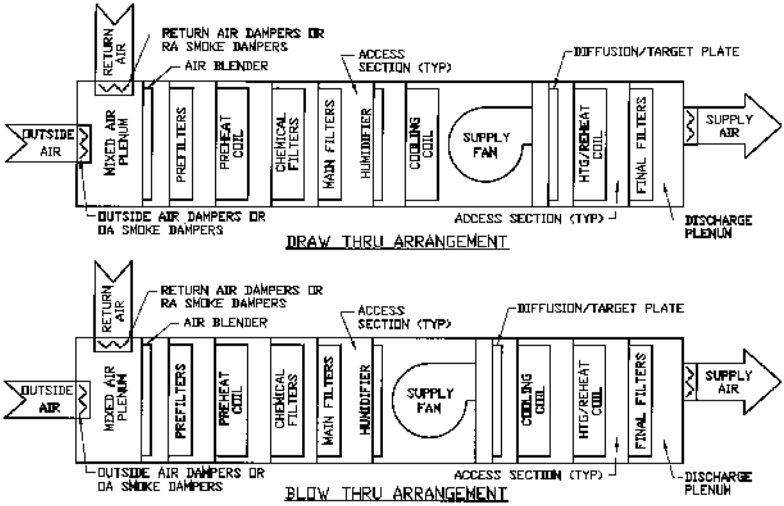


FIGURE 25.4 AIR HANDLING UNIT TERMINOLOGY.

H. Air Handling Units

1. Blow thru versus draw thru: The terminology of blow thru and draw thru 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 thru air handling unit. If the cooling coil is upstream of the fan, the unit is considered a draw thru air handling unit. See Fig. 25.4 and Fig. 25.5.
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.

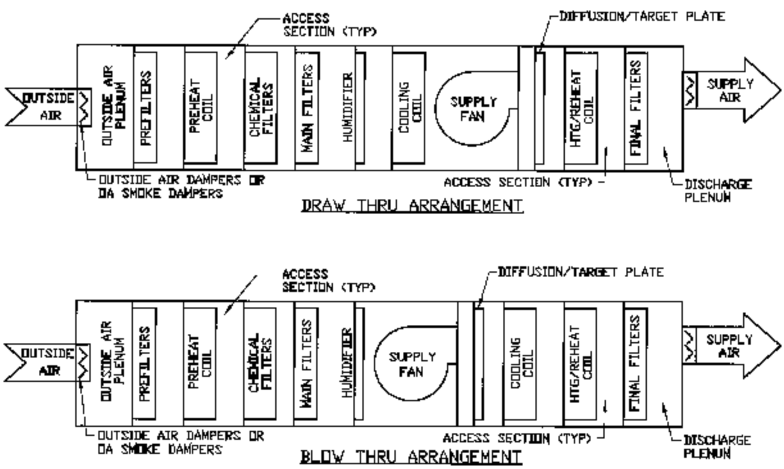


FIGURE 25.5 100% O.A. AIR HANDLING UNIT TERMINOLOGY.

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).

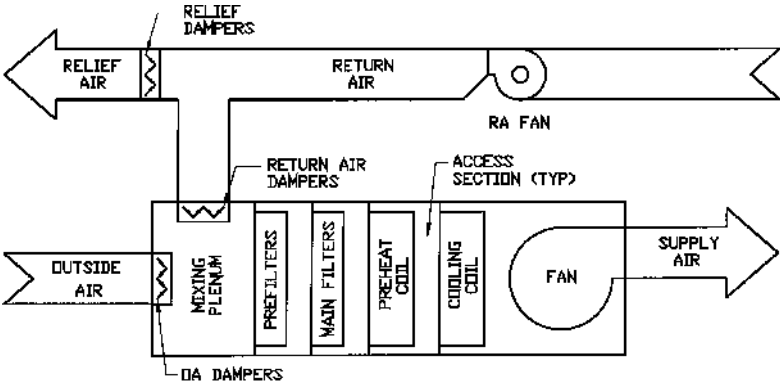


FIGURE 25.6 AHU EXAMPLE 1 AIR HANDLING UNITS—W/PREHEAT AND COOLING COILS W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.

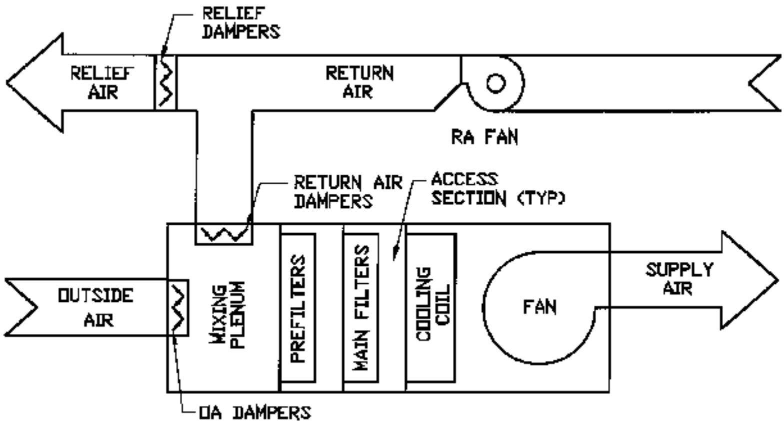
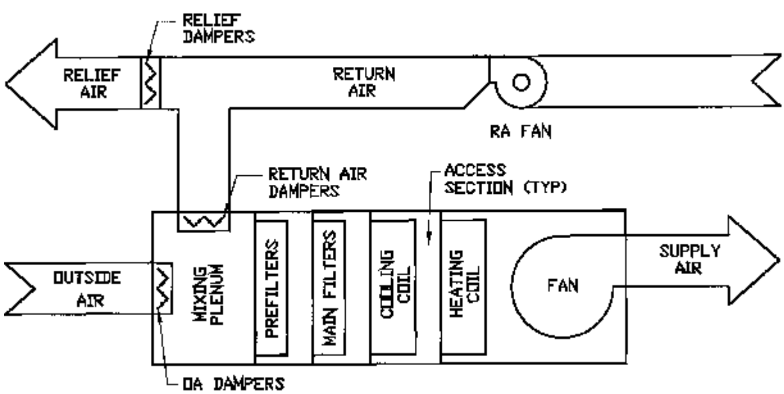


FIGURE 25.7 AHU EXAMPLE 2 AIR HANDLING UNITS—W/COOLING COIL ONLY W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.

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.



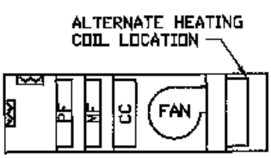


FIGURE 25.8 AHU EXAMPLE 3 AIR HANDLING UNITS—W/COOLING AND HEATING COILS W/RETURN AIR, RETURN FAN, AND POWERED RELIEF AIR.

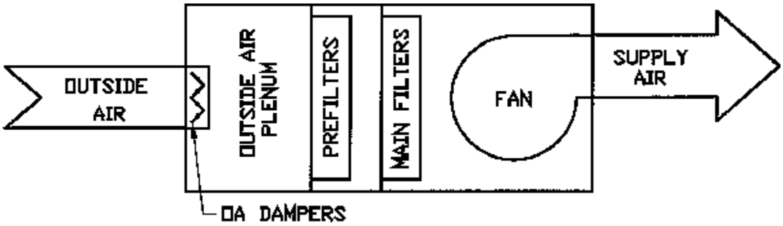


FIGURE 25.9 AHU EXAMPLE 4 AIR HANDLING UNITS—VENTILATING 100% OUTSIDE AIR.

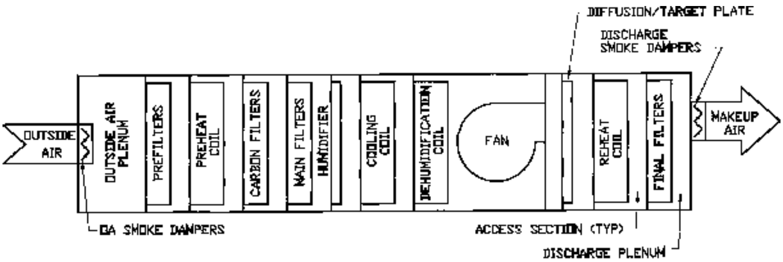


FIGURE 25.10 AHU EXAMPLE 5 CLEANROOM MAKEUP AIR HANDLING UNIT W/CARBON FILTERS AND 100% OUTSIDE AIR.

PART 26

Fans

26.01 Fans Types and Size Ranges

A. Fan types and size range 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 BI/B FC/D	0–3 0–4 0–2.5	8–36 10–36 6–12	200–27,500 250–27,500 100–3,500	1/6–30 1/6–30 1/6–3
Centrifugal	SWSI-BI/B DWDI-BI/B SWSI-AF/B DWDI-AF/B	0–12 0–12 0–14 0–14	10–73 12–73 18–120 18–120	600–123,000 1,300–225,000 1,400–447,000 2,400–804,000	1/3–200 1/3–400 1/3–1500 3/4–2500
Tubular Centrifugal	BI/B BI/D	0–9	10–108	450–332,000	1/3–750
Vane Axial	–/B –/D	0–5 0–4	18–72 18–60	1,400–115,000 1,200–148,000	1/3–100 1/3–150
Tubeaxial	–/B –/D	0–1.5 0–1	12–60 18–48	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

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.

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. Specified 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 Fig. 26.1)

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. 26.2 and 26.3).

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.

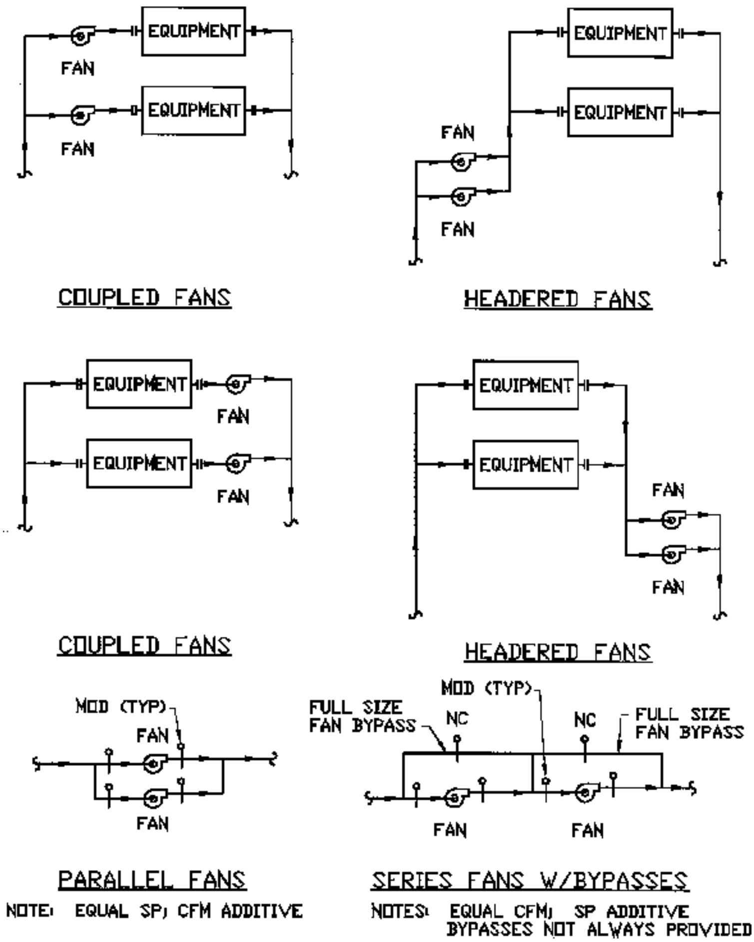


FIGURE 26.1 FAN SYSTEM ARRANGEMENTS.

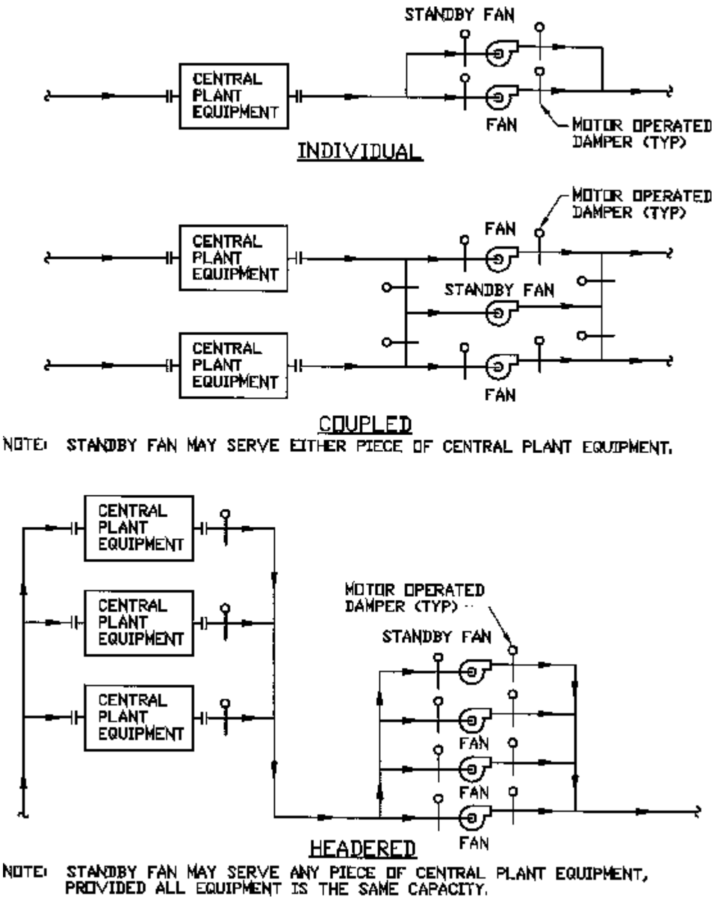


FIGURE 26.2 STANDBY FANS.

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).**

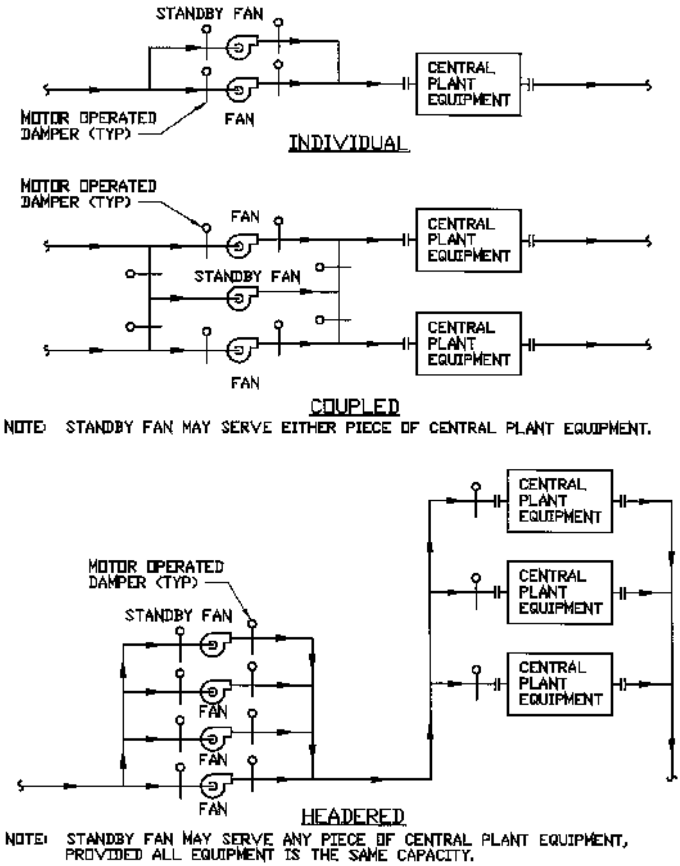


FIGURE 26.3 STANDBY FANS.

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. ***Break Horsepower (BHP)*. Break 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.

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.

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.
   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.
   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.
2. BHP increases to a maximum, and then decreases. They are nonoverloading fans. Best efficiency at medium pressure (4.0–8.0 in. W.G.).
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.
   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.
   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.

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 noisier.
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.

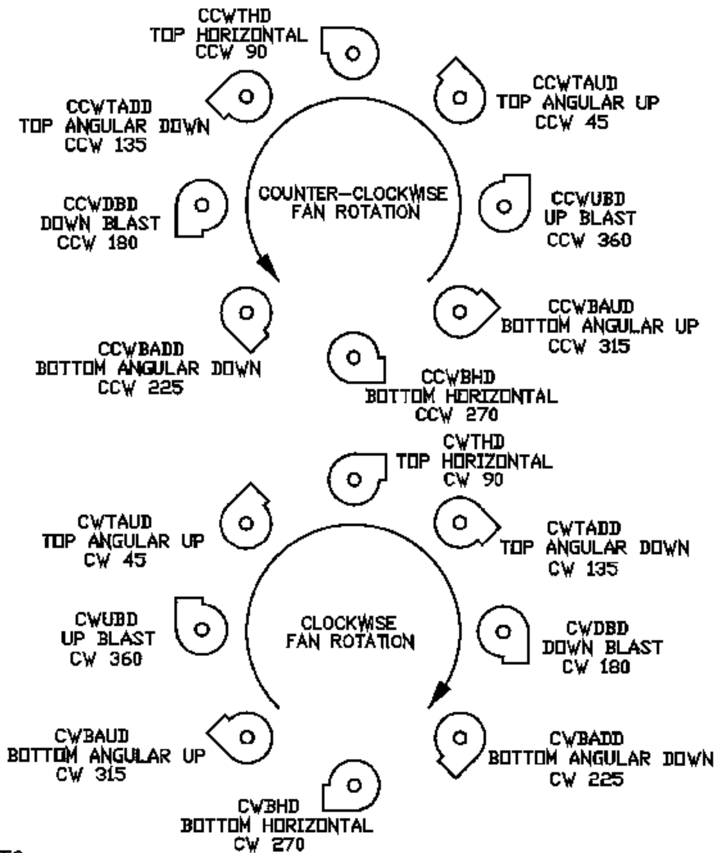
26.08 Installation and Clearance Requirements

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.

26.09 Fan Rotation and Discharge Positions

See Figure 26.4.



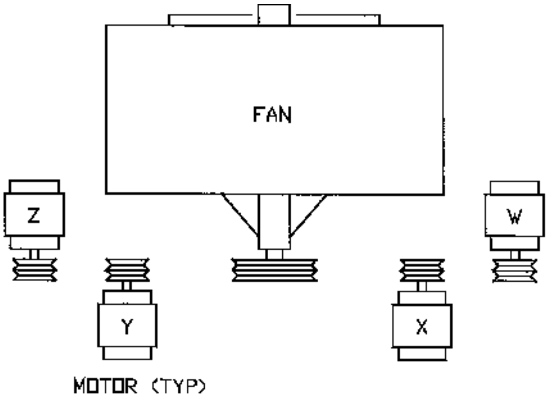
NOTES:

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.

FIGURE 26.4 FAN ROTATION AND DISCHARGE POSITIONS.

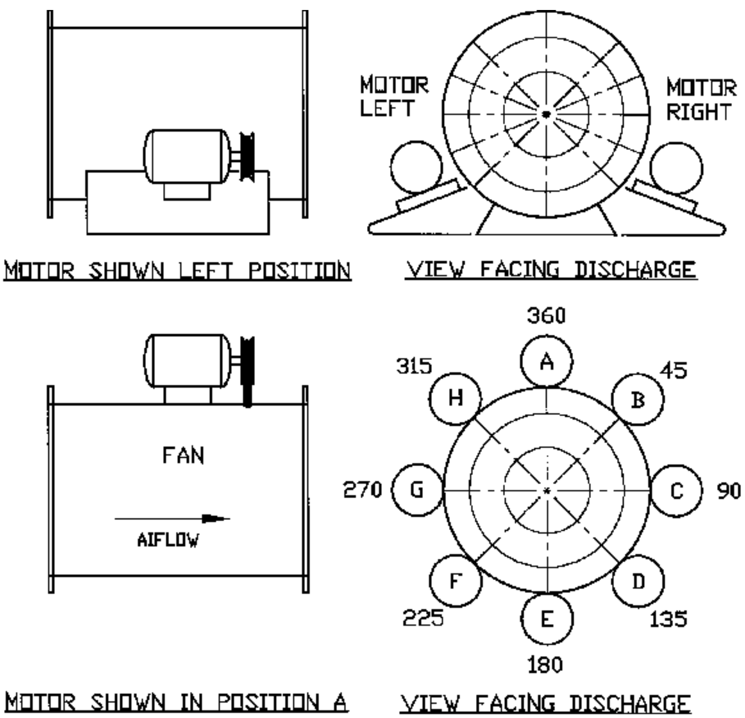
26.10 Fan Motor Positions

See Figures 26.5 and 26.6.



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.

FIGURE 26.5 CENTRIFUGAL FAN MOTOR ARRANGEMENTS.

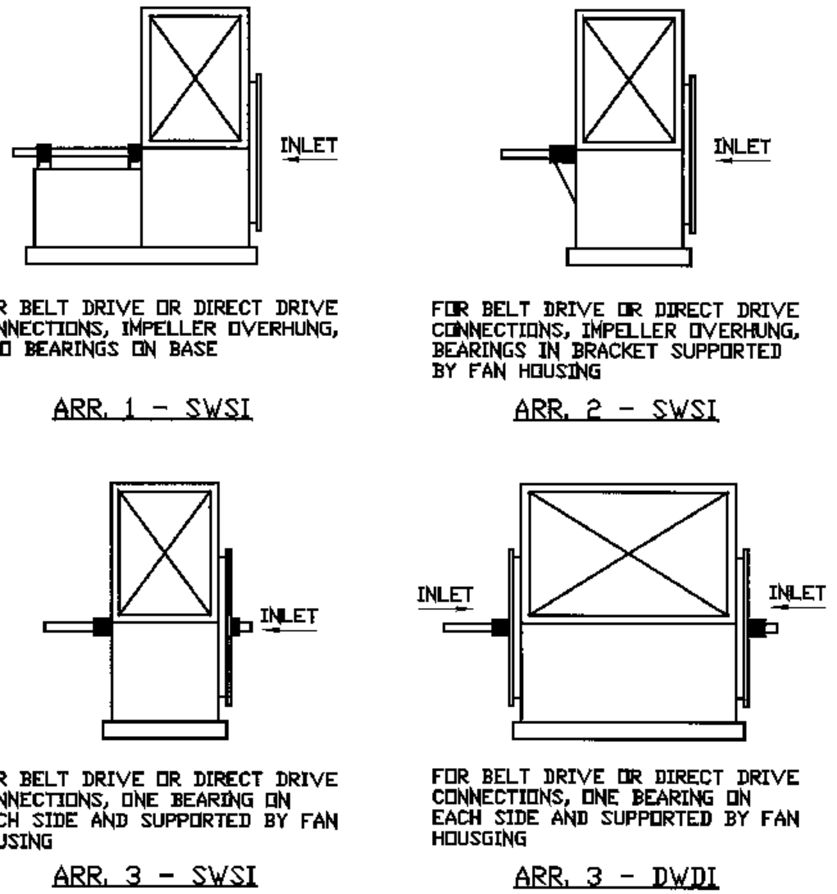


NOTES:
1. LOCATION OF THE MOTOR IS DETERMINED BY FACING THE DRIVE SIDE OF THE FAN OR BLOWER AND DESIGNATING THE MOTOR POSITION BY LETTERS A THROUGH H AS SHOWN ABOVE. FIGURE IS BASED ON AMCA STANDARD 2407.

FIGURE 26.6 INLINE FAN MOTOR ARRANGEMENTS.

26.11 Fan Drive Arrangements

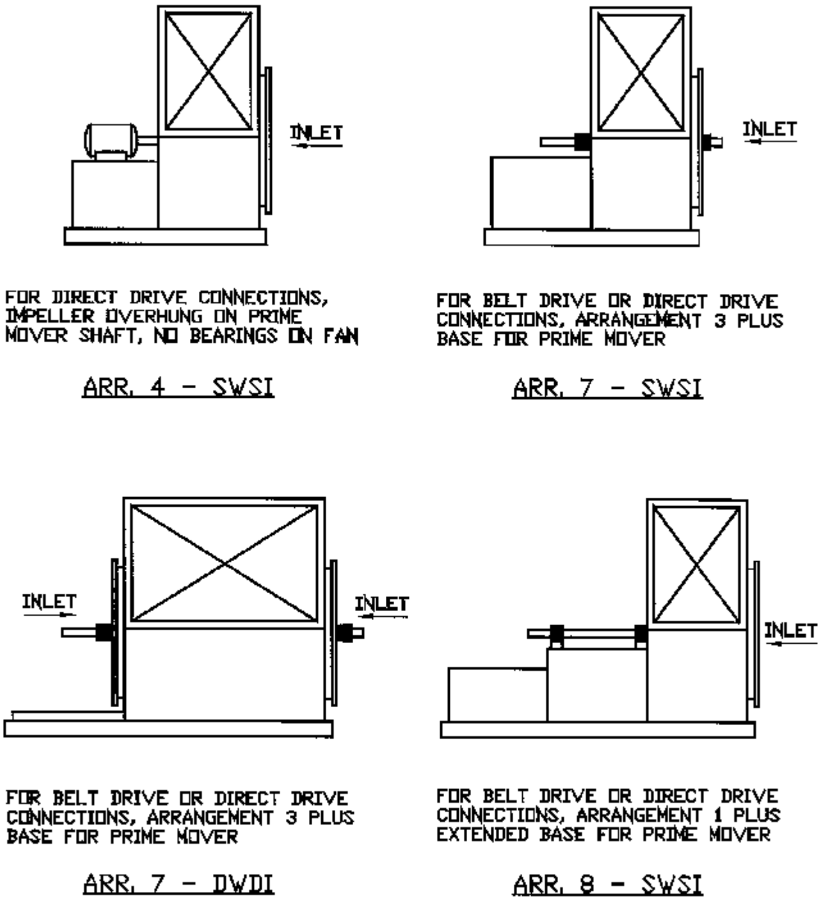
See Figures 26.7 to 26.13.



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.

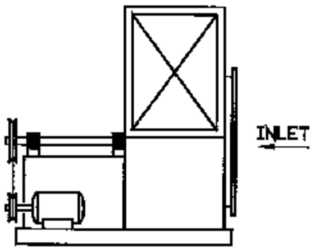
FIGURE 26.7 CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



NOTES:

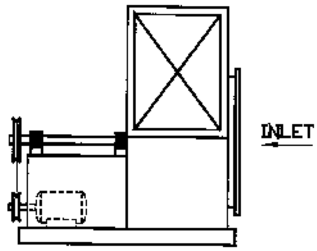
1. DRIVE ARRANGEMENTS FOR CENTRIFUGAL FANS IN ACCORDANCE WITH AMCA STANDARD 99-2404-78.
2. SWSI = SINGLE WIDTH, SINGLE INLET
3. DWDI = DOUBLE WIDTH, DOUBLE INLET
4. ARRANGEMENTS 1, 3, 7, AND 8 ARE ALSO AVAILABLE WITH BEARINGS MOUNTED ON PEDESTALS OR BASE SET INDEPENDENT OF THE FAN HOUSING.
5. ALL FIGURES SHOWN FACING DISCHARGE.

FIGURE 26.8 CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



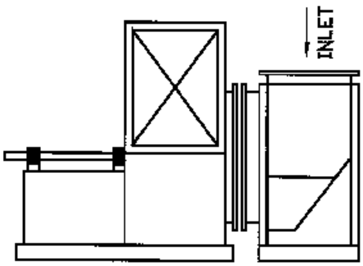
FOR BELT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS WITH PRIME MOVER OUTSIDE BASE

ARR. 9 - SWSI



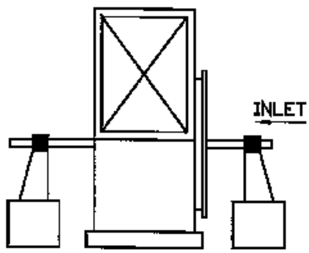
FOR BELT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS WITH PRIME MOVER INSIDE BASE

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.

FIGURE 26.9 CENTRIFUGAL FAN DRIVE ARRANGEMENTS.

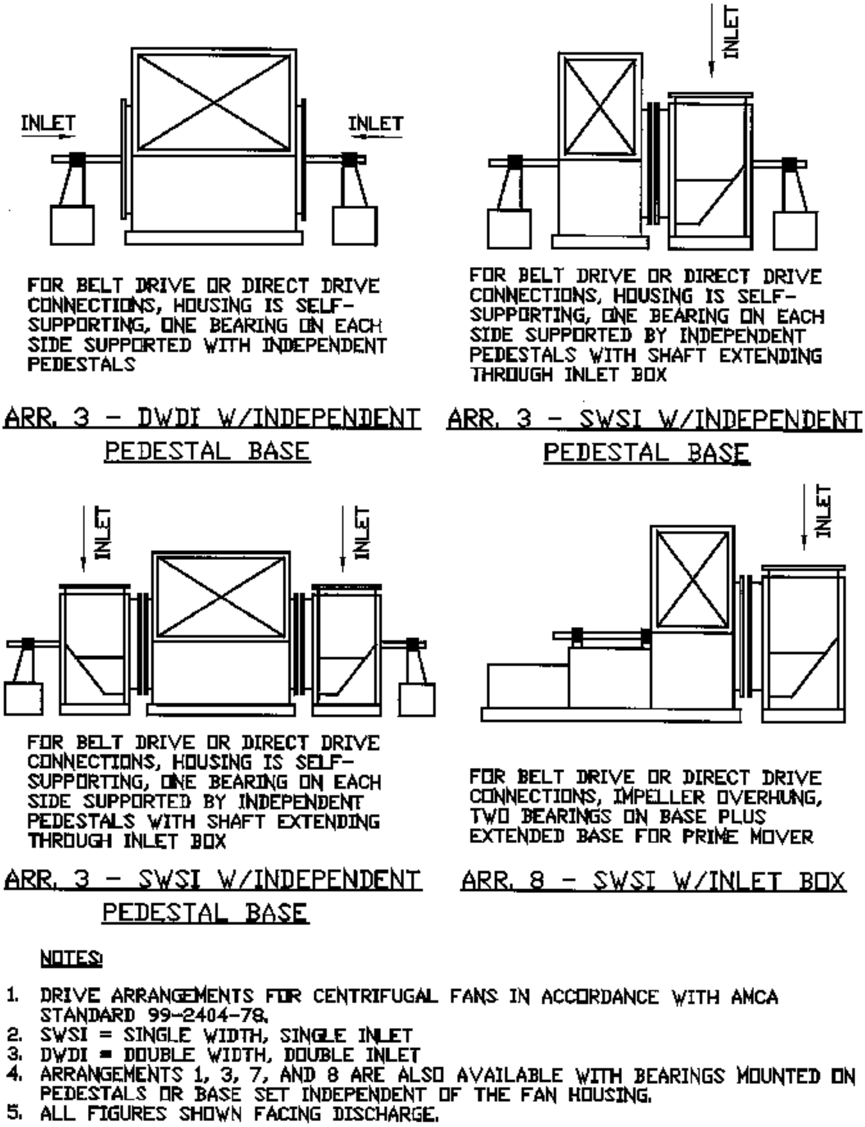
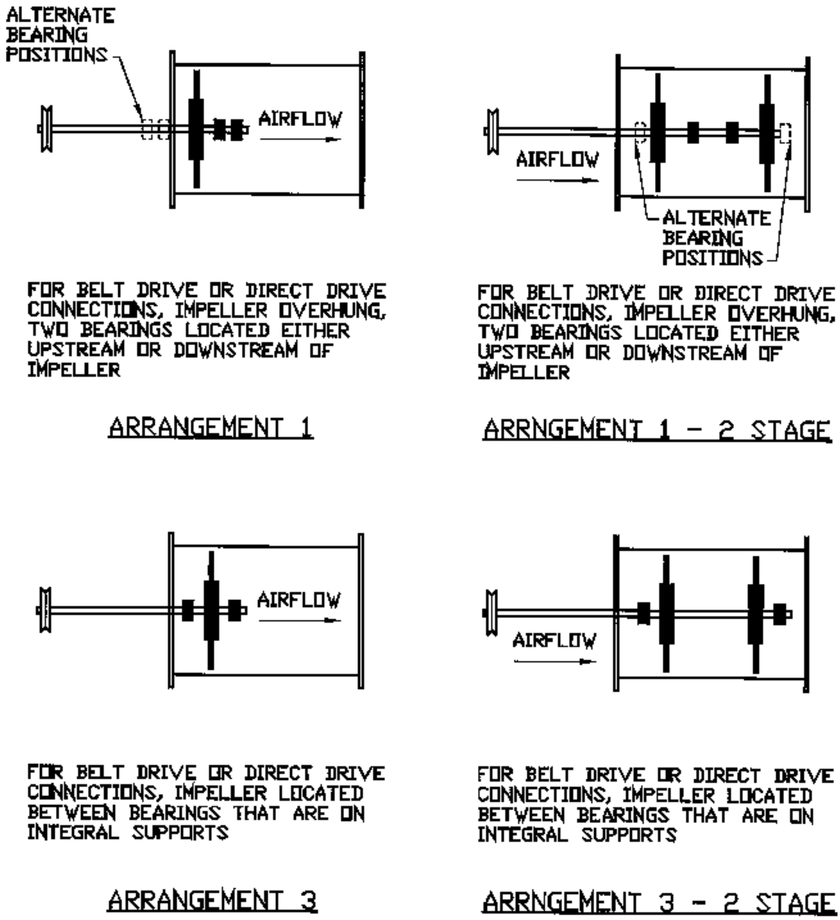


FIGURE 26.10 CENTRIFUGAL FAN DRIVE ARRANGEMENTS.



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.

FIGURE 26.11 AXIAL FAN DRIVE ARRANGEMENTS.

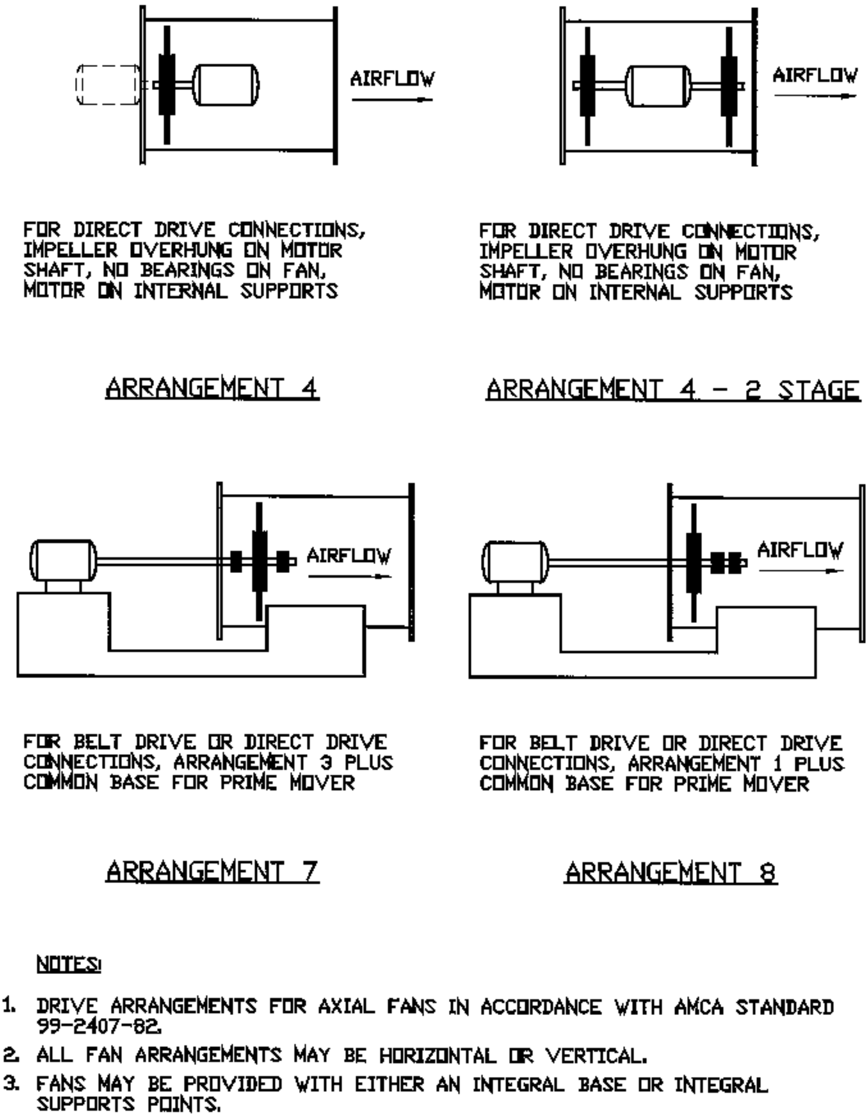


FIGURE 26.12 AXIAL FAN DRIVE ARRANGEMENTS.

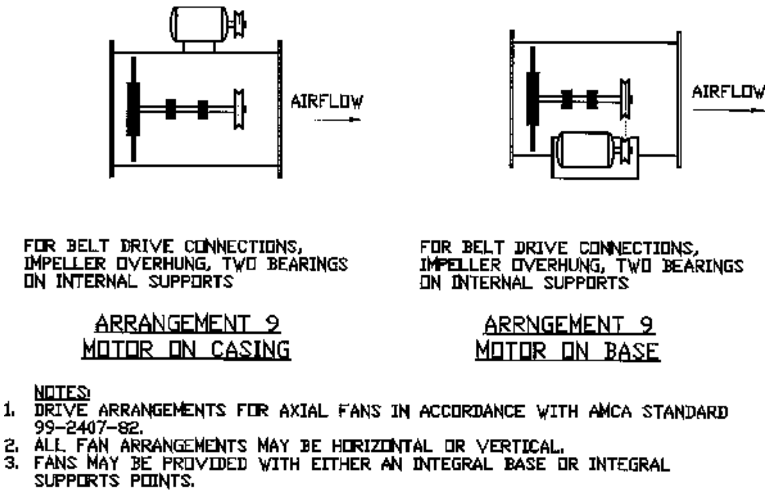


FIGURE 26.13 AXIAL FAN DRIVE ARRANGEMENTS.

26.12 Centrifugal Fan Inlet Box Positions

See Figure 26.14.

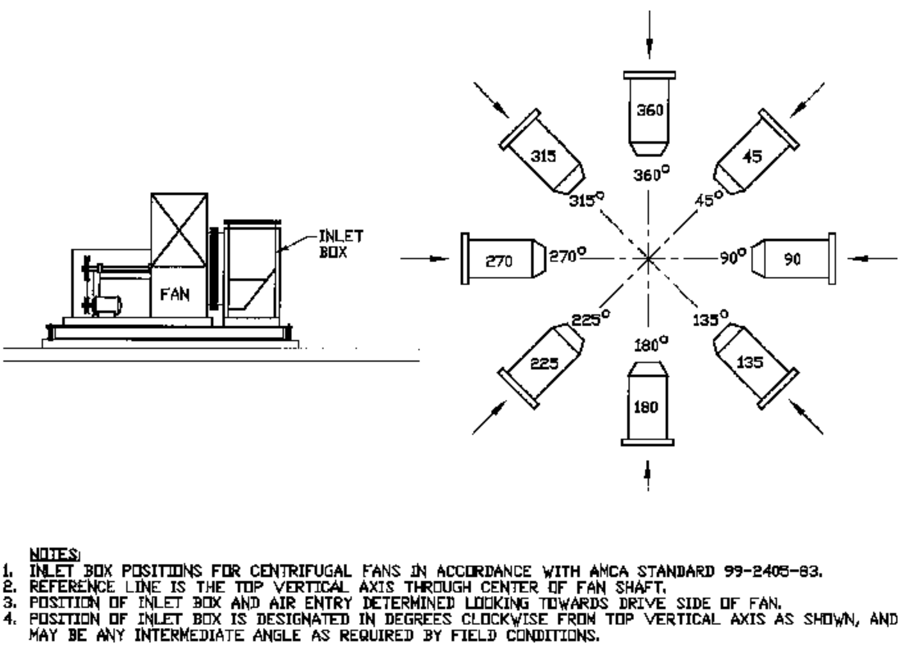


FIGURE 26.14 CENTRIFUGAL FAN INLET BOX POSITIONS.

26.13 Centrifugal Fan Damper Arrangements for Reversible Flow

See Figures 26.15 and 26.16.

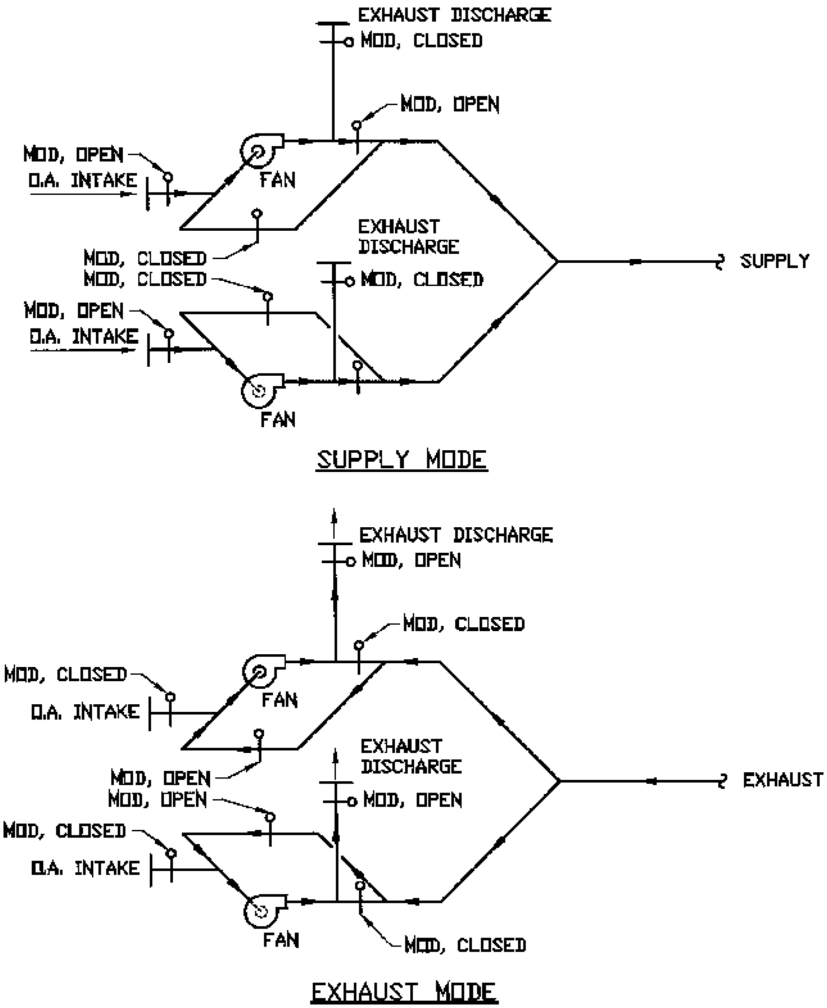


FIGURE 26.15 SWSI CENTRIFUGAL FANS (REVERSIBLE FLOW).

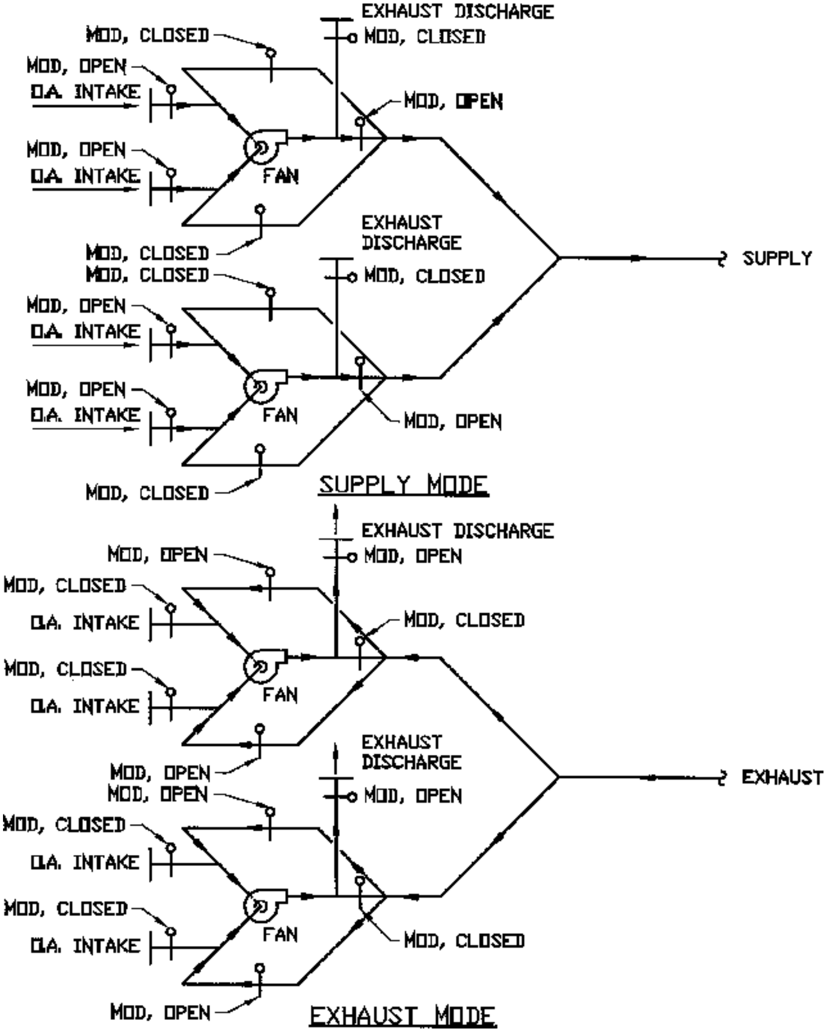


FIGURE 26.16 DWDI CENTRIFUGAL FANS (REVERSIBLE FLOW).

PART 27

Pumps

27.01 Pumps 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_2O	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. 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.

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. 27.1)

1. Series pumps: equal flow, head additive.
2. Parallel pumps: equal head, flow additive.

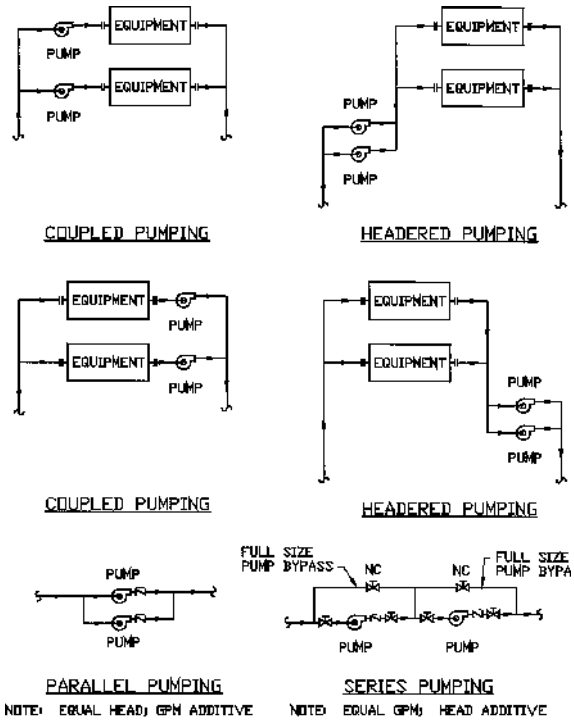


FIGURE 27.1 PUMPING ARRANGEMENTS.

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. 27.2 and 27.3).

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. The 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 of 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.

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 catalogued impeller size should be rated to produce not less than 110 percent of the specified head at the specified flow.

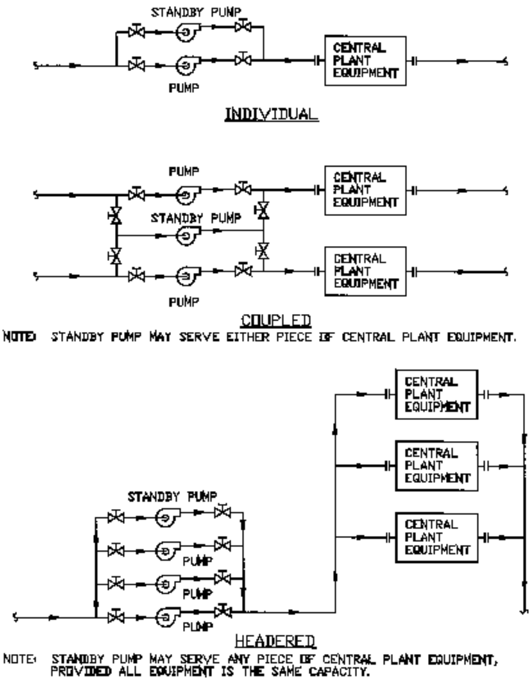


FIGURE 27.2 STANDBY PUMPS.

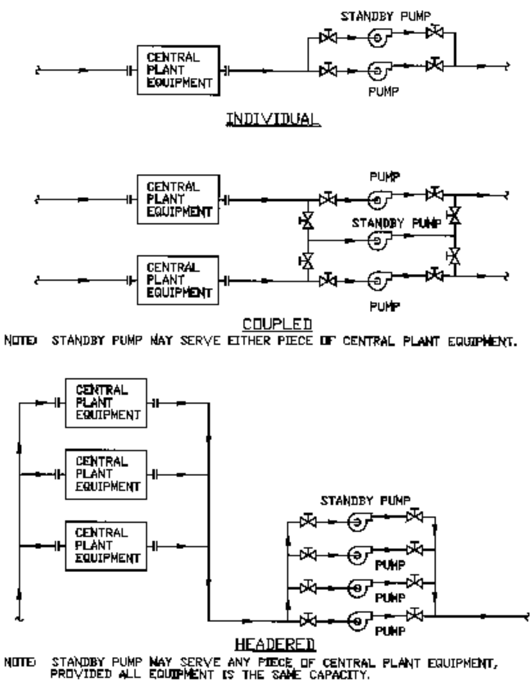


FIGURE 27.3 STANDBY PUMPS.

C. The specified head at the specified flow.

D. 110 percent of the specified flow at the specified head.

E. Parallel Pump Operation: At equal head, the GPM is additive.

F. Series Pump Operation: At equal GPM, the head is additive.

G. Selection Regions:

1. Preferred selection—85–105 percent design flow.
2. Satisfactory selection—66–115 percent design flow.

H. Pumps Curves

1. Flat. A 12 percent rise from design point to the shutoff head (0 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 (0 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.

I. Select pumps so the design point is as close as possible or to the left of the maximum efficiency point.

J. 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.

K. Pump Seals

1. Mechanical seal: closed systems.
2. Stuffing box seals: open systems.

L. 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 heads 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.

[1]Carrier Corporation, *Carrier System Design Manuals*, *Part 8—Auxiliary Equipment*, (Syracuse: Carrier Corporation, 1971), p. 8–11.

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 above the pump decreases.
   c. Friction losses increase.
   d. Fluid temperature increases.

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. *TotalDynamic 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

(*Continued*)

Velocity (ft./sec.)	Velocity Head (feet)	Velocity (ft./sec.)	Velocity Head (feet)	Velocity (ft./sec.)	Velocity Head (feet)
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.

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.

PART 28

Chillers

28.01 Chiller Types and Manufacturer Offerings

Chiller Type	Capacity Range tons	kW/ton Range (1)	COP Range (1)	Turndown % Capacity	Refrigerant	Comments
Centrifugal—Water Cooled						
Carrier	200–1500	0.55–0.62	5.66–6.39	10	134a	3
McQuay	125–1250	0.50–0.60	5.85–7.02	10	134a	3
	250–2400	0.50–0.60	5.85–7.02	10	134a	4
	1200–2700	0.50–0.60	5.85–7.02	10	134a	5
Trane	200–2000	0.45–0.55	6.39–7.80	10	123	3
	1500–4000	0.45–0.55	6.39–7.80	10	123	4
York	200–2400	0.50–0.60	5.85–7.02	10	134a	3
	2000–6000	0.50–0.60	5.85–7.02	10	134a	4
Centrifugal—Water Cooled with Unit Mounted VFD						
Carrier	200–800	0.55–0.62	5.66–6.39	10	134a	3
McQuay	125–1250	0.50–0.60	5.85–7.02	10	134a	3
	250–2400	0.50–0.60	5.85–7.02	10	134a	4
Trane	200–1500	0.45–0.55	6.39–7.80	10	123	3
York	200–1475	0.50–0.60	5.85–7.02	10	134a	3
Reciprocating—Air Cooled						
Carrier	NA	NA	NA	NA	NA	
McQuay	NA	NA	NA	NA	NA	
Trane	NA	NA	NA	NA	NA	
York	NA	NA	NA	NA	NA	
Reciprocating—Water Cooled						
Carrier	15–60	0.81–0.99	3.59–4.32	20–50	22	
McQuay	NA	NA	NA	NA	NA	
Trane	NA	NA	NA	NA	NA	
York	NA	NA	NA	NA	NA	
Rotary Screw—Air Cooled						
Carrier	75–455	1.13–1.25	2.80–3.10	6–15	134a	
McQuay	110–500	1.15–1.25	2.80–3.05	15	134a	
Trane	140–500	1.05–1.16	3.03–3.34	15	134a	
	70–125	1.05–1.13	3.11–3.34	20	22	2
York	150–500	1.15–1.20	2.93–3.05	15	134a	
Rotary Screw—Water Cooled						
Carrier	300–500	0.55–0.62	5.66–6.39	10	134a	6
	75–265	0.69–0.72	4.88–5.09	13–20	134a	
McQuay	120–190	0.54–0.70	4.93–6.50	15	134a	
Trane	140–450	0.58–0.70	5.02–6.05	15	134a	
	70–125	0.74–0.76	4.62–4.75	20	22	2
York	90–400	0.60–0.75	4.68–5.85	15	22, 407c, 134a	
Scroll—Air Cooled						
Carrier	60–390	0.84–0.91	3.87–4.16	10–20	410c	
	10–55	1.19–1.25	2.80–2.96	15–30	22	
McQuay	10–130	1.20–1.25	2.80–2.93	15–30	22, 407c	
Trane	10–60	1.05–1.20	2.93–3.34	25, 50	22	2
York	15–130	1.00–1.15	3.05–3.51	20	22, 407c	
Scroll—Water Cooled						
Carrier	NA	NA	NA	NA	NA	
McQuay	30–120	0.77–0.78	4.50–4.55	25	22	
Trane	20–60	0.77–0.78	4.50–4.56	25, 50	22	2
York	NA	NA	NA	NA	NA	

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 The Refrigerant HCFC-22 product will be changing to 134a by the end of 2007.
3 Centrifugal chillers with single compressor.
4 Centrifugal chillers with dual compressors.
5 Centrifugal chillers with dual compressors and dual refrigerant circuits.
6 Variable speed drive screw chiller.
7 COP, EER, and kW/ton relationships:

EER = COP × 3.417
COP = 12,000 / (kW/ton × 3,417)
kW/ton = 12,000 / (COP × 3,417)

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. $TONS_{COND} = TONS_{EVAP} \times 1.25$
   $= 12{,}000$ Btu/hr. ton $\times 1.25 = 15{,}000$ Btu/hr. ton.
   Therefore, motor heat gain is approximately 3,000 Btu/hr. 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/hr. ton of motor heat gain.

C. In either case, the chillers must remove the 3,000 Btu/hr. 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	2003 IECC 2006 IECC		ASHRAE Std. 90.1-2001 ASHRAE Std. 90.1-2004	
		COP	kW/TON	COP	kW/TON
Air-Cooled Chillers with Condenser—Electric	< 150 tons	2.80	1.254	2.80	1.254
	≥ 150 tons	2.50	1.405	2.80	1.254
Air-Cooled Chillers without Condenser—Electric	All Capacities	3.10	1.133	3.10	1.133
Water-Cooled Reciprocating Chillers—Electric	All Capacities	4.20	0.836	4.20	0.836
Water-Cooled Rotary Screw and Scroll Chillers—Electric	< 150 tons	4.45	0.789	4.45	0.789
	≥ 150 tons and < 300 tons	4.90	0.717	4.90	0.717
	≥ 300 tons	5.50	0.639	5.50	0.639
Water-Cooled Centrifugal Chillers—Electric	< 150 tons	5.00	0.702	5.00	0.702
	≥ 150 tons and < 300 tons	5.55	0.633	5.55	0.633
	≥ 300 tons	6.10	0.576	6.10	0.576
Air-Cooled Absorption Chillers—Single Effect	All Capacities	0.60	5.853	0.60	5.853
Water Cooled Absorption Chillers—Single Effect	All Capacities	0.70	5.017	0.70	5.017
Absorption Chillers—Double Effect, Indirect Fired	All Capacities	1.00	3.512	1.00	3.512
Absorption Chillers—Double Effect, Direct Fired	All Capacities	1.00	3.512	1.00	3.512

Notes:

1 Efficiency values apply to chillers with water temperatures above 40°F.
2 1 ton = 3,417 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, see the following table.

CENTRIFUGAL CHILLERS

2003 IECC and 2006 IECC ASHRAE Std. 90.1- 2001 and ASHRAE Std. 90.1 - 2004													
Leaving Chilled Water Temp. °F	Entering Condenser Water Temp. °F	Less than 150 tons				150 tons to 300 tons				Greater than 300 tons			
		2 GPM/ton 15°F ΔT		3 GPM/ton 10°F ΔT		2 GPM/ton 15°F ΔT		3 GPM/ton 10°F ΔT		2 GPM/ton 15°F ΔT		3 GPM/ton 10°F ΔT	
		COP	kW/ton	COP	kW/ton	COP	kW/ton	COP	kW/ton	COP	kW/ton	COP	kW/ton
48	85	4.94	0.691	5.32	0.641	5.46	0.625	5.89	0.579	6.02	0.567	6.49	0.526
47	85	4.84	0.705	5.25	0.650	5.35	0.638	5.80	0.588	5.90	0.578	6.40	0.533
46	85	5.09 4.73	0.670 0.721	5.56 5.17	0.614 0.660	5.23	0.652	5.71	0.598	5.77	0.591	6.30	0.542
45	85	4.96 4.62	0.688 0.739	5.47 5.09	0.624 0.670	5.10	0.669	5.62	0.607	5.63	0.606	6.20	0.550
44	85	4.83 4.49	0.706 0.760	5.40 **5.00**	0.632 0.682	4.96	0.688	**5.55**	0.615	5.47	0.624	**6.10**	0.559
43	85	4.68 4.35	0.729 0.784	5.28 4.91	0.646 0.695	4.81	0.709	5.42	0.630	5.30	0.643	5.98	0.571
42	85	4.51 4.19	0.757 0.814	5.17 4.81	0.660 0.709	4.63	0.737	5.31	0.643	5.11	0.668	5.86	0.582
41	85	4.33 4.02	0.788 0.849	5.05 4.70	0.676 0.726	4.45	0.767	5.19	0.657	4.90	0.696	5.72	0.597
40	85	4.13 3.84	0.826 0.889	4.92 4.58	0.693 0.745	4.24	0.805	5.06	0.674	4.68	0.729	5.58	0.611

Notes:

1 Where two values are provided, the top number is for the 2003 IECC and 2006 IECC, the bottom is for ASHRAE Std. 90.1-2001 and ASHRAE Std. 90.1-2004.
2 Chilled-water temperatures are only provided in ASHRAE Std. 90.1-2001 and ASHRAE Std. 90.1-2004.
3 The number in bold are standard rating conditions listed in the previous table.
4 For conditions other than those listed in the preceding table, see 2003 IECC, 2006 IECC, ASHRAE Std. 90.1-2001, ASHRAE Std. 90.1-2004, or use the following equations.

Lift = Entering Condenser Water Temperature (°F) – Leaving Chilled Water Temperature (°F).
Condenser ΔT = Leaving Condenser Water Temperature (°F) – Entering Condenser Water Temperature (°F).
X = Condenser ΔT + Lift.
$K_{ajd} = 6.1507 \times 0.30244(X) + 0.0062692(x)^2 - 0.000045595(x)^3$.
$COP_{adj} = K_{adj} \times COP_{std}$

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/hr.) divided by the work of the compressor (Btu/hr.). 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/hr.) 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. ***pH 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 65 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).**

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 outlet 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 inlet.

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.

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.**

28.07 Cooler (Evaporator) / Chilled-Water System

A. **Leaving Water Temperature (LWT): 42–46°F**

B. **10–20°F ΔT**

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. **ARI Evaporator Fouling Factor: 0.00010 Btu/hr.ft.^{2} °F**

L. **Chilled Water Flow Range: Chiller Design Flow ±10 percent**

M. **Chiller Tube Velocity for Variable Flow Chilled Water**

1. Minimum flow: 3.0 FPS.
2. Maximum flow: 12.0 FPS.

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. ARI Condenser Fouling Factor: 0.00025 Btu/hr. ft.^{2} °F

28.09 Chilled Water Storage Systems

A. 10°F ΔT

1. 19.3 cu.ft./ton hr.
2. 623.1 Btu/cu.ft.; 83.3 Btu/gal.

B. 12°F ΔT

1. 16.1 cu.ft./ton hr.
2. 747.7 Btu/cu.ft.; 100.0 Btu/gal.

C. 16°F ΔT

1. 12.4 cu.ft./ton hr.
2. 996.9 Btu/cu.ft.; 133.3 Btu/gal.

D. 20°F ΔT

1. 9.6 cu.ft./ton hr.
2. 1246.2 Btu/cu.ft.; 166.7 Btu/gal.

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 hr.

C. Only the latent heat capacity of ice should be used when designing ice storage systems.

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 1–1.2 percent.

28.12 Refrigerant Estimate—Split Systems

A. Total 3.0 lbs./ton

B. Equipment 2.0 lbs./ton

C. Piping 1.0 lbs./ton

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.)

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.

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. 28.1)

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.

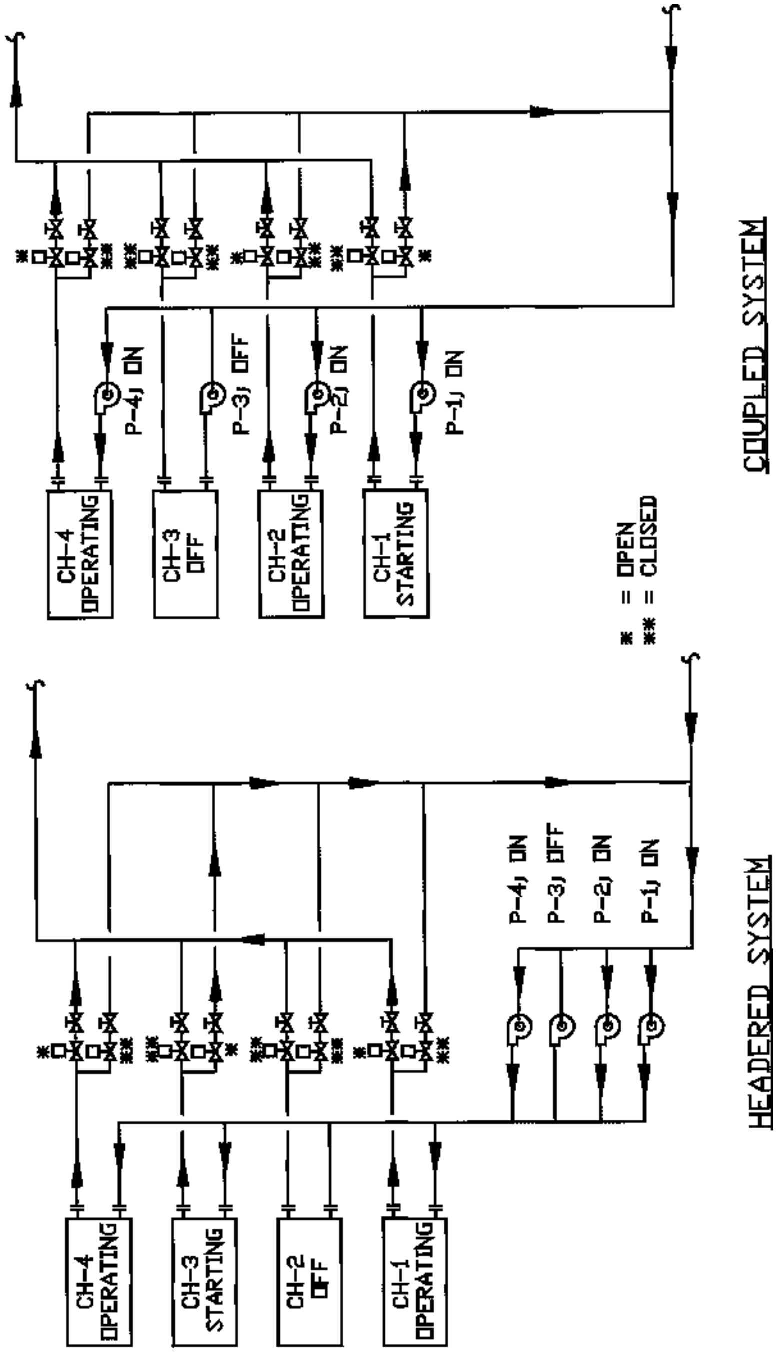


FIGURE 28.1 CHILLER STARTUP PIPING DIAGRAM.

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.

28.16 Chiller Design, Layout, and Clearance Requirements/Considerations

A. Design Conditions

1. Chiller load. Tons, Btu/hr., or MBH.
2. Chilled water temperatures. Entering and leaving or entering and ÄT.
3. Condenser water temperatures. Entering and leaving or entering and ÄT.
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 Fig. 28.2 and Fig. 28.3).
2. Parallel chiller design: Piping chillers in parallel provides a simpler installation and provides for multiple chiller arrangements with standby opportunities. Standby opportunities

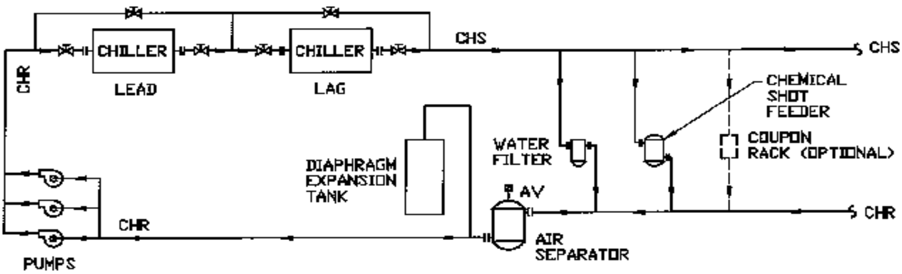


FIGURE 28.2 SERIES CHILLED WATER SYSTEM.

are also available with series chiller arrangements, but they become more complex and cumbersome (see Fig. 28.4 and Fig. 28.5).

3. 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 Fig. 28.6 and Fig. 28.7). 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.

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.

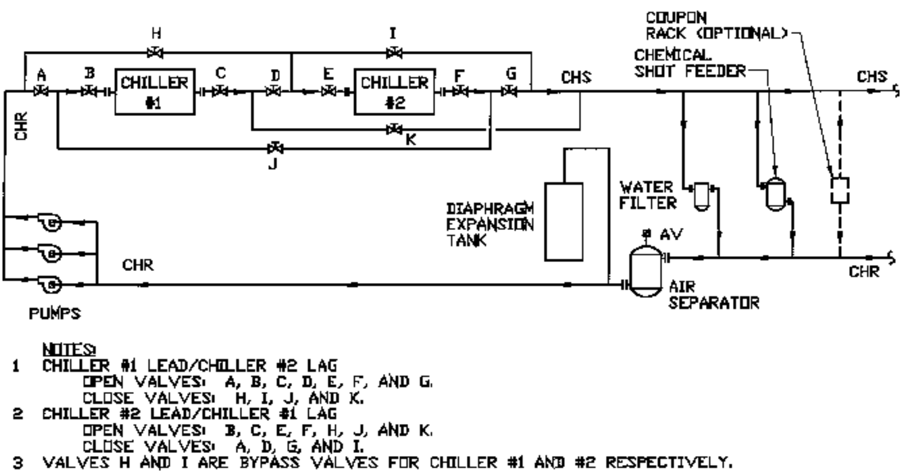


FIGURE 28.3 SERIES CHILLED WATER SYSTEM WITH LEAD-LAG CHILLER CONTROL.

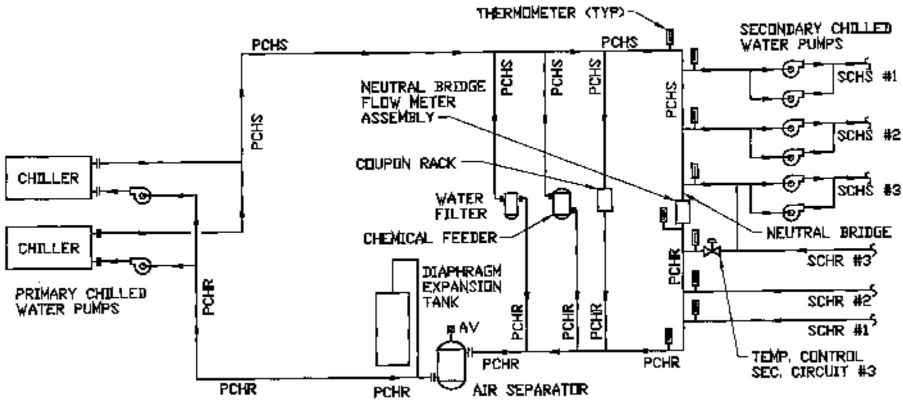


FIGURE 28.4 PARALLEL CHILLED WATER SYSTEM—COUPLED PUMPS.

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.

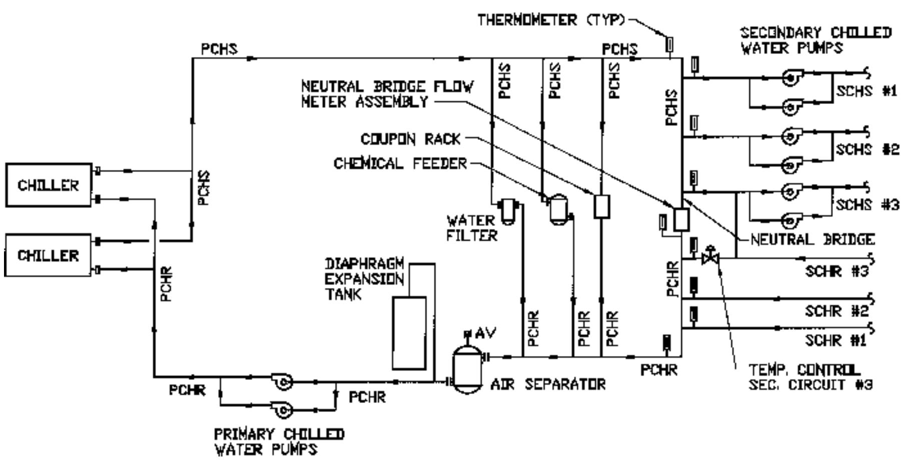


FIGURE 28.5 PARALLEL CHILLED WATER SYSTEM—HEADERED PUMPS.

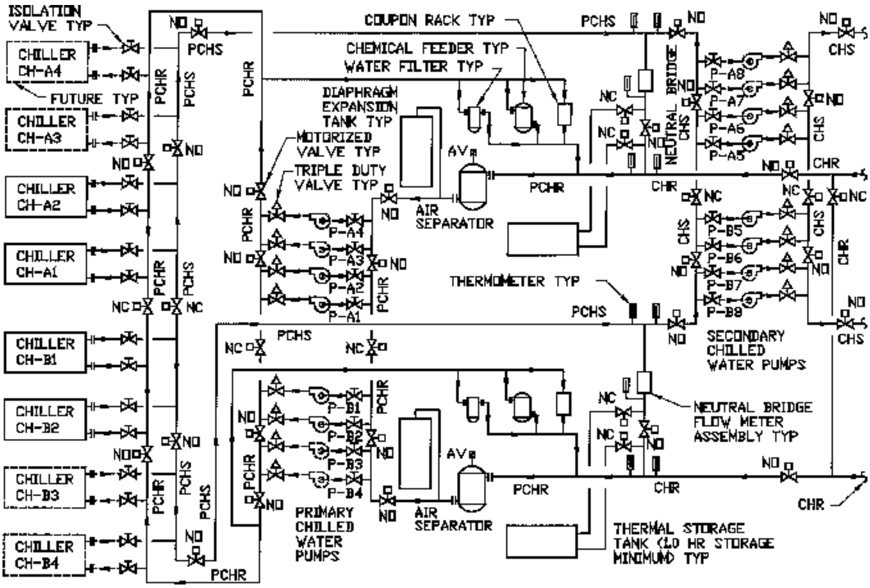


FIGURE 28.6 DUAL PRIMARY/SECONDARY CHILLED WATER SYSTEM FLOW DIAGRAM.

I. **Show the location of the chiller starter. Disconnect the switch and the 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,**

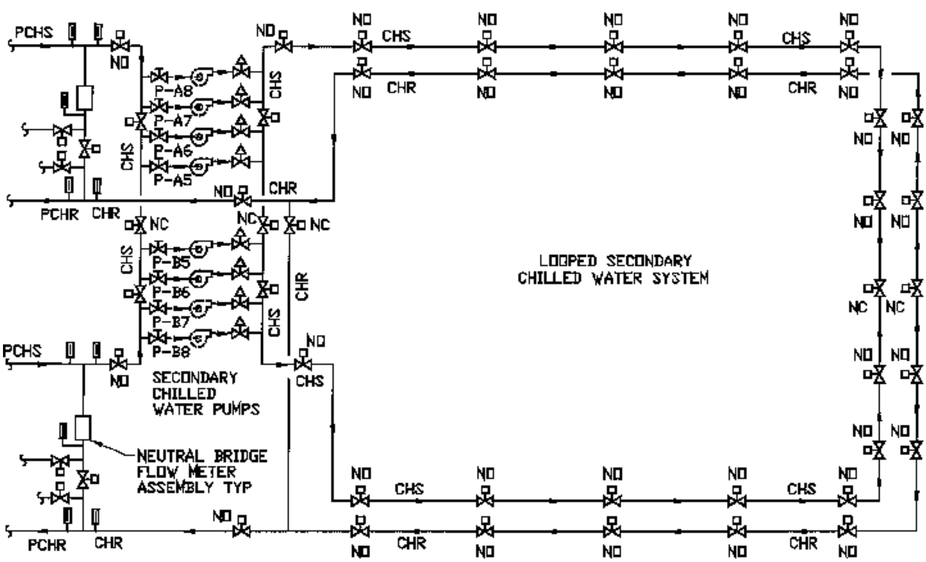


FIGURE 28.7 LOOPED SECONDARY CHILLED WATER SYSTEM FLOW DIAGRAM.

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.

PART 29

Cooling Towers and Condensers

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.

C. Ejector Parallel Flow

1. 5–750 tons.

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.

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

29.04 Power

0.035–0.040 kW/ton

29.05 $TONS_{COND}$

$= TONS_{EVAP} \times 1.25$
$= 12{,}000$ Btu/hr. ton $\times 1.25$
$= 15{,}000$ Btu/hr. ton

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

29.07 Cooling Tower Drains

Use two times the makeup water rate for sizing cooling tower drains.

29.08 Cycles of Concentration

A. Range: 2–10

B. Recommend: 3–5

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

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

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. Type 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.

PART 30

Heat Exchangers

30.01 Shell and Tube Heat Exchangers

A. Used Where the Approach of the System Is Greater than 15±°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.

30.02 Plate and Frame Heat Exchangers

A. Used Where the Approach of the System Is Less than 15±°F

B. Generally Used in Cooling Systems

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.

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/hr. (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.

PART 31

Boilers

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).
2. Water tube boilers (see Fig. 31.2).

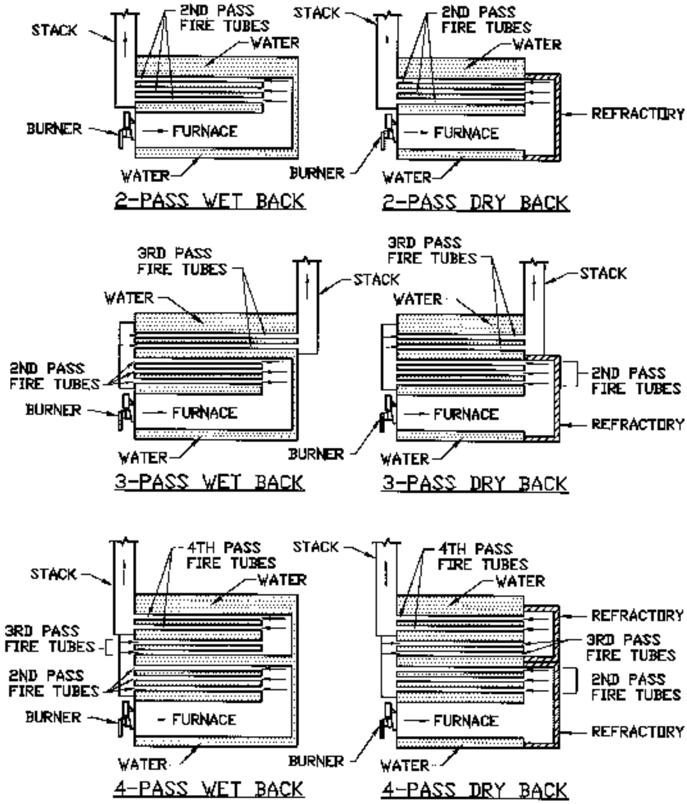


FIGURE 31.1 FIRE TUBE BOILER TYPES.

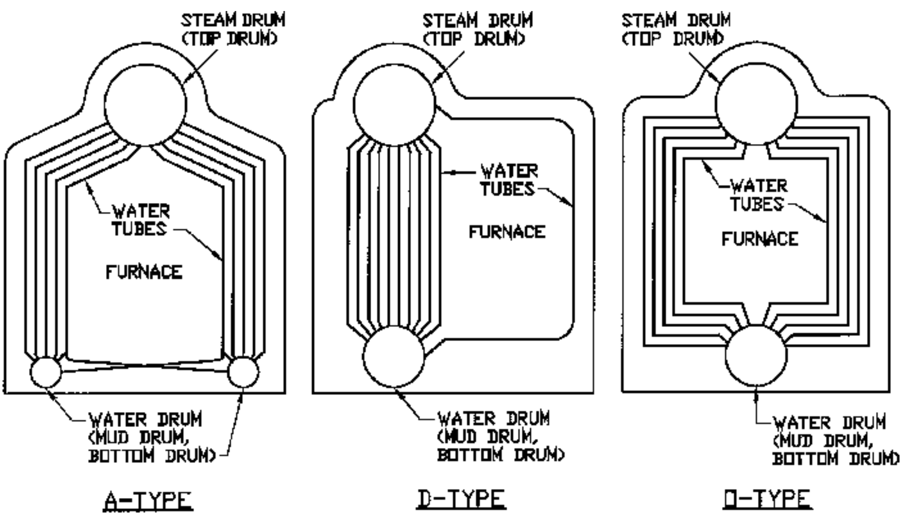


FIGURE 31.2 WATER TUBE BOILER TYPES.

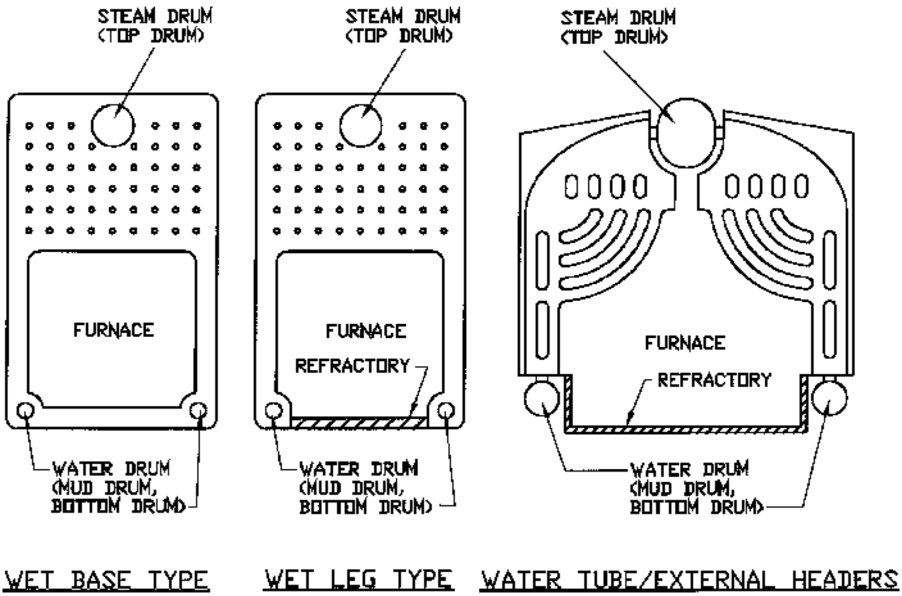


FIGURE 31.3 CAST IRON BOILER TYPES.

3. Flexible tube boilers.
4. Cast iron boilers (see Fig. 31.3).
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	350ºF	455ºF
Super Heaters	None	Available to 750ºF
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. CSD (ASME Control Code).
6. *NFPA 8501.*

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 (O_3).
2. Carbon monoxide (CO).
3. Nitrogen oxides (NO_x-NO / NO_2).
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 flow.
   h. High water flow.
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.

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. 31.4).
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 H_2O.
   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.

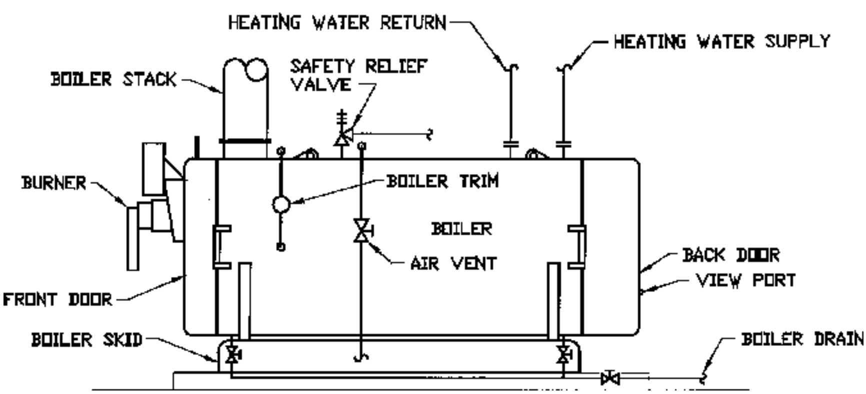


FIGURE 31.4 HEATING WATER SYSTEM AND BOILER TERMINOLOGY.

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/hr., 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/hr (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. 31.5 and 31.6).
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.

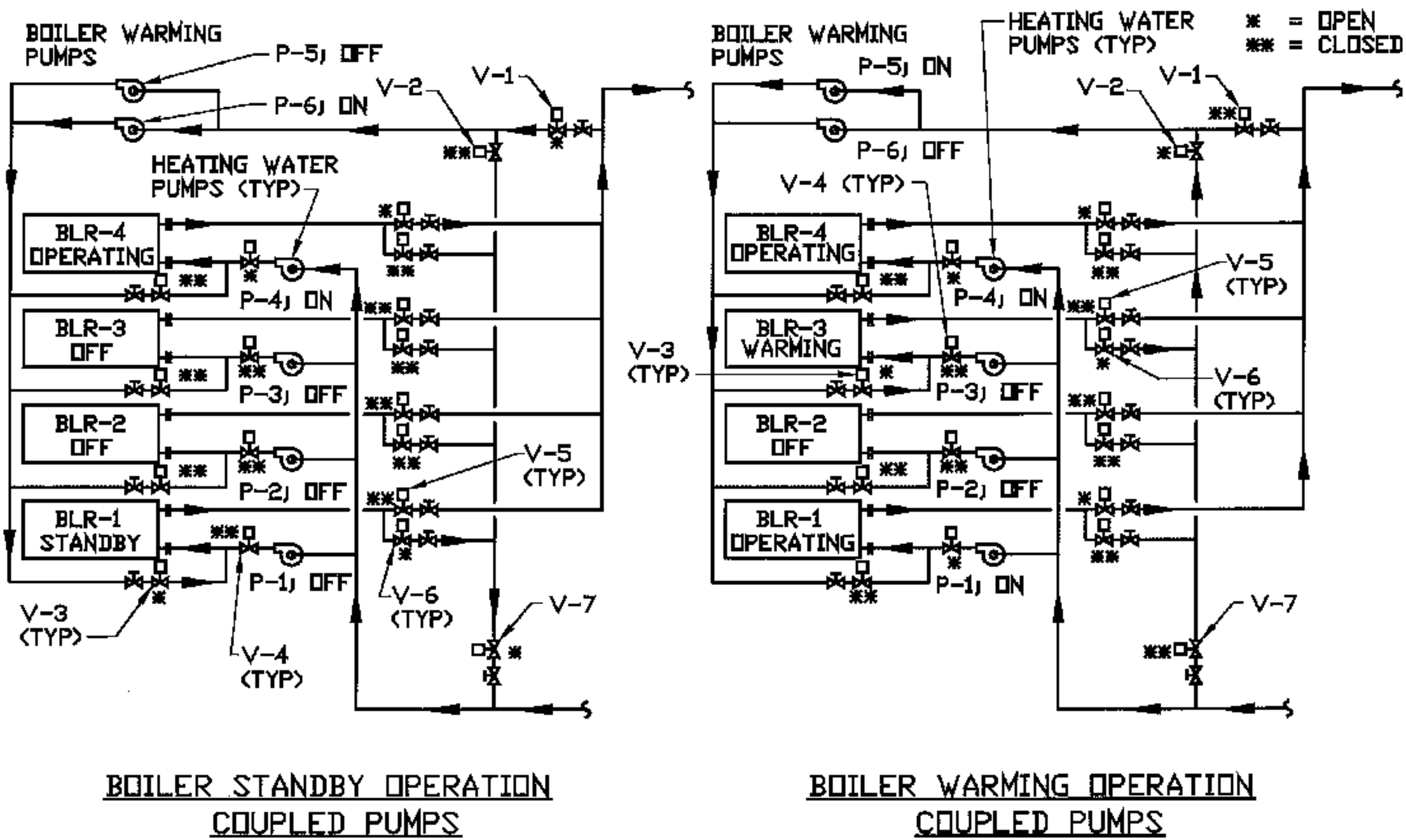


FIGURE 31.5 BOILER STANDBY AND WARMING DIAGRAM—COUPLED PUMPS.

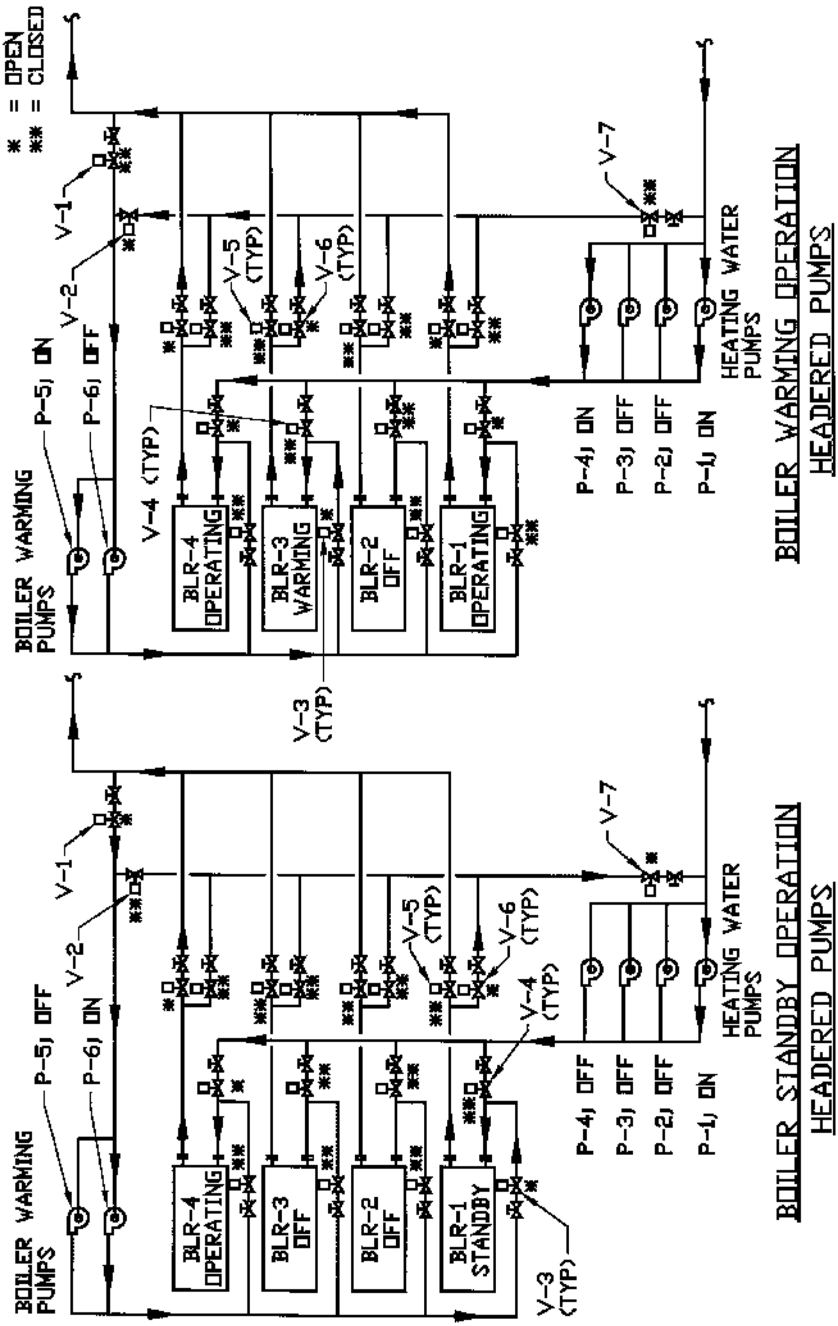
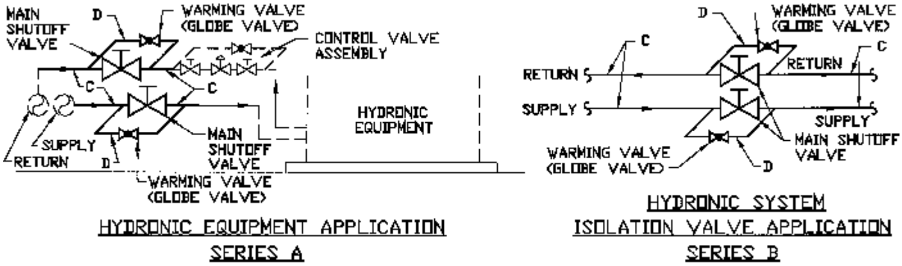


FIGURE 31.6 BOILER STANDBY AND WARMING DIAGRAM—HEADERED PUMPS.

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



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"

FIGURE 31.7 HYDRONIC SYSTEM WARMING VALVES.

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. 31.7). 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.

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 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. 31.7):
    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.

31.03 Steam Boilers

A. Boiler Types

1. Fire tube boilers:
    a. 15–800 BHP.
    b. 518–27,600 lbs./hr.
    c. 15–300 psig.
2. Water tube boilers:
    a. 350–2,400 BHP.
    b. 12,075–82,800 lbs./hr.
    c. 15–525 psig.
3. Flexible water tube boilers:
    a. 30–250 BHP.
    b. 10,000–82,000 lbs./hr.
    c. 15–525 psig.
4. Cast-iron boilers:
    a. 10–400 BHP.
    b. 1,035–8,625 lbs./hr.
    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. 31.8).
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

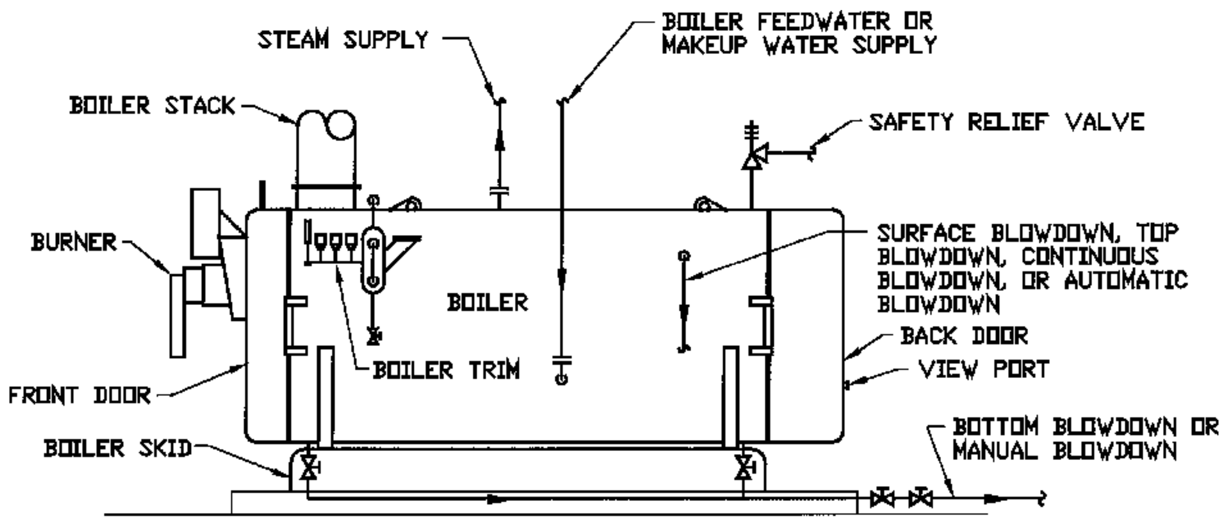
1. Approx. 1,000 Btuh/1 lb. steam.
2. lbs. steam/hr. = lb. water/hr.

STEAM CAPACITY PER BOILER HORSEPOWER

Feed-Water Temp.	Pounds of Dry Saturated Steam per Boiler hp @ System Pressure (psig) vs. Feedwater Temperature (°F)																	
	0	2	10	15	20	40	50	60	80	100	120	140	150	150	180	200	220	240
30	29.0	29.0	28.8	28.7	28.6	28.4	28.3	28.2	28.2	28.1	28.0	28.0	27.9	27.9	27.9	27.9	27.9	27.8
40	29.3	29.2	29.1	29.0	28.9	28.7	28.6	28.5	28.4	28.3	28.2	28.2	28.2	28.2	28.2	28.1	28.1	28.1
50	29.6	29.5	29.3	29.2	29.1	28.9	28.8	28.8	28.7	28.6	28.5	28.5	28.4	28.4	28.4	28.3	28.3	28.3
60	29.8	29.8	29.6	29.5	29.4	29.2	29.1	29.0	28.9	28.8	28.8	28.7	28.7	28.7	28.6	28.6	28.6	28.5
70	30.1	30.0	29.9	29.8	29.7	29.5	29.4	29.3	29.2	29.1	29.0	29.0	28.9	28.9	28.9	28.8	28.8	28.8
80	30.4	30.3	30.1	30.0	30.0	29.8	29.6	29.6	29.5	29.3	29.2	29.2	29.2	29.2	29.1	29.1	29.1	29.0
90	30.6	30.6	30.4	30.3	30.2	30.0	29.9	29.8	29.7	29.6	29.5	29.5	29.4	29.4	29.4	29.3	29.3	29.3
100	30.9	30.8	30.6	30.6	30.5	30.3	30.2	30.1	30.0	29.8	29.8	29.8	29.7	29.7	29.7	29.6	29.6	29.6
110	31.2	31.2	30.9	30.8	30.8	30.6	30.4	30.3	30.2	30.0	30.0	30.0	30.0	30.0	29.9	29.9	29.9	29.8
120	31.5	31.4	31.2	31.2	31.1	30.8	30.7	30.6	30.5	30.4	30.3	30.3	30.2	30.2	30.2	30.1	30.1	30.1
130	31.8	31.7	31.5	31.4	31.4	31.1	31.0	30.9	30.8	30.7	30.6	30.6	30.5	30.5	30.4	30.4	30.4	30.4
140	32.1	32.0	31.8	31.7	31.6	31.4	31.3	31.2	31.1	31.0	30.9	30.8	30.8	30.8	30.8	30.7	30.7	30.6
150	32.4	32.4	32.1	32.0	31.9	31.7	31.6	31.5	31.4	31.2	31.2	31.2	31.1	31.1	31.0	31.0	30.9	30.9
160	32.7	32.7	32.4	32.4	32.3	32.0	31.9	31.8	31.7	31.5	31.4	31.4	31.4	31.4	31.3	31.3	31.2	31.2
170	33.0	33.0	32.7	32.6	32.6	32.3	32.2	32.1	32.0	31.8	31.7	31.7	31.7	31.7	31.6	31.6	31.5	31.5
180	33.4	33.3	33.0	33.0	32.9	32.6	32.5	32.4	32.3	32.2	32.1	32.0	32.0	32.0	31.9	31.9	31.8	31.8
190	33.8	33.7	33.4	33.3	33.2	32.9	32.8	32.7	32.6	32.5	32.4	32.4	32.3	32.3	32.2	32.2	32.1	32.1
200	34.1	34.0	33.7	33.6	33.5	33.2	33.1	33.0	32.9	32.8	32.7	32.6	32.6	32.6	32.6	32.5	32.4	32.4
212	34.5	34.4	34.2	34.1	33.9	33.6	33.5	33.4	33.3	33.2	33.1	33.0	33.0	33.0	32.9	32.9	32.8	32.8
220	34.8	34.7	34.4	34.3	34.2	33.9	33.8	33.7	33.5	33.4	33.3	33.3	33.2	33.2	33.1	33.1	33.1	33.0
227	35.0	34.9	34.7	34.5	34.4	34.1	34.0	33.9	33.8	33.7	33.6	33.5	33.5	33.4	33.4	33.3	33.3	33.3
230	35.2	35.0	34.8	34.7	34.5	34.2	34.1	34.0	33.9	33.8	33.7	33.6	33.6	33.5	33.5	33.4	33.4	33.4

D. Steam Boiler Drums

1. Top drum: steam drum.
2. Bottom drum: mud or blowdown drum.



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.

FIGURE 31.8 STEAM SYSTEM AND BOILER TERMINOLOGY.

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 the 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/hr., 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/hr. (i.e., 2@50 percent, 2@67percent, 2@ 70 percent, 3@34percent, 3@40percent).
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.
    b. 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.
    c. 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

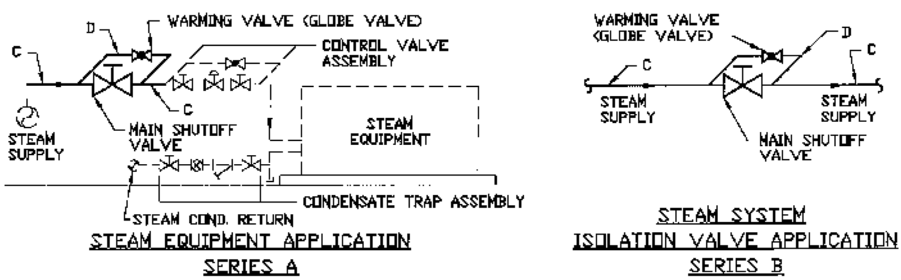
Main Valve Nominal Pipe Size	Nominal Pipe Size	
	Series A Warming Valves	Series B Bypass Valves
4	1/2	1
5	3/4	1–1/4
6	3/4	1–1/4
8	3/4	1–1/2
10	1	1–1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1 Series A 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. 31.9):
    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:



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"

FIGURE 31.9 STEAM SYSTEM WARMING VALVES.

   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. The size condensate pumps at three times the condensate return rate.

6. The 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./hr. of connected load.
9. Pumped steam condensate return units: 2.4 GPM/1,000 lbs./hr.

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./hr.
2. Continuous blowdown (surface blowdown): 0.5 GPM/1,000 lbs./hr.

M. Blowdown Separator Drains: 10 GPM/1000 lbs./hr. Boiler Output

N. Steam Boiler Water Makeup

1. Boilers: 4.0 GPM/1,000 lbs./hr. each.
2. Deaerator/feedwater unit: 4.0 GPM/1,000 lbs./hr. 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.

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 building 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, gas-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/lbs.
2. Bituminous: 13,500–15,300 Btu/lbs.

G. Wood

1. 8,000–10,000 Btu/lbs.

H. Kerosine

1. 135,000 Btu/gal.

PART 32

Motors and Motor Controllers

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—EPAct motors as a minimum; preferred premium efficiency motors. Premium efficiency motors are a higher efficiency motor than the EPAct 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 (10°C) increase in motor operating temperature, the life of the motor is cut in half. Conversely, for every 50°F (10°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:

Motors and Motor Controllers

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	*
300; 350; 400; 450; 500; 600; 700; 750; 800; 900; 1000; 1250; 1500; 1750; 2000; 2250; 2500; 3000; 3500; 4000; 4500; 5000; 5500; 6000**	MS	*

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 thru 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:
   a. 1/2 horsepower and smaller: Locked Rotor Code L.
   b. 3/4–1 horsepower: Locked Rotor Code K.
   c. 1-1/2–2 horsepower: Locked Rotor Code J.
   d. 3 horsepower: Locked Rotor Code H.
   e. 5 horsepower: Locked Rotor Code G.
3. Specify 15 horsepower and larger motors with NEMA Starting Code F or G.
4. Specify motors smaller than 15 horsepower with the manufacturer's standard starting characteristics.

G. Motor Insulation Classes are given in the following table

1. Specify all motors with class F insulation and class B motor temperature rise.
2. Specify all motors with a minimum 1.15 service factor or NEMA standard service factor, whichever is higher.

Motor Type	Motor Insulation Class Temperature Rise							
	A		B		F		H	
	ºC	ºF	ºC	ºF	ºC	ºF	ºC	ºF
1. Motors with 1.0 Service Factor (except 3 and 4 below)	60	140	80	176	105	221	125	257
2. All Motors with 1.15 Service Factor or Higher	70	158	90	194	115	239	---	---
3. Totally Enclosed Nonventilated Motor with 1.0 Service Factor	65	149	85	185	110	230	135	275
4. Motors with Encapsulated Windings and with 1.0 Service, All Enclosures	65	149	85	185	110	230	---	---

Notes:

1 Abnormal deterioration of insulation may be expected if the ambient temperature of 40ºC/104ºF is exceeded in regular operation.
2 Temperature rise based on 40ºC/104ºF 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 105ºC/221ºF.
4 Class B Motors: Motors for HVAC applications, high-quality fractional Hp motors; maximum operating temperature 130ºC/266ºF.
5 Class F Motors: Inverter duty motors, industrial motors; maximum operating temperature 155ºC/311ºF.
6 Class H Motors: High temperature, high reliability, high ambient; maximum operating temperature 180ºC/356ºF.

H. NEMA Motor Design Designations

1. Design A motors are built with high pullout torque and are used on injection molding machines.
2. 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.
3. Design C motors are built with high starting torque and used with hard-to-start loads and with conveyors.
4. 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 90.1-2001 and ASHRAE Standard 90.1-2004:* 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	94.0	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	90.2s	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
30	91.0	92.4	92.4	91.0	92.4	91.7
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

Notes:
1 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
40	18	29	726	18	35	932
50	18	30	803	18	35	933
60	20	33	970	20	34	1212
75	20	35	1105	20	35	1481
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 1200-rpm motors. Motors above the 1200 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	763
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 1200-rpm motors. Motors above the 1200 rpm rating are lighter and smaller in size.
2 Motor dimensions are rounded to the nearest inch.

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
1200	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	1/100–1/4
Full Load Speeds (RPM @ 60Hz)	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 *2005 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	2.3	30	3.5	15
3/4	1	3.2	30	5	15
1	1	4.1	30	6.25	15
1.5	1	6.0	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	2.0	30	3.2	15
3/4	1	2.8	30	4.5	15
1	1	3.6	30	5.6	15
1.5	1	5.2	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	1.0	30	1.6	15
3/4	1	1.4	30	2.25	15
1	1	1.8	30	2.8	15
1.5	1	2.6	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	300.0	600	500	500
300	6	360.0	600	600	600
400	6	480.0	800	700	700
500	7	540.0	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	0.8	30	1.25	15
3/4	1	1.1	30	1.6	15
1	1	1.4	30	2.25	15
1.5	1	2.1	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	240.0	600	350	350
300	6	290.0	600	400	400
400	6	385.0	600	500	500
500	7	480.0	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.

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 (VVIs) 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. The 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 Dripproof**
C. NEMA Type 3R:	**Outdoor, Rain Tight, Water Tight, Dust Tight**
D. NEMA Type 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**

PART 33

Humidifiers

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./hr.
4. Spray coil humidifiers: 5.0 GPM/1,000 lbs./hr.

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.

PART 34

Filters

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 particulate from the air.

E. MERV Values

MERV RATINGS

MERV Rating	Average Particle Size in Microns	Efficiency	Filter Types
1–5	3.0–10.0	Less than 20%	20–35% Flat or panel filters Carbon filters (not designed to remove particulate)
6–7	3.0–10.0	49.9%	25–35% Pleated media filters 40–45% Bag filters 20–25% Roll filters 30–40% Electronic air cleaners
8–9	3.0–10.0	84.9%	50–55% Bag filters
10–11	3.0–10.0 1.0–3.0	85% or greater 50–64.9%	60–65% Pleated media filters 60–65% Bag filters
12–13	3.0–10.0 1.0–3.0	90% or greater 80–89.9%	80–85% Pleated media filters 80–85% Bag filters
14–15	1.0–3.0 0.3–1.0	90% or greater 75–84.9%	90–95% Pleated media filters 90–95% Bag filters
16	0.3–1.0	75% or greater	HEPA filters ULPA filters

34.02 Flat or Panel Filters

A Efficiency: 20–35%

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 52-1992, Atmospheric***

34.03 Pleated Media Filters

A. Efficiency

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 52-1992, Atmospheric***

34.04 Bag Filters

A. Efficiency

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 52-1992, Atmospheric***

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)

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.

D. Final Pressure Drop

1. 99.997–99.9999%: 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)

34.07 Roll Filters

A. Efficiency: 20–25%

B. Face Velocity: 500 FPM

C. Initial Pressure Drop

1. 20%: 0.20" W.G.

D. Final Pressure Drop

1. 20%: 0.45" W.G.

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 52-1992, Atmospheric*

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 52-1992, Atmospheric*

34.09 Electronic Air Cleaners

A. Efficiency: 30–40%

B. Face Velocity: 625 FPM

C. Initial Pressure Drop

1. 90%: 0.26" W.G.

D. Final Pressure Drop

1. 90%: 0.50" W.G.

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 52-1992, Atmospheric***

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. 2003 IMC and 2006 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-2002: Filters shall be rated as either Class 1 or Class 2 in accordance with UL900.

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 (di-octyl 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.

PART 35

Insulation

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. / hr. 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. / hr. 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. hr. / 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 / hr. sq.ft. °F.

$$R = \frac{1}{C} = \frac{1}{K} \times Thickness$$

$$U = \frac{1}{\sum R}$$

B. Materials

1. Calcium silicate temperature range:	0–+1200°F.
2. Fiberglass temperature range:	–20–+1000°F.
3. Mineral wool temperature range:	+200–+1900°F.
4. Urethane, styrene, beadboard temperature range:	–350–+250°F.
5. Cellular glass temperature range:	–450–+850°F.
6. Ceramic fiber temperature range:	0–+3000°F.
7. Flexible tubing and sheets temperature range:	–40–+250°F.

35.02 Pipe Insulation

A. Insulation shall be sectional molded glass fiber, minimum 3.0 lb per cubic foot density, with a thermal conductivity not greater than 0.24 Btu-in./sq.ft./°F/hr. 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 lb per cubic foot density, with a thermal conductivity not greater than 0.28 Btu-in./sq.ft./°F/hr. 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/hr. at a mean temperature difference of 75°F.**

D. **Insulation shall be foamglass, minimum 8.5 lb per cubic foot density, with a thermal conductivity not greater than 0.35 Btu-in./sq.ft./°F/hr. at a mean temperature difference of 75°F.**

E. **Code Required Pipe Insulation Thickness**

2003 IECC AND 2006 IECC

Fluid	Nominal Pipe Diameter	
	≤1-1/2"	>1-1/2"
Steam	1.5	3.0
Hot Water	1.0	2.0
Chilled Water, Brine, and Refrigerant	1.0	1.5

ASHRAE STANDARD 90.1-2001 AND 2004

Fluid Design Operating Temperature	Conductivity Btu-in./hr.ft.^{2} ºF	Nominal Pipe or Tube Diameter					
		<1"	1–<1-1/2"	1-1/2"	>1-1/2–<4"	4–<8"	≥8"
Heating Systems—Hot Water and Steam Condensate							
>350ºF	0.32–0.34	2.5	3.0	3.0	3.0	4.0	4.0
251–350ºF	0.29–0.32	1.5	2.5	3.0	3.0	3.0	3.0
201–250ºF	0.27–0.30	1.5	1.5	2.0	2.0	2.0	2.0
141–200ºF	0.25–0.29	1.0	1.0	1.0	**1.0**	**1.5**	**1.5**
105–140ºF	0.22–0.28	**0.5**	**0.5**	1.0	**1.0**	**1.0**	**1.0**
Heating Systems—Steam							
>350ºF >120 Psig	0.32–0.34	2.5	3.0	3.0	3.0	4.0	4.0
251–350ºF 16–120 Psig	0.29–0.32	1.5	2.5	3.0	3.0	3.0	3.0
212–250ºF 0–15 Psig	0.27–0.30	1.5	1.5	2.0	**2.0**	**2.0**	**2.0**
Cooling Systems—Chilled Water, Glycol, Brine, and Refrigerant							
40–60ºF	0.22–0.28	**0.5**	**0.5**	1.0	**1.0**	**1.0**	**1.0**
<40ºF	0.22–0.28	**0.5**	1.0	1.0	**1.0**	**1.0**	1.5

Notes:
1 Bold insulation thicknesses do not meet the 2003 IECC and the 2006 IECC.

A. **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 40–60ºF (3)	1-1/2" and smaller 2" and larger	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
Chilled Water 32–40ºF (3)	1" and smaller 1-1/4–6" 8" and larger	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0
Chilled Water Below 32ºF (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)

(*Continued*)

Piping System (7)	Pipe Sizes	Insulation Thickness vs. Type (1,8)			
		A	B	C	D
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	1.0 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	1.5 2.0	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	1.5 2.5 3.0	(10)	2.5 4.5 5.0	2.5 4.0 4.5
Heating Water—High Temperature 351–450°F (4)	3/4" and smaller 1–3" 4" and larger	2.5 3.0 4.0	(10)	4.5 5.0 6.5	4.0 4.5 6.0
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	1-1/4" and smaller 1-1/2" 2" and larger	1.5 2.0 3.0	2.0 2.5 4.0	2.5 3.5 5.0	2.5 3.0 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	1.5 2.5 3.0	(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 1–3" 4" and larger	2.5 3.0 4.0	(10)	4.5 5.0 6.5	4.0 4.5 6.0
Refrigerant Suction and Liquid Lines (6)	1" and smaller 1-1/4–6" 8" and larger	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0
Refrigerant Hot Gas (6)	All sizes	0.75	1.0	1.5	1.0
Air Conditioning Condensate	All sizes	0.5	0.5	1.0	0.75

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 - 2001 and 2004, and the 2003 and 2006 IECC.

8 For piping exposed to ambient temperatures, increase the insulation thickness by 1 in.

9 For dual temperature systems, use insulation thickness for a more stringent system, usually the heating system.

10 The system temperature exceeds the temperature rating of the insulation.

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 conductance (k) not greater then 0.24 Btu/sq.ft./°F/hr. 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 conductance (k) not greater than 0.29 Btu-in./sq.ft./°F/hr. 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 lb per cubic foot density, with a thermal conductance (k) not greater than 0.23 Btu-in./sq.ft./°F/hr. 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 lb per cubic foot density, with a thermal conductance (k) not greater than 0.22 Btu-in./sq.ft./°F/hr. 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. 2003 IECC and 2006 IECC:
   a. Supply and return air ducts and plenums located in unconditioned spaces: R-5 insulation minimum.
   b. Supply and return air ducts and plenums located outside: R-8 insulation minimum.
   c. 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 90.1-2001.

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space	Indirectly Conditioned Space	Buried
Heating Ducts Only							
B-1 to B-7	None	None	None	None	None	None	None
B-8 to B-12	R-3.5	None	None	None	None	None	None
B-13 to B-15	R-3.5	None	None	None	None	None	None
B-16 to B-18	R-6	R-3.5	None	None	None	None	R-3.5
B-19 to B-20	R-6	R-6	R-3.5	None	None	None	R-3.5
B-21 to B-22	R-8	R-6	R-6	None	R-3.5	None	R-3.5
B-23	R-8	R-6	R-6	None	R-6	None	R-6
B-24	R-8	R-8	R-6	None	R-6	None	R-6
B-25	R-10	R-8	R-8	None	R-6	None	R-6
B-25	R-10	R-10	R-8	None	R-8	None	R-6

(*Continued*)

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space	Indirectly Conditioned Space	Buried
Cooling Ducts Only							
B-15, 18, 20, 22–26	R-1.9	R-1.9	R-1.9	R-1.9	R-1.9	None	None
B-12, 14, 17, 19, 21	R-3.5	R-1.9	R-3.5	R-1.9	R-1.9	None	None
B-7, 9, 11, 13, 16	R-3.5	R-3.5	R-6	R-1.9	R-1.9	None	None
B-4, 6, 8, 10	R-6	R-6	R-6	R-3.5	R-1.9	None	None
B-3, 5	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-2	R-6	R-6	R-8	R-3.5	R-3.5	None	R-3.5
B-1	R-8	R-8	R-8	R-3.5	R-3.5	None	R-3.5

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space	Indirectly Conditioned Space	Buried
Cooling and Heating Ducts							
B-1	R-8	R-6	R-8	R-3.5	R-3.5	None	R-3.5
B-2	R-6	R-6	R-8	R-3.5	R-3.5	None	R-3.5
B-3	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-4	R-6	R-3.5	R-6	R-3.5	R-1.9	None	R-3.5
B-5	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-6	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-7	R-3.5	R-3.5	R-6	R-1.9	R-1.9	None	R-1.9
B-8	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-9	R-6	R-3.5	R-6	R-1.9	R-1.9	None	R-1.9
B-10	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-11	R-6	R-6	R-6	R-3.5	R-3.5	None	R-1.9
B-12	R-3.5	R-3.5	R-3.5	R-1.9	R-1.9	None	R-1.9
B-13	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-14	R-6	R-3.5	R-6	R-1.9	R-3.5	None	R-1.9
B-15	R-3.5	R-3.5	R-3.5	R-1.9	R-1.9	None	R-1.9
B-16	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
B-17	R-6	R-6	R-6	R-1.9	R-3.5	None	R-3.5
B-18	R-6	R-3.5	R-3.5	R-1.9	R-3.5	None	R-3.5
B-19	R-8	R-6	R-6	R-1.9	R-3.5	None	R-3.5
B-20	R-6	R-6	R-6	R-1.9	R-3.5	None	R-3.5
B-21	R-8	R-6	R-6	R-1.9	R-6	None	R-3.5
B-22	R-8	R-6	R-6	R-1.9	R-3.5	None	R-3.5
B-23	R-8	R-6	R-6	R-1.9	R-6	None	R-6
B-24	R-8	R-8	R-8	R-1.9	R-6	None	R-6
B-25	R-10	R-8	R-8	R-3.5	R-6	None	R-6
B-26	R-10	R-10	R-8	R-3.5	R-8	R-3.5	R-6
Return Ducts							
1–8	R-3.5	R-3.5	R-3.5	None	None	None	None

3. ASHRAE Standard 90.1-2004

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space	Indirectly Conditioned Space	Buried
Heating Ducts Only							
1, 2	None	None	None	None	None	None	None
3	R-3.5	None	None	None	None	None	None
4	R-3.5	None	None	None	None	None	None
5	R-6	R-3.5	None	None	None	None	R-3.5
6	R-6	R-6	R-3.5	None	None	None	R-3.5
7	R-8	R-6	R-6	None	R-3.5	None	R-3.5
8	R-8	R-8	R-6	None	R-6	None	R-6
Cooling Ducts Only							
1	R-6	R-6	R-8	R-3.5	R-3.5	None	R-3.5
2	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
3	R-6	R-6	R-6	R-3.5	R-1.9	None	None
4	R-3.5	R-3.5	R-6	R-1.9	R-1.9	None	None
5, 6	R-3.5	R-1.9	R-3.5	R-1.9	R-1.9	None	None
7, 8	R-1.9	R-1.9	R-1.9	R-1.9	R-1.9	None	None
Cooling and Heating Ducts							
1	R-6	R-6	R-8	R-3.5	R-3.5	None	R-3.5
2	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
3	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
4	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
5	R-6	R-6	R-6	R-1.9	R-3.5	None	R-3.5
6	R-8	R-6	R-6	R-1.9	R-3.5	None	R-3.5
7	R-8	R-6	R-6	R-1.9	R-3.5	None	R-3.5
8	R-8	R-8	R-8	R-1.9	R-6	None	R-6
Return Ducts							
1–8	R-3.5	R-3.5	R-3.5	None	None	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	Unconditioned Space	Indirectly Conditioned Space	Buried
Heating Ducts Only							
All Climate Zones	R-8	R-8	R-8	R-5	R-5	R-5	R-5
Duct Liner	2"	2"	2"	1.5"	1.5"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"	1.5"	1.5"
Cooling Ducts Only							
All Climate Zones	R-8	R-8	R-8	R-5	R-5	R-5	R-5
Duct Liner	2"	2"	2"	1.5"	1.5"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"	1.5"	1.5"

(*Continued*)

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insul. Ceiling	Unvented Attic w/Roof Insulation	Unconditioned Space	Indirectly Conditioned Space	Buried
Cooling and Heating Ducts							
All Climate Zones	R-8	R-8	R-8	R-5	R-5	R-5	R-5
Duct Liner	2"	2"	2"	1.5"	1.5"	1.5"	1.5"
Duct Wrap	3"	3"	3"	2"	2"	2"	2"
Duct Board	2"	2"	2"	1.5"	1.5"	1.5"	1.5"
Return Ducts							
All Climate Zones	R-8	R-8	R-8	None	None	None	None
Duct Liner	2"	2"	2"	None	None	None	None
Duct Wrap	3"	3"	3"	None	None	None	None
Duct Board	2"	2"	2"	None	None	None	None

Notes:
1 The duct liner represented in the table has a K-value of 0.24 and a density of 1.5 lbs./ft^3.
2 The duct wrap represented in the table has a K-value of 0.29 and a density of 0.75 lbs./ft^3.
3 The duct board represented in the table has a K-value of 0.22 and a density of 3.0 lbs./ft^3.

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.

PART 36

Fire-Stopping and Through-Penetration Systems

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 an 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.

PART 37

Makeup Water

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./hr. each
2. Deaerator/feedwater unit: 4.0 GPM/1,000 lbs./hr. 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./hr.
2. Continuous blowdown (surface blowdown): 0.5 GPM/1,000 lbs./hr.

G. Blowdown Separator Drains: 10 GPM/1,000 lbs./hr. Boiler Output

H. Vacuum Type Steam Condensate Return Units: 0.1 GPM/1,000 lbs./hr. of Connected Load

I. Pumped Steam Condensate Return Units: 2.4 GPM/1,000 lbs./hr.

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./hr.
4. Spray coil humidifiers: 5.0 GPM/1,000 lbs./hr.

K. Air Conditioning Condensate

1. Unitary packaged AC equipment: 0.006 GPM/ton.
2. Air handling units (100% outside 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.

PART 38

Water Treatment and Chemical Feed Systems

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) Quartarnary ammonium salts.
            f) Organo-tin/quaternary ammonium salts.
            g) Glutaraldehyde.
            h) Dodecylguanidine.
            i) Triazine.
            j) Thiocynates.
            k) Quartarnary ammonium metalics.
        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)	E	G	G	Usable pH range 5 to 8. Effective at neutral pH (pH = 7). Less effective at high pH. Reacts with -NH_2 groups.
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				
Carbamate	E	E	G	pH range of 5 to 9. Good in high suspended solids systems. Incompatible with chromate treatment programs.
Organo-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.

(*Continued*)

Biocide	Effectiveness Against			Comments
	Bacteria	Fungi	Algae	
Glutaraldehyde	E	E	G	Effective over a broad pH range. Deactivated by -NH2 groups.
Dodecylguanidine (DGH)	E	E	G	pH range of 6 to 9.
Triazine	N	N	E	pH range of 6 to 9. Specific for algae control. Must be used with other biocides.

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.

38.02 Closed System Chemical Treatment (Chilled-Water Systems, Heating Water Systems)

A. The objective of chemical treatment 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. Nitritite-based inhibitors.

D. Water analysis should be conducted at least once a year, preferably semiannually or quarterly, depending on system water losses.

E. See Fig. 38.1 regarding the chemical treatment components used in a closed piping system.

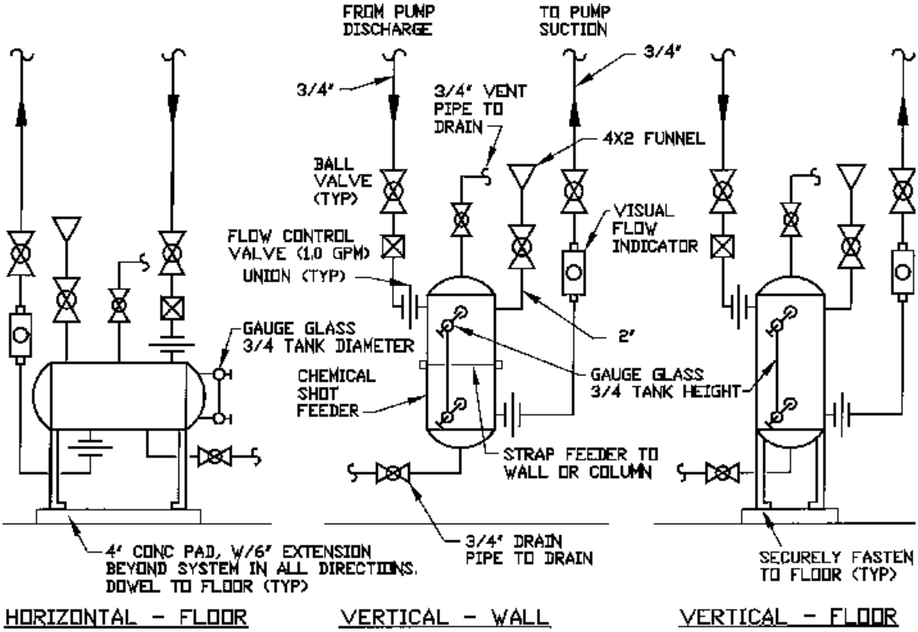


FIGURE 38.1 CLOSED SYSTEM CHEMICAL SHOT FEEDER.

38.03 Open System Chemical Treatment (Condenser Water Systems)

A. The chemical treatment objective is to prevent and control:

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. 38.2 and 38.3 for chemical treatment components used in an open piping system.

38.04 Steam Systems

A. The Chemical Treatment Objective Is to Prevent and Control...

1. Scale formation.
2. Corrosion. Major concern.
3. System pH. Between 8 and 9.

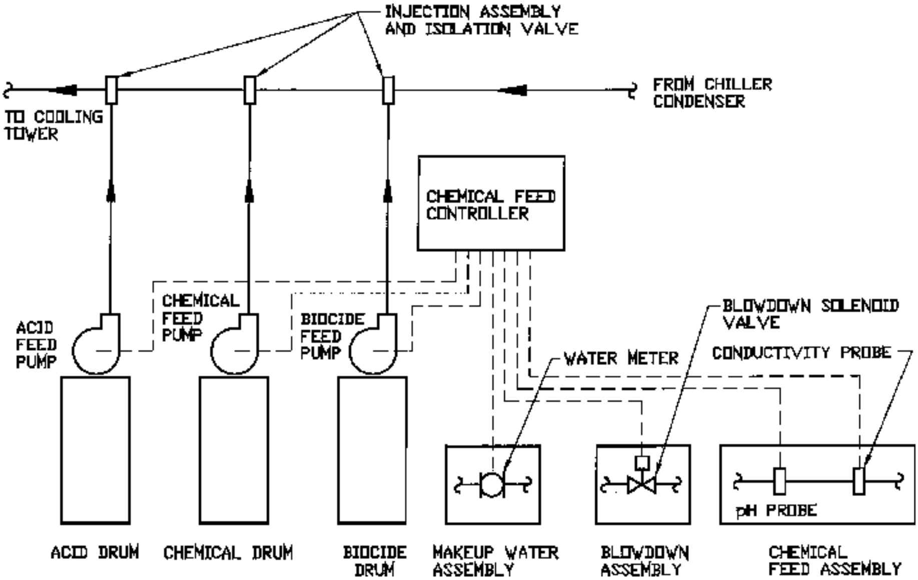


FIGURE 38.2 OPEN SYSTEM CHEMICAL TREATMENT.

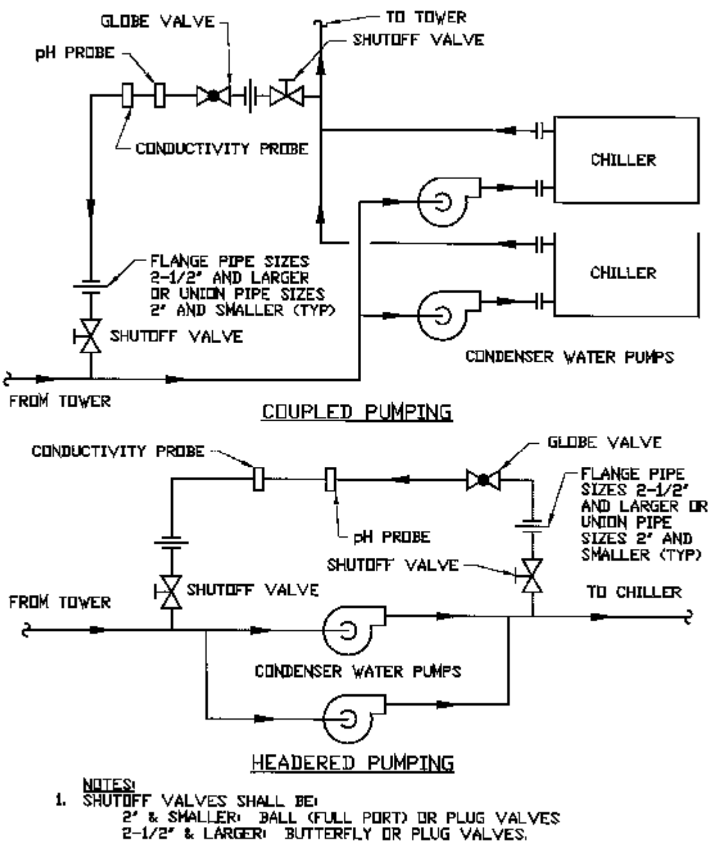


FIGURE 38.3 OPEN SYSTEM CHEMICAL FEED CONTROL ASSEMBLY.

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. 38.4 and 38.5 for steam system chemical treatment. Fig. 38.4 shows all the potential treatment equipment; however, many steam systems only require water softening.
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.

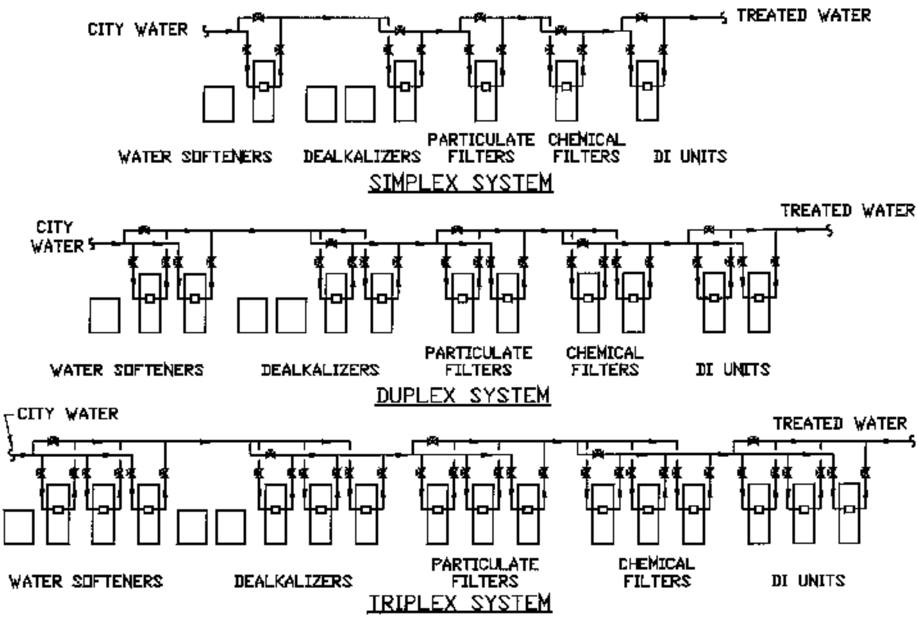


FIGURE 38.4 STEAM SYSTEM WATER TREATMENT.

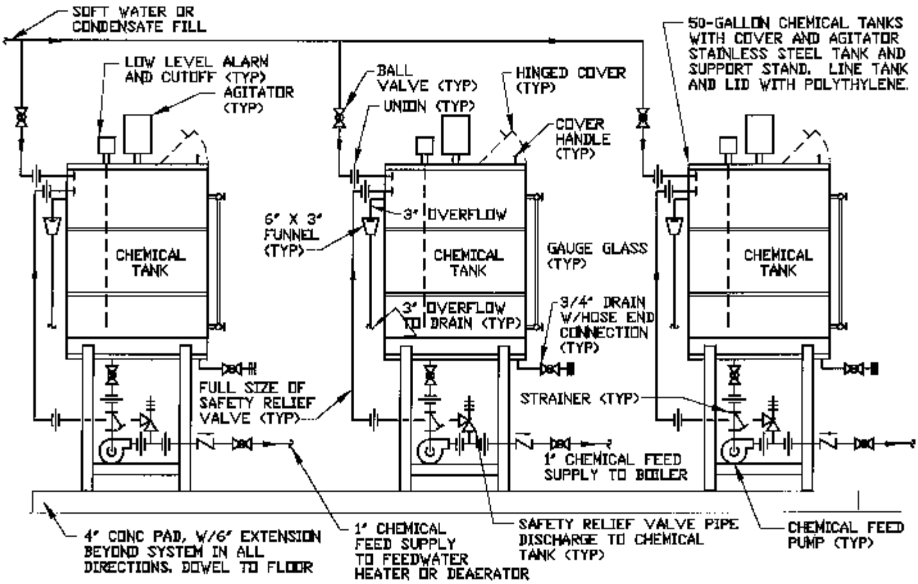


FIGURE 38.5 STEAM BOILER & FEEDWATER CHEMICAL TREATMENT SYSTEM.

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.

PART 39

Automatic Controls Building Automation Systems

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) Pager.
      4) PDA.
      5) 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 52:

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 position the device assumes when the control signal is removed (the position of the device in the box prior to installation).

XX. *Normally Open*. The position the device assumes when the control signal is removed (the position of the device 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 (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.

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.

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 Speed Drives (VFD)—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 Speed Drives (VFD)—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.

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.

39.06 Control Points List

A. Inputs:

1. Analog:
    a. Measured:
        1) Temperature.
            a) Air
            b) Water
            c) Steam
        2) Relative humidity.
        3) Dew point.
        4) Pressure.
            a) Air
            b) Water
            c) Steam
        5) Differential pressure
        6) Airflow—CFM.
        7) Water flow—GPM.
        8) Steam flow—Lb/Hr.
        9) Btu/Hr.
        10) Tons.
        11) Gas flow—CFH.
        12) Oil flow—GPH.
        13) KW.
        14) Current.
        15) Voltage.
        16) VFD speed.
        17) CO_2 concentration.
        18) CO sensor.
        19) Refrigerant sensor.
        20) Filter static.
        21) Water or liquid level
    b. Calculated:
        1) Relative humidity.
        2) Dew point.
        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/Hr.
        11) Tons

12) KWH.
13) Runtime.
14) Efficiency.
15) Volume—Gals.

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.
   i. Electric heat—Stages.

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.

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, CO_2, 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—maybe furnished and installed under another division.
   e. Control dampers—maybe furnished and installed under another division.
   f. Water flow meters—maybe furnished and installed under another division.
   g. Airflow meters—maybe furnished and installed under another division.
   h. Energy meters—maybe furnished and installed under another division.
   i. Terminal unit controls—maybe 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 maybe 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.

PART 40

Equipment Schedules

40.01 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/hr.
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_2O)
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. ÄT = Delta T, Temperature Difference, °F
36. CHWS = Chilled Water Supply 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

40.02 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

40.03 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

40.04 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

40.05 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

40.06 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/hr.
- Steam Pressure psig

Electric:
- MCA
- MOCP
- Volts-phase-hertz

Operating Weight lbs.
Manufacturers' Name and Model No.
Remarks

40.07 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

40.08 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

40.09 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

40.10 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

40.11 Boilers, Steam

Designation
Location
Service
Output # Steam/hr.
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

40.12 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/hr.
- Steam Pressure psig

Electric Coil:
- KW
- No. of Control Steps
- Volts-phase-hertz

Runouts:
- Supply
- Return

Manufacturers' Name and Model No.
Remarks

40.13 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

40.14 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/hr.
- 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

40.15 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

40.16 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

40.17 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

40.18 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

40.19 Coils, Steam

Designation
Location
Equipment Served
Service (HC, PHC, RHC)
MBH
CFM
EAT
LAT
Maximum Face Velocity FPM
APD
Steam/hr.
Steam Pressure psig
Runout Sizes
- Supply
- Return

Remarks

40.20 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

40.21 Condensate Pump and Receiver Sets

Designation
Location
Service
Type (Simplex, Duplex)
GPM
Head ft. H_2O
Motor hp
Volts-phase-hertz
Tank Capacity Gallons
Operating Weight lbs.
Manufacturers' Name and Model No.
Remarks

40.22 Convectors

Designation
Location
Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)
Capacity MBH
EAT
GPM
EWT
WPD
Steam/hr.
Steam Pressure psig
KW
No. of Control Steps
Volts-phase-hertz
Runout Size:
- Supply
- Return

Manufacturers' Name and Model No.
Remarks

40.23 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

40.24 Deaerators

Designation
Location
Service
Type
Number of Stages
Outlet Capacity lbs./hr.
Storage Capacity:
- Pounds
- Minutes

Steam:
- lbs./hr.
- psig

Size (Length × Diameter)
Operating Weight lbs.
Manufacturers' Name and Model No.
Remarks

40.25 Design Conditions—Airside

Summer:
- Outside: °F DB/°F WB
- Inside: °F DB/%RH
- Winter:
- Outside: °F DB/°F WB
- Inside: °F DB/%RH

Remarks

40.26 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

40.27 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

40.28 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

40.29 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 H_2O
- Volts-phase-hertz

Basin Heaters:
- KW
- Volts-phase-hertz

Operating Weight lbs.
Manufacturers' Name and Model No.
Remarks

40.30 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

40.31 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

40.32 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

40.33 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/hr.
  Steam Pressure
Manufacturers' Name and Model No.
Remarks

40.34 Flash Tanks

Designation
Location
Service
Type
Discharge Steam Pressure psig
Tanks Size (Diameter × Height)
Operating Weight lbs.
Manufacturers' Name and Model No.
Remarks

40.35 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 H_2O
- 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

40.36 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

40.37 Gas Pressure Regulators

Designation
Location
Capacity cu.ft./hr.
Inlet:
- psig
- Pipe Size

Outlet:
- psig
- Pipe Size

Manufacturers' Name and Model No.
Remarks

40.38 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

40.39 Heat Exchangers, Plate and Frame, Steam to Water

Designation
Location
Service
Capacity MBH
Cold Side:
- GPM
- EWT
- LWT
- WPD

Hot Side:
- # Steam/hr.
- Steam Pressure psig

Operating Weight lbs.
Manufacturers' Name and Model No.
Remarks

40.40 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

40.41 Heat Exchangers, Shell and Tube, Steam to Water (Converter)

Designation
Location
Service
Capacity MBH
Shell:
- # Steam/hr.
- 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

40.42 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

40.43 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

40.44 Heat Pumps, Water 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
- 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

40.45 Humidifiers

Designation
Location
Service
Capacity:
- # Steam/hr.
- 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

40.46 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

40.47 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/hr.
- Steam Pressure psig

Electric:
- MCA
- MOCP
- Volts-phase-hertz

Operating Weight lbs.
Remarks

40.48 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

40.49 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

40.50 Radiant Ceiling Panels

Designation
Type
Width
Average Water Temperature
Capacity Btu/hr.
WPD
Manufacturers' Name and Model No.
Remarks

40.51 Steam Pressure Reducing Valves

Designation
Location
Capacity # Steam/hr.
Inlet:
- Pressure psig
- Pipe Size

Outlet:
- Pressure psig
- Pipe Size

Manufacturers' Name and Model No.
Remarks

40.52 Steam Pressure Relief Valve

Designation
Location
Capacity # Steam/hr.
Relief Valve Setting psig
Discharge Pipe Size
Manufacturers' Name and Model No.
Remarks

40.53 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

40.54 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/hr.
- 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

40.55 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

40.56 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/hr.
- 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

40.57 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/hr.
- 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

40.58 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/hr.
- 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

40.59 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

PART 41

Equipment Manufacturers

41.01 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.

41.02 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.

41.03 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.

41.04 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.

41.05 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. ISTEC 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. ISTEC 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. ISTEC 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.

41.06 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–Class125

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.

41.07 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. Micro Industries, Inc.
2. Portable Pipe Hangers, Inc.

41.08 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.

41.09 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

41.10 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.

41.11 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, s 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.

Equipment Manufacturers

3. PABCO Metals Corporation.
4. RPR Products, Inc.

41.12 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; Worldwide Applied Systems Group
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.

41.13 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.

41.14 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; 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.

41.15 Section 231126—Facility Liquefied-Petroleum 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, 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.

41.16 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.

41.17 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; Div. 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.

41.18 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. ISTEC 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.

41.19 Section 232223—Steam Condensate Pumps

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.

41.20 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.

41.21 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.

41.22 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.

41.23 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.

41.24 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.

41.25 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.

41.26 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.

41.27 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.

41.28 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.

41.29 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.

41.30 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.

41.31 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.

41.32 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.

41.33 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.

41.34 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.

41.35 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.

41.36 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.

41.37 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.

41.38 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.

41.39 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.

41.40 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.

41.41 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.

41.42 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.

41.43 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.

41.44 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.

41.45 Section 235513—Fuel-Fired Duct Heaters

A. Lennox Industries, Inc.

B. Modine Manufacturing Company.

C. Reznor/Thomas & Betts Corporation.

D. Sterling HVAC Products; Div. of Mestek Technology Inc.

41.46 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.

41.47 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.

41.48 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.

41.49 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 Co. (The); Worldwide Applied Systems Group.
6. York International Corp.

B. Condensing Units, Water Cooled

1. Carrier Corporation; Carrier Air Conditioning Div.
2. McQuay International.
3. Trane Co. (The); Worldwide Applied Systems Group.
4. York International Corp.

41.50 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 Co. (The); Worldwide Applied Systems Group.

F. York International Corp.

41.51 Section 236333—Evaporative Refrigerant Condensers

A. Baltimore Aircoil Company.

B. Recold.

41.52 Section 236413.13—Direct-Fired Absorption Water Chillers

A. Broad Corporation.

B. Carrier; a United Technologies Company.

C. Hitachi International.

D. Trane Company (The).

E. YORK International Corporation.

41.53 Section 236413.16—Indirect-Fired Absorption Water Chillers

A. Carrier Corporation; a United Technologies company.

B. Trane, a division of American Standard.

C. YORK, a Johnson Controls company.

41.54 Section 236416—Centrifugal Water Chillers

A. Carrier Corporation; Carrier Air Conditioning Div.

B. McQuay International.

C. Trane Co. (The); Worldwide Applied Systems Group.

D. York International Corp.

41.55 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 Co. (The); Worldwide Applied Systems Group.
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 Co. (The); Worldwide Applied Systems Group.
6. York International Corp.

41.56 Section 236423—Scroll Water Chillers

A. Packaged Water-Cooled Water Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. McQuay International.

3. Trane Co. (The); Worldwide Applied Systems Group.
4. York International Corp.

B. Packaged Air-Cooled Water Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. McQuay International.
3. Trane Co. (The); Worldwide Applied Systems Group.
4. York International Corp.

41.57 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 Co. (The); Worldwide Applied Systems Group.
4. York International Corp.

B. Packaged, Water-Cooled, Multiple-Compressor Chillers

1. Carrier Corporation; Carrier Air Conditioning Div.
2. Dunham-Bush, Inc.
3. Trane Co. (The); Worldwide Applied Systems Group.
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 Co. (The); Worldwide Applied Systems Group.
5. York International Corp.

41.58 Section 236427—Medical, Laboratory, and Process Chillers

A. ArtiChill, Inc.

B. Filtrine Manufacturing Company.

C. Liebert Corporation.

41.59 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.

41.60 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; American Standard, Inc.

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; American Standard, Inc.
13. Wing, L. J.; Mestek Technology, Inc.

41.61 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; American Standard, Inc.

H. YORK International Corporation.

41.62 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; American Standard, Inc.

L. YORK International Corporation.

41.63 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 Company; Unitary Products Group.

O. Weather-Rite, Inc.

41.64 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, Div. 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 Company (The); Unitary Products Group.

P. Weather-Rite, Inc.

41.65 Section 237413—Packaged, Outdoor, Central-Station Air-Handling Units

A. AAON, Inc.

B. Carrier Corporation.

C. Engineered Air.

D. McQuay International.

E. Trane; American Standard Companies, Inc.

F. YORK International Corporation.

41.66 Section 237414—Custom Outdoor 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; American Standard, Inc.

L. YORK International Corporation.

41.67 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.

41.68 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, a business of American Standard Companies.

41.69 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 Company, North American Commercial Group.

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 Co.; North American Commercial Group.

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 Co.; North American Commercial Group.

D. Integral Air-Cooled, Self-Contained Air-Conditioners (15 Tons and Smaller)

1. McQuay International.
2. Trane Co.; North American Commercial Group.

E. Integral Air-Cooled, Wall-Mount Self-Contained Air-Conditioners (15 Tons and Smaller)

1. Bard Manufacturing Co.
2. Stulz Air Technology Systems, Inc.

41.70 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.

41.71 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 Company (The); Unitary Products Group.

K. York International Corp.

41.72 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.

41.73 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.

41.74 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.

41.75 Section 238219—Fan Coil Units

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.**

41.76 Section 238223—Unit Ventilators

A. **Carrier Corporation.**

B. **Engineered Air Ltd.**

C. **McQuay International.**

D. **Nesbitt Aire, Inc.; PEF Industries, Inc.**

E. **Trane.**

41.77 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 div. 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.

41.78 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.

41.79 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.

41.80 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.

41.81 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.

41.82 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.

41.83 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.

41.84 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.

41.85 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.

41.86 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.

41.87 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.

PART 42

Building Construction Business Fundamentals

42.01 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.

42.02 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 provided 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.

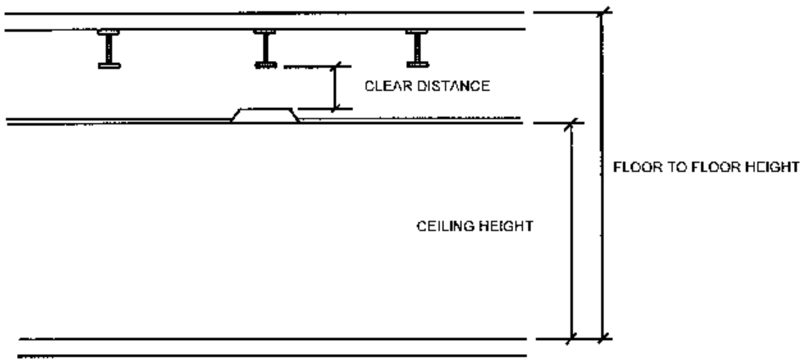
L. Contractors

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 sub 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 sub some or all of the work to other contractors (plumbing, sheet metal, fire protection, automatic 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 sub 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 the subcontractor to perform a particular portion of the subcontractor's work.

PART 43

Architectural, Structural, and Electrical Information

43.01 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"	36"
9'0"	7'0"	*	*	*	*	*	*	*	*	*	*
	7'6"	*	*	*	*	*	*	*	*	*	*
	8'0"	*	*	*	*	*	*	*	*	*	*
	8'6"	*	*	*	*	*	*	*	*	*	*
	9'0"	*	*	*	*	*	*	*	*	*	*
10'0"	7"0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
	7'6"	4.5	2.5	*	*	*	*	*	*	*	*
	8'0"	*	*	*	*	*	*	*	*	*	*
	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	10.5
	8'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	4.5
	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	22.5
	8'6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5	16.5
	9'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	10.5
	9'6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	4.5
	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	*	*	*	*	*	*	*

(*Continued*)

CEILING PLENUM SPACE (*Continued*)

Clear Distance—Light to Beam in Inches											
Floor to Floor	Ceiling Height	Beam Depth									
		12"	14"	16"	18"	21"	24"	27"	30"	33"	36"
15'0"	8'0"	58.5	56.5	54.5	52.5	49.5	46.5	43.5	40.5	37.5	34.5
	8'6"	52.5	50.5	48.5	46.5	43.5	40.5	37.5	34.5	31.5	28.5
	9'0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5	22.5
	9'6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5	16.5
	10'0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	10.5
	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	1.5	*	*	*	*	*
20'0"	9'0"	106	104	102	100	97.5	94.5	91.5	88.5	85.5	82.5
	9'6"	100	98.5	96.5	94.5	91.5	88.5	85.5	82.5	79.5	76.5
	10'0"	94.5	92.5	90.5	88.5	85.5	62.5	79.5	76.5	73.5	70.5
	10'6"	88.5	86.5	84.5	82.5	79.5	76.5	73.5	70.5	67.5	64.5
	11'0"	82.5	80.5	78.5	76.5	73.5	70.5	67.5	64.5	61.5	58.5
	11'6"	76.5	74.5	72.5	70.5	67.5	64.5	61.5	58.5	55.5	52.5
	12'0"	70.5	68.5	66.5	64.5	61.5	58.5	55.5	52.5	49.5	46.5

Notes:

1 Assumptions: 2" fire proofing on beam, 6" fluorescent light depth, 5-1/2" floor slab thickness, 2" suspended ceiling thickness.
2 For depth from beam to ceiling, add 4" to the preceding figures.
3 For depth from underside of the slab to light, add depth of beam plus 2".
4 * Indicates a beam protruding through the ceiling.

43.02 Building Structural Systems

A. Standard Nominal Structural Steel Depths

1. W-Shapes (Wide Flange Beams): 4, 5, 6, 8, 10, 12, 14, 16, 18, 21, 24, 27, 30, 33, 36, 40, 44.
2. S-Shapes (I beams): 3, 4, 5, 6, 7, 8, 10, 12, 15, 18, 20, 24.
3. C-Shapes (Channels): 3, 4, 5, 6, 7, 8, 9, 10, 12, 15.

B. Standard Nominal Joist Depths as Manufactured by Vulcraft

1. K-Series: 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30.
2. 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 Girders	
	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. (3,5)
20 ft.	10"	14"	16"	24"	12"	14"	18"	28"
30 ft.	16"	18"	21"	33"	16"	24"	20"	40"
40 ft.	21"	24"	24"	36"	20"	24"	24"	52"
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 = ± 5'0".
5 Assumed Spacing = ± 30'0".
6 Assumed Spacing = ± 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 are approximately 1/2 the length of the span.
11 Rule of Thumb: Girder and joist girder depths are approximately 3/4 the length of the span.

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.

43.03 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 information is needed by the Structural Engineer. Obtain weights and sizes from the manufacturer's catalogs or the manufacturer's representative. 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 Appendix A 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. See the Appendix for pipe weight information.

STRUCTURAL LIST

PROJECT STRUCTURAL LIST

PROJECT NAME: ____

SHEET NO. ____________ OF____________ PROJECT NO.____________

SUBMITTAL	BY	DATE	ITEM #s
PRELIMINARY	____________	____________	____________
FIRST	____________	____________	____________
SECOND	____________	____________	____________
THIRD	____________	____________	____________
FINAL	____________	____________	____________

ITEM NO.	ITEM DESIGNATION	LOCATION	SIZE			WEIGHT LBS.	ROOF/FLOOR OPENINGS		SPECIAL REMARKS
			LENGTH	WIDTH	HEIGHT		LENGTH	WIDTH	

43.04 Electrical Information

A. Provide electrical information for all mechanical equipment requiring electrical power to the electrical engineer. Electrical information should include the following information at minimum.

1. Item designation.
2. Location.
3. Voltage-phase-hertz.
4. Horsepower, full load amps, locked rotor amps, KW, minimum circuit amps: provide 1 or more.
5. Is equipment to be on emergency power?
6. Who provides the starter? Who provides the disconnect switch?
7. Control type, hand-off-automatic (HOA), manual, two-speed, etc.
8. Special requirements?

ELECTRICAL LIST

PROJECT ELECTRICAL LIST

PROJECT NAME: ______________________________

SHEET NO. __________ OF __________ PROJECT NO. __________

SUBMITTAL	BY	DATE	ITEM #s
PRELIMINARY	__________	__________	__________
FIRST	__________	__________	__________
SECOND	__________	__________	__________
THIRD	__________	__________	__________
FINAL	__________	__________	__________

ITEM NO.	ITEM DESIGNATION	LOCATION	VOLTAGE/ PHASE	HP OR FLA	EMERG. POWER	STARTER BY	DISC. SW. BY	CONTROL TYPE	SPECIAL REQUIREMENTS

43.05 Mechanical/Electrical Equipment Space Requirements

A. Commercial Buildings

1. 1.8–20% 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 boiler 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 or width of the tubes or 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 1000 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.

43.06 Americans with Disabilities Act (ADA)

A. ADA Titles

1. Title I—Equal Employment Opportunity.
2. Title II—State and Local Governments.
3. Title III—New and Existing Public Accommodations and New Commercial Facilities.
4. Title IV—Telecommunications.
5. Title V—Miscellaneous Provisions.

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, and 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.

PART 44

Properties of Air

44.01 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.H_2O/lbs.DA or Gr.H_2O/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.H_2O. 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. Dew point 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/hr. Symbol: H_S.
9. Latent heat: Heat that causes a change in state (e.g., liquid water to gaseous water). Units: Btu/hr. Symbol: H_L.
10. Total heat: Sum of sensible heat and latent heat. Units: Btu/hr. 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 tables

Temperature Range °F	Specific Heat Btu/lbs °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

THERMODYNAMIC PROPERTIES OF MOIST AIR @14.696 PSIA

Temp °F	Humidity Ratio		Specific Volume ft.^{3}/lbs. DA			Enthalpy Btu/lbs. DA		
	Grains/ lbs. DA	Pounds/ lbs. DA	N_a	N_{as}	N_s	h_a	h_{as}	h_s
–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

(*Continued*)

THERMODYNAMIC PROPERTIES OF MOIST AIR @ 14.696 PSIA (*Continued*)

Temp °F	Humidity Ratio		Specific Volume ft.^{3}/lbs. DA			Enthalpy Btu/lbs. DA		
	Grains/ lbs. DA	Pounds/ lbs. DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
–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

(*Continued*)

THERMODYNAMIC PROPERTIES OF MOIST AIR @ 14.696 PSIA (*Continued*)

Temp °F	Humidity Ratio		Specific Volume ft.^{3}/lbs. DA			Enthalpy Btu/lbs. DA		
	Grains/ lbs. DA	Pounds/ lbs. DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
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	27.6290	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

(*Continued*)

THERMODYNAMIC PROPERTIES OF MOIST AIR @ 14.696 PSIA (*Continued*)

Temp °F	Humidity Ratio		Specific Volume ft.^{3}/lbs. DA			Enthalpy Btu/lbs. DA		
	Grains/ lbs. DA	Pounds/ lbs. DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
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

(*Continued*)

THERMODYNAMIC PROPERTIES OF MOIST AIR @ 14.696 PSIAE (*Continued*)

Temp °F	Humidity Ratio		Specific Volume ft.^{3}/lbs. DA			Enthalpy Btu/lbs. DA		
	Grains/ lbs. DA	Pounds/ lbs. DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
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

44.02 Barometric Properties of Air

BAROMETRIC PRESSURES AT VARIOUS ALTITUDES AT 70°F

Altitude Feet	Barometer (Absolute Pressure)				Relative Density
	in. Hg.	psi	ft. H_2O	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
–1000	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	32.16	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

44.03 Properties of Air—Affects on Standard HVAC Air Equations

AIR EQUATION CONSTANTS FOR ALTITUDE

Altitude Feet	Sensible Heat (1)	Latent Heat		Total Heat (4)
		Gr.H_2O (2)	lbs.H_2O (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	3340	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

(*Continued*)

AIR EQUATION CONSTANTS FOR ALTITUDE (*Continued*)

Altitude Feet	Sensible Heat (1)	Latent Heat Gr.H_2O (2)	Latent Heat lbs.H_2O (3)	Total Heat (4)
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/hr. CFM °F.
2 Equation Constants Units: Btu lbs. DA/hr. Gr.H_2O CFM.
3 Equation Constants Units: Btu lbs. DA/hr. lbs.H_2O CFM.
4 Equation Constants Units: lbs.DA/hr. CFM.
5 Use table values in lieu of constants in equations in Part 3.

AIR EQUATION CONSTANTS FOR TEMPERATURE

Temperature °F	Sensible Heat (1)	Latent Heat Gr.H_2O (2)	Latent Heat lbs.H_2O (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/hr. CFM °F.
2 Equation Constants Units: Btu lbs.DA/hr. Gr.H_2O CFM.
3 Equation Constants Units: Btu lbs.DA/hr. lbs.H_2O CFM.
4 Equation Constants Units: lbs.DA/hr. 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

Notes:

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

Notes:

1 **Multiply constants in equations in PART 3 EQUATIONS by values in the table.**

AIR EQUATION FACTORS FOR DENSITY

Altitude Feet	Temperature °F						
	600	650	700	750	800	900	1000
60,000	0.04	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
40,000	0.09	0.09	0.09	0.08	0.08	0.07	0.07
30,000	0.15	0.14	0.14	0.13	0.12	0.12	0.11
20,000	0.23	0.22	0.21	0.20	0.19	0.18	0.17
15,000	0.28	0.27	0.26	0.25	0.24	0.22	0.20
10,000	0.34	0.33	0.32	0.31	0.29	0.27	0.25
9,000	0.35	0.34	0.33	0.32	0.30	0.28	0.26
8,000	0.37	0.36	0.34	0.33	0.31	0.29	0.27
7,000	0.39	0.37	0.35	0.33	0.32	0.30	0.28
6,000	0.40	0.38	0.37	0.35	0.33	0.31	0.29
5,000	0.41	0.40	0.38	0.37	0.35	0.32	0.30
4,000	0.43	0.41	0.39	0.38	0.36	0.33	0.31
3,500	0.44	0.42	0.40	0.39	0.37	0.34	0.32
3,000	0.45	0.43	0.41	0.39	0.37	0.35	0.32
2,500	0.46	0.44	0.42	0.40	0.38	0.36	0.33
2,000	0.46	0.45	0.43	0.41	0.39	0.36	0.33
1,500	0.47	0.46	0.44	0.42	0.40	0.37	0.34
1,000	0.48	0.46	0.44	0.42	0.40	0.37	0.35
500	0.49	0.47	0.45	0.43	0.41	0.38	0.36
Sea Level	0.50	0.48	0.46	0.44	0.42	0.39	0.36
–500	0.51	0.49	0.47	0.45	0.43	0.40	0.37
–1,000	0.52	0.50	0.48	0.46	0.44	0.41	0.38
–2,000	0.54	0.52	0.49	0.47	0.45	0.42	0.39
–3,000	0.56	0.53	0.51	0.49	0.47	0.43	0.40
–4,000	0.58	0.55	0.53	0.51	0.48	0.45	0.42
–5,000	0.60	0.57	0.55	0.55	0.50	0.47	0.43

Notes:
1 Multiply constants in equations in Part 3 by values in the table.

44.04 Physical Properties of Gases—Comparison with Air

PHYSICAL PROPERTIES OF GASES

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lbs.m	Density lbs.m/cu.ft.	Specific Gravity
Gases						
Air	---	28.996	Gas	13.333	0.075	1.000
Carbon	C	12.01	Solid	---	---	---
Hydrogen	H_2	2.016	Gas	187.723	0.005	0.067
Ammonia	Nh_3	17.031	Gas	21.914	0.046	0.613
Sulfur	S	32.06	Gas	7.407	0.135	1.800
Hydrogen Sulfide	H_2s	34.076	Gas	10.979	0.091	1.213
Nitrous Oxide	N_2o	44.013	Gas	8.772	0.114	1.520
Ozone	O_3	48.0	Gas	8.032	0.125	1.660
Argon	Ar	39.948	Gas	9.662	0.104	1.380
Chlorine	Cl_2	70.906	Gas	5.442	0.184	2.450
Helium	He	4.002	Gas	96.618	0.010	0.138
Neon	Ne	20.179	Gas	19.130	0.052	0.697

(*Continued*)

PHYSICAL PROPERTIES OF GASES (*Continued*)

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lbs.m	Density lbs.m/cu.ft.	Specific Gravity
Products of Combustion—Complete						
Carbon Dioxide	Co_2	44.01	Gas	8.548	0.117	1.560
Water Vapor	H_2o	18.016	Gas	21.017	0.048	0.640
Oxygen	O_2	32.000	Gas	11.819	0.085	1.133
Nitrogen	N_2	28.016	Gas	13.443	0.074	0.987
Products of Combustion—Incomplete						
Carbon Monoxide	Co	28.01	Gas	13.699	0.073	0.967
Nitric Oxide	No	30.006	Gas	12.821	0.078	1.040
Nitrogen Dioxide	No_2	46.006	Gas	---	---	---
Nitrous Trioxide	No_3	62.005	Gas	---	---	---
Nox	No_x	---	Gas	---	---	---
Sulfuric Oxide	So	48.063	Gas	---	---	---
Sulfur Dioxide	So_2	64.06	Gas	5.770	0.173	2.307
Sulfur Trioxide	So_3	80.062	Gas	---	---	---
Sox	So_x	---	Gas	---	---	---

PART 45

Properties of Water

45.01 Thermodynamic Properties of Water

BOILING POINTS OF WATER

Psia	Boiling Point ºF	Psia	Boiling Point ºF	Psia	Boiling Point ºF
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	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	254.1	98	326.4	825	521.9
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

THERMODYNAMIC PROPERTIES OF WATER

Temp ºF	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
–80	0.000116	0.01732	1953234	1953234	–193.50	1219.19	1025.69
–79	0.000125	0.01732	1814052	1814052	–193.11	1219.24	1026.13
–78	0.000135	0.01732	1685445	1685445	–192.71	1219.28	1026.57
–77	0.000145	0.01732	1566663	1566663	–192.31	1219.33	1027.02
–76	0.000157	0.01732	1456752	1456752	–191.92	1219.38	1027.46
–75	0.000169	0.01733	1355059	1355059	–191.52	1219.42	1027.90
–74	0.000182	0.01733	1260977	1260977	–191.12	1219.47	1028.34
–73	0.000196	0.01733	1173848	1173848	–190.72	1219.51	1028.79
–72	0.000211	0.01733	1093149	1093149	–190.32	1219.55	1029.23
–71	0.000227	0.01733	1018381	1018381	–189.92	1219.59	1029.67
–70	0.000245	0.01733	949067	949067	–189.52	1219.63	1030.11
–69	0.000263	0.01733	884803	884803	–189.11	1219.67	1030.55
–68	0.000283	0.01733	825187	825187	–188.71	1219.71	1031.00
–67	0.000304	0.01734	769864	769864	–188.30	1219.74	1031.44
–66	0.000326	0.01734	718508	718508	–187.90	1219.78	1031.88

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
–65	0.000350	0.01734	670800	670800	–187.49	1219.82	1032.32
–64	0.000376	0.01734	626503	626503	–187.08	1219.85	1032.77
–63	0.000404	0.01734	585316	585316	–186.67	1219.88	1033.21
–62	0.000433	0.01734	548041	548041	–186.26	1219.91	1033.65
–61	0.000464	0.01734	511446	511446	–185.85	1219.95	1034.09
–60	0.000498	0.01734	478317	478317	–185.44	1219.98	1034.54
–59	0.000533	0.01735	447495	447495	–185.03	1220.01	1034.98
–58	0.000571	0.01735	418803	418803	–184.61	1220.03	1035.42
–57	0.000612	0.01735	392068	392068	–184.20	1220.06	1035.86
–56	0.000655	0.01735	367172	367172	–183.78	1220.09	1036.30
–55	0.000701	0.01735	343970	343970	–183.37	1220.11	1036.75
–54	0.000750	0.01735	322336	322336	–182.95	1220.14	1037.19
–53	0.000802	0.01735	302157	302157	–182.53	1220.16	1037.63
–52	0.000857	0.01735	283335	283335	–182.11	1220.18	1038.07
–51	0.000916	0.01736	265773	265773	–181.69	1220.21	1038.52
–50	0.000979	0.01736	249381	249381	–181.27	1220.23	1038.96
–49	0.001045	0.01736	234067	234067	–180.85	1220.25	1039.40
–48	0.001116	0.01736	219766	219766	–180.42	1220.26	1039.84
–47	0.001191	0.01736	206398	206398	–181.00	1220.28	1040.28
–46	0.001271	0.01736	193909	193909	–179.57	1220.30	1040.73
–45	0.001355	0.01736	182231	182231	–179.14	1220.31	1041.17
–44	0.001445	0.01736	171304	171304	–178.72	1220.33	1041.61
–43	0.001541	0.01737	161084	161084	–178.29	1220.34	1042.05
–42	0.001642	0.01737	151518	151518	–177.86	1220.36	1042.50
–41	0.001749	0.01737	142566	142566	–177.43	1220.37	1042.94
–40	0.001863	0.01737	134176	134176	–177.00	1220.38	1043.38
–39	0.001984	0.01737	126322	126322	–176.57	1220.39	1043.82
–38	0.002111	0.01737	118959	118959	–176.13	1220.40	1044.27
–37	0.002247	0.01737	112058	112058	–175.70	1220.40	1044.71
–36	0.002390	0.01738	105592	105592	–175.26	1220.41	1045.15
–35	0.002542	0.01738	99522	99522	–174.83	1220.42	1045.59
–34	0.002702	0.01738	93828	93828	–174.39	1220.42	1046.03
–33	0.002872	0.01738	88489	88489	–173.95	1220.43	1046.48
–32	0.003052	0.01738	83474	83474	–173.51	1220.43	1046.92
–31	0.003242	0.01738	78763	78763	–173.07	1220.43	1047.36
–30	0.003443	0.01738	74341	74341	–172.63	1220.43	1047.80
–29	0.003655	0.01738	70187	70187	–172.19	1220.43	1048.25
–28	0.003879	0.01739	66282	66282	–171.74	1220.43	1048.69
–27	0.004116	0.01739	62613	62613	–171.30	1220.43	1049.13
–26	0.004366	0.01739	59161	59161	–170.86	1220.43	1049.57
–25	0.004630	0.01739	55915	55915	–170.41	1220.42	1050.01
–24	0.004909	0.01739	52861	52861	–169.96	1220.42	1050.46
–23	0.005203	0.01739	49986	49986	–169.51	1220.41	1050.90
–22	0.005514	0.01739	47281	47281	–169.07	1220.41	1051.34
–21	0.005841	0.01740	44733	44733	–168.62	1220.40	1051.78
–20	0.006186	0.01740	42333	42333	–168.16	1220.39	1052.22
–19	0.006550	0.01740	40073	40073	–167.71	1220.38	1052.67
–18	0.006933	0.01740	37943	37943	–167.26	1220.37	1053.11
–17	0.007337	0.01740	35934	35934	–166.81	1220.36	1053.55
–16	0.007763	0.01740	34041	34041	–166.35	1220.34	1053.99
–15	0.008211	0.01740	32256	32256	–165.90	1220.33	1054.43
–14	0.008683	0.01741	30572	30572	–165.44	1220.31	1054.87
–13	0.009179	0.01741	28983	28983	–164.98	1220.30	1055.32
–12	0.009702	0.01741	27483	27483	–164.52	1220.28	1055.76
–11	0.010252	0.01741	26067	26067	–164.06	1220.26	1056.20
–10	0.010830	0.01741	24730	24730	–163.60	1220.24	1056.64
–9	0.011438	0.01741	23467	23467	–163.14	1220.22	1057.08
–8	0.012077	0.01741	22274	22274	–162.68	1220.20	1057.53
–7	0.012749	0.01742	21147	21147	–162.21	1220.18	1057.97
–6	0.013456	0.01742	20081	20081	–162.75	1220.16	1058.41

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
–5	0.014197	0.01742	19074	19074	–161.28	1220.13	1058.85
–4	0.014977	0.01742	18121	18121	–160.82	1220.11	1059.29
–3	0.015795	0.01742	17220	17220	–160.35	1220.08	1059.73
–2	0.016654	0.01742	16367	16367	–159.88	1220.05	1060.17
–1	0.017556	0.01742	15561	15561	–159.41	1220.02	1060.62
0	0.018502	0.01743	14797	14797	–158.94	1220.00	1061.06
1	0.019495	0.01743	14073	14073	–158.47	1219.96	1061.50
2	0.020537	0.01743	13388	13388	–157.99	1219.93	1061.94
3	0.021629	0.01743	12740	12740	–157.52	1219.90	1062.38
4	0.022774	0.01743	12125	12125	–157.05	1219.87	1062.82
5	0.023975	0.01743	11543	11543	–156.57	1219.83	1063.26
6	0.025233	0.01743	10991	10991	–156.09	1219.80	1063.70
7	0.026552	0.01744	10468	10468	–155.62	1219.76	1064.14
8	0.027933	0.01744	9971	9971	–155.14	1219.72	1064.58
9	0.029379	0.01744	9500	9500	–154.66	1219.68	1065.03
10	0.030894	0.01744	9054	9054	–154.18	1219.64	1065.47
11	0.032480	0.01744	8630	8630	–153.70	1219.60	1065.91
12	0.034140	0.01744	8228	8228	–153.21	1219.56	1066.35
13	0.035878	0.01745	7846	7846	–152.73	1219.52	1066.79
14	0.037696	0.01745	7483	7483	–152.24	1219.47	1067.23
15	0.039597	0.01745	7139	7139	–151.76	1219.43	1067.67
16	0.041586	0.01745	6811	6811	–151.27	1219.38	1068.11
17	0.043666	0.01745	6501	6501	–150.78	1219.33	1068.55
18	0.045841	0.01745	6205	6205	–150.30	1219.28	1068.99
19	0.048113	0.01745	5924	5924	–149.81	1219.23	1069.43
20	0.050489	0.01746	5657	5657	–149.32	1219.18	1069.87
21	0.052970	0.01746	5404	5404	–148.82	1219.13	1070.31
22	0.055563	0.01746	5162	5162	–148.33	1219.08	1070.75
23	0.058271	0.01746	4932	4932	–147.84	1219.02	1071.19
24	0.061099	0.01746	4714	4714	–147.34	1218.97	1071.63
25	0.064051	0.01746	4506	4506	–146.85	1218.91	1072.07
26	0.067133	0.01747	4308	4308	–146.35	1218.85	1072.50
27	0.070349	0.01747	4119	4119	–145.85	1218.80	1072.94
28	0.073706	0.01747	3940	3940	–145.35	1218.74	1073.38
29	0.077207	0.01747	3769	3769	–144.85	1218.68	1073.82
30	0.080860	0.01747	3606	3606	–144.35	1218.61	1074.26
31	0.084669	0.01747	3450	3450	–143.85	1218.55	1074.70
32	0.08865	0.01602	3302.07	3302.09	–0.02	1075.15	1075.14
33	0.09229	0.01602	3178.15	3178.16	0.99	1074.59	1075.58
34	0.09607	0.01602	3059.47	3059.49	2.00	1074.02	1076.01
35	0.09998	0.01602	2945.66	2945.68	3.00	1073.45	1076.45
36	0.10403	0.01602	2836.60	2836.61	4.01	1072.88	1076.89
37	0.10822	0.01602	2732.13	2732.15	5.02	1072.32	1077.33
38	0.11257	0.01602	2631.88	2631.89	6.02	1071.75	1077.77
39	0.11707	0.01602	2535.86	2535.88	7.03	1071.18	1078.21
40	0.12172	0.01602	2443.67	2443.69	8.03	1070.62	1078.65
41	0.12654	0.01602	2355.22	2355.24	9.04	1070.05	1079.09
42	0.13153	0.01602	2270.42	2270.43	10.04	1069.48	1079.52
43	0.13669	0.01602	2189.02	2189.04	11.04	1068.92	1079.96
44	0.14203	0.01602	2110.92	2110.94	12.05	1068.35	1080.40
45	0.14755	0.01602	2035.91	2035.92	13.05	1067.79	1080.84
46	0.15326	0.01602	1963.85	1963.87	14.05	1067.22	1081.28
47	0.15917	0.01602	1894.71	1894.73	15.06	1066.66	1081.71
48	0.16527	0.01602	1828.28	1828.30	16.06	1066.09	1082.15
49	0.17158	0.01602	1764.44	1764.46	17.06	1065.53	1082.59
50	0.17811	0.01602	1703.18	1703.20	18.06	1064.96	1083.03
51	0.18484	0.01602	1644.25	1644.26	19.06	1064.40	1083.46
52	0.19181	0.01603	1587.64	1587.65	20.07	1063.83	1083.90
53	0.19900	0.01603	1533.22	1533.24	21.07	1063.27	1084.34
54	0.20643	0.01603	1480.89	1480.91	22.07	1062.71	1084.77

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.³/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
55	0.21410	0.01603	1430.61	1430.62	23.07	1062.14	1085.21
56	0.22202	0.01603	1382.19	1382.21	24.07	1061.58	1085.65
57	0.23020	0.01603	1335.65	1335.67	25.07	1061.01	1086.08
58	0.23864	0.01603	1290.85	1290.87	26.07	1060.45	1086.52
59	0.24735	0.01603	1247.76	1247.78	27.07	1059.89	1086.96
60	0.25635	0.01604	1206.30	1206.32	28.07	1059.32	1087.39
61	0.26562	0.01604	1166.38	1166.40	29.07	1058.76	1087.83
62	0.27519	0.01604	1127.93	1127.95	30.07	1058.19	1088.27
63	0.28506	0.01604	1090.94	1090.96	31.07	1057.63	1088.70
64	0.29524	0.01604	1055.32	1055.33	32.07	1057.07	1089.14
65	0.30574	0.01604	1020.98	1021.00	33.07	1056.50	1089.57
66	0.31656	0.01604	987.95	987.97	34.07	1055.94	1090.01
67	0.32772	0.01605	956.11	956.12	35.07	1055.37	1090.44
68	0.33921	0.01605	925.44	925.45	36.07	1054.81	1090.88
69	0.35107	0.01605	895.86	895.87	37.07	1054.24	1091.31
70	0.36328	0.01605	867.34	867.36	38.07	1053.68	1091.75
71	0.37586	0.01605	839.87	839.88	39.07	1053.11	1092.18
72	0.38882	0.01606	813.37	813.39	40.07	1052.55	1092.61
73	0.40217	0.01606	787.85	787.87	41.07	1051.98	1093.05
74	0.41592	0.01606	763.19	763.21	42.06	1051.42	1093.48
75	0.43008	0.01606	739.42	739.44	43.06	1050.85	1093.92
76	0.44465	0.01606	716.51	716.53	44.06	1050.29	1094.35
77	0.45966	0.01607	694.38	694.40	45.06	1049.72	1094.78
78	0.47510	0.01607	673.05	673.06	46.06	1049.16	1095.22
79	0.49100	0.01607	652.44	652.46	47.06	1048.59	1095.65
80	0.50736	0.01607	632.54	632.56	48.06	1048.03	1096.08
81	0.52419	0.01608	613.35	613.37	49.06	1047.46	1096.51
82	0.54150	0.01608	594.82	594.84	50.05	1046.89	1096.95
83	0.55931	0.01608	576.90	576.92	51.05	1046.33	1097.38
84	0.57763	0.01608	559.63	559.65	52.05	1045.76	1097.81
85	0.59647	0.01609	542.93	542.94	53.05	1045.19	1098.24
86	0.61584	0.01609	526.80	526.81	54.05	1044.63	1098.67
87	0.63575	0.01609	511.21	511.22	55.05	1044.06	1099.11
88	0.65622	0.01609	496.14	496.15	56.05	1043.49	1099.54
89	0.67726	0.01610	481.60	481.61	57.04	1042.92	1099.97
90	0.69889	0.01610	467.52	467.53	58.04	1042.36	1100.40
91	0.72111	0.01610	453.91	453.93	59.04	1041.79	1100.83
92	0.74394	0.01611	440.76	440.78	60.04	1041.22	1101.26
93	0.76740	0.01611	428.04	428.06	61.04	1040.65	1101.69
94	0.79150	0.01611	415.74	415.76	62.04	1040.08	1102.12
95	0.81625	0.01612	403.84	403.86	63.03	1039.51	1102.55
96	0.84166	0.01612	392.33	392.34	64.03	1038.95	1102.98
97	0.86776	0.01612	381.20	381.21	65.03	1038.38	1103.41
98	0.89456	0.01612	370.42	370.44	66.03	1037.81	1103.84
99	0.92207	0.01613	359.99	360.01	67.03	1037.24	1104.26
100	0.95031	0.01613	349.91	349.92	68.03	1036.67	1104.69
101	0.97930	0.01613	340.14	340.15	69.03	1036.10	1105.12
102	1.00904	0.01614	330.69	330.71	70.02	1035.53	1105.55
103	1.03956	0.01614	321.53	321.55	71.02	1034.95	1105.98
104	1.07088	0.01614	312.67	312.69	72.02	1034.38	1106.40
105	1.10301	0.01615	304.08	304.10	73.02	1033.81	1106.83
106	1.13597	0.01615	295.76	295.77	74.02	1033.24	1107.26
107	1.16977	0.01616	287.71	287.73	75.01	1032.67	1107.68
108	1.20444	0.01616	279.91	279.92	76.01	1032.10	1108.11
109	1.23999	0.01616	272.34	272.36	77.01	1031.52	1108.54
110	1.27644	0.01617	265.02	265.03	78.01	1030.95	1108.96
111	1.31381	0.01617	257.91	257.93	79.01	1030.38	1109.39
112	1.35212	0.01617	251.02	251.04	80.01	1029.80	1109.81
113	1.39138	0.01618	244.36	244.38	81.01	1029.23	1110.24
114	1.43162	0.01618	237.89	237.90	82.00	1028.66	1110.66

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
115	1.47286	0.01619	231.62	231.63	83.00	1028.08	1111.09
116	1.51512	0.01619	225.53	225.55	84.00	1027.51	1111.51
117	1.55842	0.01619	219.63	219.65	85.00	1026.93	1111.93
118	1.60277	0.01620	213.91	213.93	86.00	1026.36	1112.36
119	1.64820	0.01620	208.36	208.37	87.00	1025.78	1112.78
120	1.69474	0.01620	202.98	202.99	88.00	1025.20	1113.20
121	1.74240	0.01621	197.76	197.76	89.00	1023.62	1113.62
122	1.79117	0.01621	192.69	192.69	90.00	1024.05	1114.05
123	1.84117	0.01622	187.78	187.78	90.99	1024.47	1114.47
124	1.89233	0.01622	182.98	182.99	91.99	1022.90	1114.89
125	1.94470	0.01623	178.34	178.36	92.99	1022.32	1115.31
126	1.99831	0.01623	173.85	173.86	93.99	1021.74	1115.73
127	2.05318	0.01623	169.47	169.49	94.99	1021.16	1116.15
128	2.10934	0.01624	165.23	165.25	95.99	1020.58	1116.57
129	2.16680	0.01624	161.11	161.12	96.99	1020.00	1116.99
130	2.22560	0.01625	157.11	157.12	97.99	1019.42	1117.41
131	2.28576	0.01625	153.22	153.23	98.99	1018.84	1117.83
132	2.34730	0.01626	149.44	149.46	99.99	1018.26	1118.25
133	2.41025	0.01626	145.77	145.78	100.99	1017.68	1118.67
134	2.47463	0.01627	142.21	142.23	101.99	1017.10	1119.08
135	2.54048	0.01627	138.74	138.76	102.99	1016.52	1119.50
136	2.60782	0.01627	135.37	135.39	103.98	1015.93	1119.92
137	2.67667	0.01628	132.10	132.12	104.98	1015.35	1120.34
138	2.74707	0.01628	128.92	128.94	105.98	1014.77	1120.75
139	2.81903	0.01629	125.83	125.85	106.98	1014.18	1121.17
140	2.89260	0.01629	122.82	122.84	107.98	1013.60	1121.58
141	2.96780	0.01630	119.90	119.92	108.98	1013.01	1122.00
142	3.04465	0.01630	117.05	117.07	109.98	1012.43	1122.41
143	3.12320	0.01631	114.29	114.31	110.98	1011.84	1122.83
144	3.20345	0.01631	111.60	111.62	111.98	1011.26	1123.24
145	3.28546	0.01632	108.99	109.00	112.98	1010.67	1123.66
146	3.36924	0.01632	106.44	106.45	113.98	1010.09	1124.07
147	3.45483	0.01633	103.96	103.98	114.98	1009.50	1124.48
148	3.54226	0.01633	101.55	101.57	115.98	1008.91	1124.89
149	3.63156	0.01634	99.21	99.22	116.98	1008.32	1125.31
150	3.72277	0.01634	96.93	96.94	117.98	1007.73	1125.72
151	3.81591	0.01635	94.70	94.72	118.99	1007.14	1126.13
152	3.91101	0.01635	92.54	92.56	119.99	1006.55	1126.54
153	4.00812	0.01636	90.44	90.46	120.99	1005.96	1126.95
154	4.10727	0.01636	88.39	88.41	121.99	1005.37	1127.36
155	4.20848	0.01637	86.40	86.41	122.99	1004.78	1127.77
156	4.31180	0.01637	84.45	84.47	123.99	1004.19	1128.18
157	4.41725	0.01638	82.56	82.58	124.99	1003.60	1128.59
158	4.52488	0.01638	80.72	80.73	125.99	1003.00	1128.99
159	4.63472	0.01639	78.92	78.94	126.99	1002.41	1129.40
160	4.7468	0.01639	77.175	77.192	127.99	1001.82	1129.81
161	4.8612	0.01640	75.471	75.488	128.99	1001.22	1130.22
162	4.9778	0.01640	73.812	73.829	130.00	1000.63	1130.62
163	5.0969	0.01641	72.196	72.213	131.00	1000.03	1131.03
164	5.2183	0.01642	70.619	70.636	132.00	999.43	1131.43
165	5.3422	0.01642	69.084	69.101	133.00	998.84	1131.84
166	5.4685	0.01643	67.587	67.604	134.00	998.24	1132.24
167	5.5974	0.01643	66.130	66.146	135.00	997.64	1132.64
168	5.7287	0.01644	64.707	64.723	136.01	997.04	1133.05
169	5.8627	0.01644	63.320	63.336	137.01	996.44	1133.45
170	5.9993	0.01645	61.969	61.989	138.01	995.84	1133.85
171	6.1386	0.01646	60.649	60.666	139.01	995.24	1134.25
172	6.2806	0.01646	59.363	59.380	140.01	994.64	1134.66
173	6.4253	0.01647	58.112	58.128	141.02	994.04	1135.06
174	6.5729	0.01647	56.887	56.904	142.02	993.44	1135.46

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
175	6.7232	0.01648	55.694	55.711	143.02	992.83	1135.86
176	6.8765	0.01648	54.532	54.549	144.03	992.23	1136.26
177	7.0327	0.01649	53.397	53.414	145.03	991.63	1136.65
178	7.1918	0.01650	52.290	52.307	146.03	991.02	1137.05
179	7.3539	0.01650	51.210	51.226	147.03	990.42	1137.45
180	7.5191	0.01651	50.155	50.171	148.04	989.81	1137.85
181	7.6874	0.01651	49.126	49.143	149.04	989.20	1138.24
182	7.8589	0.01652	48.122	48.138	150.04	988.60	1138.64
183	8.0335	0.01653	47.142	47.158	151.05	987.99	1139.03
184	8.2114	0.01653	46.185	46.202	152.05	987.38	1139.43
185	8.3926	0.01654	45.251	45.267	153.05	986.77	1139.82
186	8.5770	0.01654	44.339	44.356	154.06	986.16	1140.22
187	8.7649	0.01655	43.448	43.465	155.06	985.55	1140.61
188	8.9562	0.01656	42.579	42.595	156.07	984.94	1141.00
189	9.1510	0.01656	41.730	41.746	157.07	984.32	1141.39
190	9.3493	0.01657	40.901	40.918	158.07	983.71	1141.78
191	9.5512	0.01658	40.092	40.108	159.08	983.10	1142.18
192	9.7567	0.01658	39.301	39.317	160.08	982.48	1142.57
193	9.9659	0.01659	38.528	38.544	161.09	981.87	1142.95
194	10.1788	0.01659	37.774	37.790	162.09	981.25	1143.34
195	10.3955	0.01660	37.035	37.052	163.10	980.63	1143.73
196	10.6160	0.01661	36.314	36.331	164.10	980.02	1144.12
197	10.8404	0.01661	35.611	35.628	165.11	979.40	1144.51
198	11.0687	0.01662	34.923	34.940	166.11	978.78	1144.89
199	11.3010	0.01663	34.251	34.268	167.12	978.16	1145.28
200	11.5374	0.01663	33.594	33.610	168.13	977.54	1145.66
201	11.7779	0.01664	32.951	32.968	169.13	976.92	1146.05
202	12.0225	0.01665	32.324	32.340	170.14	976.29	1146.43
203	12.2713	0.01665	31.710	31.726	171.14	975.67	1146.81
204	12.5244	0.01666	31.110	31.127	172.15	975.05	1147.20
205	12.7819	0.01667	30.523	30.540	173.16	974.42	1147.58
206	13.0436	0.01667	29.949	29.965	174.16	973.80	1147.96
207	13.3099	0.01668	29.388	29.404	175.17	973.17	1148.34
208	13.5806	0.01669	28.839	28.856	176.18	972.54	1148.72
209	13.8558	0.01669	28.303	28.319	177.18	971.92	1149.10
210	14.1357	0.01670	27.778	27.795	178.19	971.29	1149.48
212	14.7096	0.01671	26.763	26.780	180.20	970.03	1150.23
214	15.3025	0.01673	25.790	25.807	182.22	968.76	1150.98
216	15.9152	0.01674	24.861	24.878	184.24	967.50	1151.73
218	16.5479	0.01676	23.970	23.987	186.25	966.23	1152.48
220	17.2013	0.01677	23.118	23.134	188.27	964.95	1153.22
222	17.8759	0.01679	22.299	22.316	190.29	963.67	1153.96
224	18.5721	0.01680	21.516	21.533	192.31	962.39	1154.70
226	19.2905	0.01682	20.765	20.782	194.33	961.11	1155.43
228	20.0316	0.01683	20.045	20.062	196.35	959.82	1156.16
230	20.7961	0.01684	19.355	19.372	198.37	958.52	1156.89
232	21.5843	0.01686	18.692	18.709	200.39	957.22	1157.62
234	22.3970	0.01688	18.056	18.073	202.41	955.92	1158.34
236	23.2345	0.01689	17.466	17.463	204.44	954.62	1159.06
238	24.0977	0.01691	16.860	16.877	206.46	953.31	1159.77
240	24.9869	0.01692	16.298	16.314	208.49	952.00	1160.48
242	25.9028	0.01694	15.757	15.774	210.51	950.68	1161.19
244	26.8461	0.01695	15.238	15.255	212.54	948.35	1161.90
246	27.8172	0.01697	14.739	14.756	214.57	948.03	1162.60
248	28.8169	0.01698	14.259	14.276	216.60	946.70	1163.29
250	29.8457	0.01700	13.798	13.815	218.63	945.36	1163.99
252	30.9043	0.01702	13.355	13.372	220.66	944.02	1164.68
254	31.9934	0.01703	12.928	12.945	222.69	942.68	1165.37
256	33.1135	0.01705	12.526	12.147	224.73	939.99	1166.72
258	34.2653	0.01707	12.123	12.140	226.76	939.97	1166.73

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
260	35.4496	0.01708	11.742	11.759	228.79	938.61	1167.40
262	36.6669	0.01710	11.376	11.393	230.83	937.25	1168.08
264	37.9180	0.01712	11.024	11.041	232.87	935.88	1168.74
266	39.2035	0.01714	10.684	10.701	234.90	934.50	1169.41
268	40.5241	0.01715	10.357	10.374	236.94	933.12	1170.07
270	41.8806	0.01717	10.042	10.059	238.98	931.74	1170.72
272	43.2736	0.01719	9.737	9.755	241.03	930.35	1171.38
274	44.7040	0.01721	9.445	9.462	243.07	928.95	1172.02
276	46.1723	0.01722	9.162	9.179	245.11	927.55	1172.67
278	47.6794	0.01724	8.890	8.907	247.16	926.15	1173.31
280	49.2260	0.01726	8.627	8.644	249.20	924.74	1173.94
282	50.8128	0.01728	8.373	8.390	251.25	923.32	1174.57
284	52.4406	0.01730	8.128	8.146	253.30	921.90	1175.20
286	54.1103	0.01731	7.892	7.910	255.35	920.47	1175.82
288	55.8225	0.01733	7.664	7.681	257.40	919.03	1176.44
290	57.5780	0.01735	7.444	7.461	259.45	917.59	1177.05
292	59.3777	0.01737	7.231	7.248	261.51	916.15	1177.66
294	61.2224	0.01739	7.026	7.043	263.56	914.69	1178.26
296	63.1128	0.01741	6.827	6.844	265.62	913.24	1178.86
298	65.0498	0.01743	6.635	6.652	267.68	911.77	1179.45
300	67.03	0.01745	6.450	6.467	269.74	910.3	1180.04
302	69.01	0.01747	6.275	6.292	271.79	909.0	1180.79
304	71.09	0.01749	6.102	6.119	273.86	907.5	1181.36
306	73.22	0.01751	5.933	5.951	275.93	906.0	1181.93
308	75.40	0.01753	5.771	5.789	278.00	904.5	1182.50
310	77.64	0.01755	5.614	5.632	280.06	903.0	1183.06
312	79.92	0.01757	5.462	5.480	282.13	901.5	1183.63
314	82.26	0.01759	5.315	5.333	284.21	899.9	1184.11
316	84.65	0.01761	5.172	5.190	286.28	898.4	1184.68
318	87.10	0.01763	5.034	5.052	288.36	896.9	1185.26
320	89.60	0.01765	4.901	4.919	290.43	895.3	1185.73
322	92.16	0.01767	4.772	4.790	292.51	893.8	1186.31
324	94.78	0.01770	4.647	4.665	294.59	892.2	1186.79
326	97.46	0.01772	4.525	4.543	296.67	890.7	1187.37
328	100.20	0.01774	4.408	4.426	298.76	889.1	1187.86
330	103.00	0.01776	4.294	4.312	300.84	887.5	1188.34
332	105.86	0.01778	4.183	4.201	302.93	885.9	1188.83
334	108.78	0.01780	4.076	4.094	305.02	884.3	1189.32
336	111.76	0.01783	3.973	3.991	307.11	882.7	1189.81
338	114.82	0.01785	3.872	3.890	309.21	881.1	1190.31
340	117.93	0.01787	3.774	3.792	311.30	879.5	1190.80
342	121.11	0.01789	3.680	3.698	313.39	877.9	1191.29
344	124.36	0.01792	3.588	3.606	315.49	876.3	1191.79
346	127.68	0.01794	3.499	3.517	317.59	874.6	1192.19
348	131.07	0.01796	3.412	3.430	319.70	873.0	1192.70
350	134.53	0.01799	3.328	3.346	321.80	871.3	1193.10
352	138.06	0.01801	3.247	3.265	323.91	869.6	1193.51
354	141.66	0.01804	3.167	3.185	326.02	868.0	1194.02
356	145.34	0.01806	3.091	3.109	328.13	866.3	1194.43
358	149.09	0.01808	3.286	3.304	330.24	864.6	1194.84
360	152.92	0.01811	2.943	2.961	332.35	862.9	1195.25
362	156.82	0.01813	2.873	2.891	334.47	861.2	1195.67
364	160.80	0.01816	2.804	2.822	336.59	859.5	1196.09
366	164.87	0.01818	2.738	2.756	338.71	857.7	1196.41
368	169.01	0.01821	2.673	2.691	340.83	856.0	1196.83
370	173.23	0.01823	5.283	2.628	342.96	854.2	1197.16
372	177.53	0.01826	2.549	2.567	345.08	852.5	1197.58
374	181.92	0.01828	2.325	2.508	347.21	850.7	1197.91
376	186.39	0.01831	2.432	2.450	349.35	848.9	1198.25
378	190.95	0.01834	2.376	2.394	351.48	847.2	1198.68

(*Continued*)

THERMODYNAMIC PROPERTIES OF WATER (*Continued*)

Temp °F	Press Psia	Specific Volume ft.^{3}/lbs.			Enthalpy Btu/lbs.		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
380	195.60	0.01836	2.321	2.339	353.62	845.4	1199.02
382	200.33	0.01839	2.268	2.286	355.76	843.6	1199.36
384	205.15	0.01842	2.216	2.234	357.90	841.7	1199.60
386	210.06	0.01844	2.165	2.183	360.04	839.9	1199.94
388	215.06	0.01847	2.116	2.134	362.19	838.1	1200.29
390	220.2	0.01850	2.069	2.087	364.34	836.2	1200.54
392	225.3	0.01853	2.021	2.040	366.49	834.4	1200.89
394	230.6	0.01855	1.976	1.995	368.64	832.5	1201.14
396	236.0	0.01858	1.932	1.951	370.80	830.6	1204.40
398	241.5	0.01861	1.889	1.908	372.96	828.7	1201.66
400	247.1	0.01864	1.847	1.866	375.12	826.8	1201.92
405	261.4	0.01871	1.747	1.766	380.53	822.0	1202.53
410	276.5	0.01878	1.654	1.673	385.97	817.2	1203.17
415	292.1	0.01886	1.566	1.585	391.42	812.2	1203.62
420	308.5	0.01894	1.483	1.502	396.89	807.2	1204.09
425	325.6	0.01901	1.406	1.425	402.38	802.1	1204.48
430	343.3	0.01909	1.333	1.352	407.89	796.9	1204.79
435	361.9	0.01918	1.265	1.284	413.42	791.7	1205.12
440	381.2	0.01926	1.200	1.219	418.98	786.3	1205.28
445	401.2	0.01935	1.139	1.158	424.55	780.9	1205.45
450	422.1	0.01943	1.082	1.101	430.20	775.4	1205.60
455	443.8	0.01952	1.027	1.047	435.80	769.8	1205.60
460	466.3	0.01961	0.976	0.996	441.40	764.1	1205.50
465	489.8	0.01971	0.928	0.948	447.10	758.3	1205.40
470	514.1	0.01980	0.883	0.903	452.80	752.4	1205.20
475	539.3	0.01990	0.840	0.8594	458.5	746.4	1204.9
480	565.5	0.02000	0.799	0.8187	464.3	740.3	1204.6
485	592.6	0.02011	0.760	0.7801	470.1	734.1	1204.2
490	620.7	0.02021	0.723	0.7436	475.9	727.8	1203.7
495	649.8	0.02032	0.689	0.7090	481.8	721.3	1203.1
500	680.0	0.02043	0.656	0.6761	487.7	714.8	1202.5
525	847.1	0.02104	0.514	0.5350	517.8	680.0	1197.8
550	1044.0	0.02175	0.406	0.4249	549.1	641.6	1190.6
575	1274.0	0.02259	0.315	0.3378	581.9	598.6	1180.4
600	1541.0	0.02363	0.244	0.2677	616.7	549.7	1166.4

PROPERTIES OF WATER

Temp °F	Specific Heat Btu/lbs. °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

45.02 Properties of Water—Affects 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 Chapter 20.

A. 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
   $c_w = 1.02$ Btu/$\cancel{\text{Lb } H_2O}$ °F $\times$ 62.4 $\cancel{\text{Lbs.} H_2O/\text{ft.}^3}$ $\times$ 1.0 $\cancel{\text{ft.}^3}$ / 7.48052 gal. $\times$ 60 min./hr. $\times$ 0.94 (SG)
   = 480 Btu min./hr. °F gal.
   H_{250F} = 480 Btu min./hr. °F Gal. $\times$ GPM (gal./min.) $\times\ \Delta T$ (°F)
   $H_{250F} = 480 \times GPM \times \Delta T$ (°F)

   Water @ 450°F
   $c_w = 1.13$ Btu/$\cancel{\text{Lb } H_2O}$ °F $\times$ 62.4 $\cancel{\text{Lbs.} H_2O/\text{ft.}^3}$ $\times$ 1.0 $\cancel{\text{ft.}^3}$/7.48052 gal. $\times$ 60 min./hr. $\times$ 0.83 (SG)
   = 470 Btu min./hr. °F gal.
   H_{450F} = 470 Btu min./hr. °F gal. $\times$ GPM (gal./min.) $\times\ \Delta T$ (°F)
   $H_{450F} = 470 \times GPM \times \Delta T$ (°F)

PART 46

Cleanroom Criteria

46.01 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 pollen	150–750	Grain dusts	5–1,000+
Mold	3–12	Sawdust	30–600
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	0.3–60	Human hair	60–600
Viruses	0.005–0.1	Hair	5–200
Dust mites	100–300	Red blood cells	5–10
Spider web	2.5	Liquid droplets, sneezed	0.5–5
Disintegrated feces	0.8–1.5		---
Feces	10–45	Bone dust	3–350
Combustion			
Combustion	0.01–0.1	Smoke particles: natural	---
Tobacco smoke	0.01–4.5	matls.	0.01–0.1
Burning wood	0.2–3	Synthetic matls.	1–50
Rosin smoke	0.01–1	Smoldering cooking oil	0.3–0.9
Coal flue gas	0.08–0.2	Flaming cooking oil	0.3–0.9
Oil smoke	0.03–1	Auto emissions	1–150
Fly ash	0.9–1000		

(*Continued*)

AIRBORNE PARTICLE SIZE TABLE (*Continued*)

Particle	Particle Size Microns	Particle	Particle Size Microns
Mineral			
Asbestos	0.7–90	Carbon dust	0.25–5
Cement dust	3–100	Carbon dust-graphite	0.02–2
Coal dust	1–100	Fertilizer	10–1,000
Sea salt	0.035–0.5	Ground limestone	10–1,000
Textiles	6–20	Lead	0.1–0.7
Clay	0.1–50	Bromine	0.1–0.7
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 dust	0.1–1,000
NH_3Cl fumes	0.1–3	Metallurgical fumes	0.1–1,000
Other			
Atmospheric dust	0.001–40	Yeast cells	2–75
Lung damaging dust	0.6–7	Sugars	0.0008–0.005
Mist	70–350	Gelatin	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		---
Dusting aid	6–15	Artificial textile fibers	10–30
Paint pigments	0.1–5	Insecticide dusts	0.5–10

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.

46.02 Cleanroom Class Designations: FED-STD-209E

CLEANROOM CLASS DESIGNATIONS

Cleanroom Class Name		Class Limits									
		0.1 µm		0.2 µm		0.3 µm		0.5 µm		5 µm	
		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	Ft^3	M^3	Ft^3
M1		350	9.91	75.7	2.14	30.9	0.875	10.0	0.283	---	---
M1.5	1	1,240	35.0	265	7.50	106	3.00	35.3	1.00	---	---
M2		3,500	99.1	757	21.4	309	8.75	100	2.83	---	---
M2.5	10	12,400	350	2,650	75.0	1,060	30.0	353	10.0	---	---
M3		35,000	991	7,570	214	3,090	87.5	1,000	28.3	---	---
M3.5	100	---	---	26,500	750	10,600	300	3,530	100	---	---
M4		---	---	75,700	2,140	30,900	875	10,000	283	---	---
M4.5	1,000	---	---	---	---	---	---	35,300	1,000	247	7.00
M5		---	---	---	---	---	---	100,000	2,830	618	17.5
M5.5	10,000	---	---	---	---	---	---	353,000	10,000	2,470	70.0
M6		---	---	---	---	---	---	1,000,000	28,300	6,180	175
M6.5	100,000	---	---	---	---	---	---	3,530,000	100,000	24,700	700
M7		---	---	---	---	---	---	10,000,000	283,000	61,800	1,750

Notes:

1 Federal Standard 209E is obsolete and superseded by the International Organization Standard ISO 14644.

2 Federal Standard 209E information provided for comparison purposes only.

46.03 Cleanroom Class Designations: ISO Standard 14644-1

CLEANROOM CLASS DESIGNATIONS

ISO Class	Maximum Number of Particles in the Air (Particles in Each Cubic Meter Equal to or Greater than the Specified Particle Size)					
	Particle Size					
	>0.1 µm	>0.2 µm	>0.3 µm	>0.5 µm	>1.0 µm	>5.0 µm
ISO Class 1	10	2	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.

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:
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

46.04 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	M6.5
Circulation Rate AC/hr. (8)	360–540	360–540	210–540	120–300	30–120	12–60
Room Air Velocity ft./min.	60–90	60–90	35–90 (1)	20–50	5–20	2–10
% 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/hr.
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 / hr.
d. Example: 45 percent RH, ±5.0 percent RH
7 Fire protection/smoke purge exhaust: 3–5 CFM/sq.ft.
8 The air change rate is based on a 10'0" ceiling height.

PART 47

Wind Chill and Heat Index

47.01 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
–25	–25	–31	–52	–65	–76	–83	–87	–90	–94	–94	–96
–30	–30	–35	–58	–70	–81	–89	–94	–98	–101	–101	–103
–35	–35	–41	–64	–78	–88	–96	–101	–105	–107	–108	–110
–40	–40	–47	–70	–85	–96	–104	–109	–113	–116	–118	–120
–45	–45	–54	–77	–90	–103	–112	–117	–123	–128	–129	–130

Notes:

1 The table provides equivalent wind chill temperatures at various outside dry bulb temperatures and corresponding wind velocities.

2 Wind speeds greater than 40 mph have little additional chilling effect.

3 $WCF \cong T_{DB} - (1.5 \times W_S)$

WCF = Wind Chill Factor
T_{DB} = Dry Bulb Air Temperature
W_S = Wind Speed

47.02 Heat Index

HEAT INDEX

%RH	Apparent Temperature, °F.														
	Temperature, °F.														
	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
0	64	69	73	78	83	87	91	95	99	103	107	111	117	120	125
5	64	69	74	79	84	88	83	97	102	107	111	115	122	128	
10	65	70	75	80	85	90	95	100	105	111	116	123	131		
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	72	77	83	88	94	101	109	117	127	139				
30	67	73	78	84	90	96	104	113	123	135	148				
35	67	73	79	85	91	98	107	118	130	143					
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 temperatures and corresponding relative humidities.

2 The heat index is a measure of how the average person perceives temperature and 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 or greater.

PART 48

Miscellaneous

48.01 Area 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
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	2.2253
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
38	1134.11	7.8758	119.38	9.9484
39	1194.59	8.2958	122.52	10.2102
40	1256.64	8.7266	125.66	10.4720

(*Continued*)

AREAS AND CIRCUMFERENCES OF CIRCLES (*Continued*)

Diameter in Inches	Area		Circumference	
	Square Inches	Square Feet	Inches	Feet
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

48.02 Fraction/Decimal Equivalents

FRACTION/DECIMAL EQUIVALENTS

64THS	32NDS	16THS	8THS	4THS	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

(*Continued*)

FRACTION/DECIMAL EQUIVALENTS (*Continued*)

64THS	32NDS	16THS	8THS	4THS	Half	Whole	Decimal
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
31/64	-	-	-	-	-	-	0.4844
32/64	16/32	8/16	4/8	2/4	1/2	-	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

48.03 Physical Properties of Fuels and Oils

PHYSICAL PROPERTIES OF FUELS AND OILS

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lbm	Density lbm/cu.ft.	Specific Grav-ity
			Fuels			
Gasoline	---	113.0	Liq.	0.0223	44.9	0.72
Kerosene	---	154.0	Liq.	0.0200	49.9	0.80
Diesel Fuel (1-D)	---	170.0	Liq.	0.0183	54.6	0.875
Diesel Fuel (2-D)	---	184.0	Liq.	0.0174	57.4	0.920
Diesel Fuel (4-D)	---	198.0	Liq.	0.0167	59.9	0.960

(*Continued*)

PHYSICAL PROPERTIES OF FUELS AND OILS (*Continued*)

Substance	Formula	Molecular Weight	Phase	Specific Volume cu.ft./lbm	Density lbm/cu.ft.	Specific Gravity
Fuel Oil No.1	---	---	Liq.	0.0183	54.6	0.875
Fuel Oil No.2	---	---	Liq.	0.0174	57.4	0.920
Fuel Oil No.4	---	198.0	Liq.	0.0167	59.8	0.959
Fuel Oil No.5 Lt	---	---	Liq.	0.0167	59.9	0.960
Fuel Oil No.5 Hv	---	---	Liq.	0.0167	59.9	0.960
Fuel Oil No.6	---	---	Liq.	0.0167	59.9	0.960
Paraffin or Alkane Series						
Methane (Nat. Gas)	CH_4	16.041	Gas	24.0963	0.0415	0.553
Ethane	C_2H_6	30.067	Gas	12.9032	0.0775	1.033
Propane	C_3H_8	44.092	Gas	8.7719	0.114	1.520
N-Butane	C_4H_{10}	58.118	Gas	0.0276	36.14	481.9
Isobutane	C_4H_{10}	58.118	Gas	0.0288	34.77	463.6
N-Pentane	C_5H_{12}	72.144	Liq.	0.0256	39.08	0.626
Isopentane	C_5H_{12}	72.144	Liq.	0.0258	38.77	0.621
Neopentane	C_5H_{12}	72.144	Gas	0.0261	38.27	510.3
N-Hexane	C_6H_{14}	86.178	Liq	0.0243	41.14	0.659
Neohexane	C_6H_{14}	86.178	Liq.	0.0247	40.51	0.649
N-Heptane	C_7H_{16}	100.206	Liq.	0.0239	41.70	0.668
Triptane	C_7H_{16}	100.206	Liq.	0.0232	43.07	0.690
N-Octane	C_8H_{18}	114.223	Liq.	0.0227	44.14	0.707
Iso-Octane	C_8H_{18}	114.223	Liq.	0.0228	43.82	0.702
Olefin or Alkene Series						
Ethylene	C_2H_4	28.054	Gas	13.6426	0.0733	0.977
Propylene	C_3H_6	42.081	Gas	7.5187	0.113	1.507
Butylene	C_4H_8	56.108	Gas	0.0269	37.12	494.9
Isobutene	C_4H_8	56.108	Gas	0.0272	36.83	491.1
N-Pentene	C_5H_{10}	70.135	Liq.	0.0250	40.02	0.641
Aromatic Series						
Benzene	C_6H_6	78.114	Liq.	0.0172	58.18	0.932
Tolulene	C_7H_8	92.141	Liq.	0.0181	55.31	0.886
Xylene	C_8H_{10}	106.169	Liq.	0.0186	53.75	0.861
Other Hydrocarbons						
Acetylene	C_2H_2	26.038	Gas	14.8148	0.0675	0.900
Naphthalene	$C_{10}H_8$	128.175	Solid	---	71.48	---
Methyl Alcohol	CH_3OH	32.041	Liq.	0.0204	49.10	0.789
Ethyl Alcohol	C_2H_5OH	46.067	Liq.	0.0204	49.01	0.787
Motor Oils						
5W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
10W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
20W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
30W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
40W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
50W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
Gear Oils						
75W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
80W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
85W	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
90	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
120	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
140	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94
150	---	---	Liq.	0.0176	54.9–58.7	0.88–0.94

PHYSICAL PROPERTIES OF FUELS AND OILS

Substance	Boiling Pt. ºF	Ignition Temp. ºF	Flash Point	Flammability Limits (in Air) % by Volume
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
Isopentane	82.2	788	<–60	1.32–9.16
Neopentane	49.1	842	GAS	1.38–7.22
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
Tolulene	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	---
20W	---	---	465	---
30W	---	---	450	---
40W	--	---	475	---
50W	---	---	485	---

(*Continued*)

PHYSICAL PROPERTIES OF FUELS AND OILS (*Continued*)

Substance	Boiling Pt. ºF	Ignition Temp. ºF	Flash Point	Flammability Limits (in Air) % by Volume
Gear Oils				
75W	---	---	375	---
80W	---	---	425	---
85W	---	---	435	---
90	---	---	425	---
120	---	---	425	---
140	---	---	580	---
150	---	---	580	---

48.04 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

<table>
<tr><th>Pressure Level
dB</th><th>Typical Sound</th><th>Subjective Impression</th></tr>
<tr><td>150</td><td rowspan="2">Jet plane take-off
Military jet take-off at 100 ft.</td><td rowspan="2">Short exposure can cause hearing loss.</td></tr>
<tr><td>140</td></tr>
<tr><td>130</td><td>Artillery fire at 10 ft.
Machine gun</td><td rowspan="2">Deafening (threshold of pain)</td></tr>
<tr><td>120</td><td>Siren at 100 ft.
Jet plane (passenger ramp)
Thunder
Sonic boom</td></tr>
<tr><td>110</td><td>Wood working shop
Accelerating motorcycle
Hard rock band
75-piece orchestra</td><td>Threshold of discomfort</td></tr>
<tr><td>100</td><td>Subway (steel wheels)
Propeller plane, outboard motor
Loud street noise
Power lawn mower</td><td rowspan="2">Very loud</td></tr>
<tr><td>90</td><td>Truck unmuffled
Train whistle
Kitchen blender
Pneumatic jackhammer
Shouting at 5 ft.</td></tr>
<tr><td>80</td><td>Printing press
Subway (rubber wheels)
Noisy office
Computer printout room
Average factory</td><td>Loud
Intolerable for phone use</td></tr>
<tr><td>70</td><td>Average street noise
Quiet typewriter
Freight train at 100 ft.
Average radio
Speech at 3 ft.</td><td>Loud</td></tr>
<tr><td>60</td><td>Noisy home
Average office
Normal conversation at 3 ft.</td><td>Loud
Unusual background</td></tr>
<tr><td>50</td><td>General office
Quiet office
Quiet radio, window AC unit
Average home
Quiet street</td><td>Moderate</td></tr>
<tr><td>40</td><td>Private office
Quiet home/residential area</td><td>Moderate</td></tr>
<tr><td>30</td><td>Quiet conversation
Broadcast studio</td><td>Noticeably quiet</td></tr>
<tr><td>20</td><td>Empty auditorium
Whisper
Watch ticking
Buzzing inset at 3 ft.
Rural ambient</td><td>Very quiet</td></tr>
<tr><td>10</td><td rowspan="2">Rustling leaves
Soundproof room
Human breathing</td><td>Very faint
Threshold of good hearing</td></tr>
<tr><td>0</td><td>Intolerably quiet
Threshold of audibility (youthful hearing)</td></tr>
</table>

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
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 washer, TV–loud	80
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 CHARATERISTICS

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 Scale) dB
Apartments	NC 25–35	RC 25–35	35–45
Assembly Halls	NC 25–30	RC 25–30	35–40
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
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

48.05 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
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

PART 49

General Notes

49.01 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.

49.02 Piping

A. Provide all materials and equipment and perform all labor required to install complete and operable piping systems as indicated on the drawings, and as specified and required by code.

B. Elevations as 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 the 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. in 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./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 the 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 a 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.

49.03 Plumbing

A. Provide all materials and equipment and perform all labor required to install complete and operable plumbing systems as indicated on the drawings, and as specified and 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 as 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 of the 1/2-in. 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.

49.04 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, and as specified and 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 and 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 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.**

49.05 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.

PART 50

Designer's Checklist

50.01 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 cleanspace 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 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 space 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?

50.02 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 DI, RO, or UPW water.

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 space been coordinated and/or located?

O. Does air handling equipment need to be on emergency power?

50.03 Piping Systems—General

A. Expansion tank: has size, location, adequate space, support, makeup water pressure, and makeup water location been coordinated with a 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?

50.04 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?

50.05 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?

50.06 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.

50.07 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 use 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 thermostats?

QQ. Are adequate service space or equipment size access panels noted on drawings to 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 a 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?

50.08 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?

50.09 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 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 de-rated?

Q. Has additional insulation been included for low temperature systems?

R. Has split single-phase protection been included for packaged (single and/or split systems) air conditioning and heat pump compressor motors?

50.10 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 and 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 (open or closed) indicated where applicable?

N. Is the compressor size for ultimate duty?

50.11 Sanitary and Storm Water Systems

A. See the "Piping Systems–General" section earlier for additional requirements.

B. Adjust sewer inverts to keep tops of pipes in line (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, oil/water interceptors, 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 the 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.

50.12 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?

50.13 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)?

50.14 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%, or it may use three regulators sized at 15–35–50% or 25–25–50%.

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.

50.15 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 Pennsylvania 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?

50.16 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?

50.17 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. Are there a north arrow, title blocks, 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, structures, and ducts and pipes.
2. Clearances between conduits out of electrical panels and pull boxes, structures, 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* 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?

50.18 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 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 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?

50.19 Structural Engineer Coordination

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?

50.20 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 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?

PART 51

Professional Societies and Trade Organizations

51.01 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
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
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
ARI	Air-Conditioning and Refrigeration Institute
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
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 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

PART 52

References and Design Manuals

52.01 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

ASHRAE. *ASHRAE Handbook, 2006 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2006.
ASHRAE. *ASHRAE Handbook, 2005 Fundamentals Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2005.
ASHRAE. *ASHRAE Handbook, 2004 HVAC Systems and Equipment Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Handbook, 2003 HVAC Applications Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2003.
ASHRAE. *ASHRAE Handbook, 2002 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2002.
ASHRAE. *ASHRAE Handbook, 2001 Fundamentals Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2001.
ASHRAE. *ASHRAE Handbook, 2000 HVAC Systems and Equipment Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 2000.
ASHRAE. *ASHRAE Handbook, 1999 HVAC Applications Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1999.
ASHRAE. *ASHRAE Handbook, 1998 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1998.
ASHRAE. *ASHRAE Handbook, 1997 Fundamentals Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1997.
ASHRAE. *ASHRAE Handbook, 1996 HVAC Systems and Equipment Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1996.
ASHRAE. *ASHRAE Handbook, 1995 HVAC Applications Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1995.
ASHRAE. *ASHRAE Handbook, 1994 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1994.
ASHRAE. *ASHRAE Handbook, 1993 Fundamentals Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1993.
ASHRAE. *ASHRAE Handbook, 1992 HVAC Systems and Equipment Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1992.
ASHRAE. *ASHRAE Handbook, 1991 HVAC Applications Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1991.
ASHRAE. *ASHRAE Handbook, 1990 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1990.
ASHRAE. *ASHRAE Handbook, 1989 Fundamentals Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1989.
ASHRAE. *ASHRAE Handbook, 1988 Equipment Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1988.
ASHRAE. *ASHRAE Handbook, 1987 HVAC Systems and Applications Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1987.
ASHRAE. *ASHRAE Handbook, 1986 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1986.
ASHRAE. *ASHRAE Handbook, 1985 Fundamentals Volume, Inch-Pound Edition.* Atlanta, GA: ASHRAE, 1985.
ASHRAE. *ASHRAE Handbook, 1984 Systems Volume.* Atlanta, GA: ASHRAE, 1984.

ASHRAE. *ASHRAE Handbook, 1983 Equipment Volume.* Atlanta, GA: ASHRAE, 1983.
ASHRAE. *ASHRAE Handbook, 1982 Applications Volume.* Atlanta, GA: ASHRAE, 1982.
ASHRAE. *ASHRAE Handbook, 1981 Fundamentals Volume.* Atlanta, GA: ASHRAE, 1981.
ASHRAE. *ASHRAE Handbook, 1980 Systems Volume.* Atlanta, GA: ASHRAE, 1980.

C. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standards, and Manuals

1. Standards:

ASHRAE. *ASHRAE Standard 15-2004, Safety Code for Mechanical Refrigeration.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 34-2004, Design and Safety Classification of Refrigerants.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 52.1-1992, Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter.* Atlanta, GA: ASHRAE, 1992.
ASHRAE. *ASHRAE Standard 52.2-1999, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.* Atlanta, GA: ASHRAE, 1999.
ASHRAE. *ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 62.1-2001, Ventilation for Acceptable Indoor Air Quality.* Atlanta, GA: ASHRAE, 2001.
ASHRAE. *ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 62.2-2004, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 90.1-2001, Energy Standard for Buildings Except Low-Rise Residential Buildings.* Atlanta, GA: ASHRAE, 2001.
ASHRAE. *ASHRAE Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 90.2-2001, Energy Efficient Design of Low-Rise Residential Buildings.* Atlanta, GA: ASHRAE, 2001.
ASHRAE. *ASHRAE Standard 90.2-2004, Energy Efficient Design of Low-Rise Residential Buildings.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 100-2006, Energy Conservation in Existing Buildings.* Atlanta, GA: ASHRAE, 2006.
ASHRAE. *ASHRAE Standard 110-1995, Method of Testing Performance of Laboratory Fume Hoods.* Atlanta, GA: ASHRAE, 1995.
ASHRAE. *ASHRAE Standard 111-1988, Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems.* Atlanta, GA: ASHRAE, 1988.
ASHRAE. *ASHRAE Standard 114-1986, Energy Management Control Systems Instrumentation.* Atlanta, GA: ASHRAE, 1986.
ASHRAE. *ASHRAE Standard 135-2004, BACnet: A Data Communication Protocol for Building Automation Control Networks.* Atlanta, GA: ASHRAE, 2004.
ASHRAE. *ASHRAE Standard 135.1-2003, Method of Test for Conformance to BACnet.* Atlanta, GA: ASHRAE, 2003.
ASHRAE. *ASHRAE Standard 154-2003, Ventilation for Commercial Cooking Operations.* Atlanta, GA: ASHRAE, 2003.

2. Guidelines:

ASHRAE. *ASHRAE Guideline 1-1996, Guideline for Commissioning of HVAC Systems.* Atlanta, GA: ASHRAE, 1996.
ASHRAE. *ASHRAE Guideline 3-1990, Reducing Emission of Fully Halogenated Chlorofluorocarbon (CFC) Refrigerants in Refrigeration and Air-Conditioning Equipment and Applications.* Atlanta, GA: ASHRAE, 1990.
ASHRAE. *ASHRAE Guideline 4-1993, Preparation of Operating and Maintenance Documentation for Building Systems.* Atlanta, GA: ASHRAE, 1993.

ASHRAE. *ASHRAE Guideline 5-1994, Commissioning of Smoke Management Systems.* Atlanta, GA: ASHRAE, 1994.

ASHRAE. *ASHRAE Guideline 12-2000, Minimizing the Risk of Legionellosis Associated with Building Water Systems.* Atlanta, GA: ASHRAE, 2000.

ASHRAE. *ASHRAE Guideline 13-2000, Specifying Direct Digital Control Systems.* Atlanta, GA: ASHRAE, 2000.

3. Manuals:

ASHRAE. *Design of Smoke Control Systems for Buildings.* 1st Ed., Atlanta, GA: ASHRAE, 1983.

ASHRAE. *Pocket Handbook for Air Conditioning, Heating, Ventilation, Refrigeration.* Atlanta, GA: ASHRAE, 1987.

McIntosh, Ian B.D., Dorgan, Chad B., and Dorgan, Charles E. *ASHRAE Laboratory Design Guide.* Atlanta, GA: ASHRAE, 2001.

ASHRAE. *ASHRAE HVAC Design Manual for Hospitals and Clinics.* Atlanta, GA: ASHRAE, 2003.

Klote, John H. and Milke, James A. *Principles of Smoke Management*. Atlanta, GA: ASHRAE, 2002.

Grumman, David L., Editor. *ASHRAE Green Guide*. Atlanta, GA: ASHRAE, 2003.

Ross, Donald E. *HVAC Design Guide for Tall Commercial Buildings*. Atlanta, GA: ASHRAE, 2004.

D. American National Standards Institute (ANSI) and American Society of Mechanical Engineers (ASME)

ANSI/ASME. *ANSI/ASME A13.1 Scheme for the Identification of Piping Systems.* New York, NY: ANSI/ASME, 1996.

ANSI/ASME. *ANSI/ASME B31.1 Power Piping, 2004.* New York, NY: ANSI/ASME, 2004.

ANSI/ASME. *ANSI/ASME B31.3 Process Piping, 1996.* New York, NY: ANSI/ASME, 2006.

ANSI/ASME. *ANSI/ASME B31.5 Refrigerant Piping, 1987.* New York, NY: ANSI/ASME, 2001.

ANSI/ASME. *ANSI/ASME B31.9 Building Services Piping Code, 1996.* New York, NY: ANSI/ASME, 2004.

ANSI/ASME. *ANSI/ASME Boiler and Pressure Vessel Code, 2004.* New York, NY: ANSI/ASME, 2004.

E. Bell and Gossett Manuals

ITT Corporation. *Pump and System Curve Data for Centrifugal Pump Selection and Application.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1967.

ITT Corporation. *Pump Data Book.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1970.

ITT Corporation. *Parallel and Series Pump Application.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Principles of Centrifugal Pump Construction and Maintenance.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Cooling Tower Pumping and Piping.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1968.

ITT Corporation. *Variable Speed/Variable Volume Pumping Fundamentals.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1985.

ITT Corporation. *Heat Exchangers, Application and Installation.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.

ITT Corporation. *Primary Secondary Pumping Application Manual.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1968.

ITT Corporation. *One Pipe Primary Systems, Flow Rate and Water Temperature Determination.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.

ITT Corporation. *Primary Secondary Pumping Adaptations to Existing Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.

ITT Corporation. *Dual Temperature Change Over Single Zone.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1967.
ITT Corporation. *Single Coil Instantaneous Room by Room Heating-Cooling Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.
ITT Corporation. *Equipment Room Piping Practice.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.
ITT Corporation. *Pressurized Expansion Tank Sizing/Installation Instructions for Hydronic Heating/Cooling Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1988.
ITT Corporation. *Snow Melting System Design and Problems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.
ITT Corporation. *Hydronic Systems Anti-Freeze Design.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1965.
ITT Corporation. *Air Control for Hydronic Systems.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1966.
ITT Corporation. *Basic System Control and Valve Sizing Procedures.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1970.
ITT Corporation. *Hydronic Systems: Analysis and Evaluation.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1969.
ITT Corporation. *Circuit Setter Valve Balance Procedure Manual.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1971.
ITT Corporation. *Domestic Water Service.* Morton Grove, IL: ITT Corporation, Training and Education Department, Fluid Handling Division, 1970.

F. Carrier Manuals

Carrier Corporation. *Carrier System Design Manuals, Part 1—Load Estimating.* Syracuse, NY: Carrier Corporation, 1972.
Carrier Corporation. *Carrier System Design Manuals, Part 2—Air Distribution.* Syracuse, NY: Carrier Corporation, 1974.
Carrier Corporation. *Carrier System Design Manuals, Part 3—Piping Design.* Syracuse, NY: Carrier Corporation, 1973.
Carrier Corporation. *Carrier System Design Manuals, Part 4—Refrigerants, Brines, Oils.* Syracuse, NY: Carrier Corporation, 1969.
Carrier Corporation. *Carrier System Design Manuals, Part 5—Water Conditioning.* Syracuse, NY: Carrier Corporation, 1972.
Carrier Corporation. *Carrier System Design Manuals, Part 6—Air Handling Equipment.* Syracuse, NY: Carrier Corporation, 1968.
Carrier Corporation. *Carrier System Design Manuals, Part 7—Refrigeration Equipment.* Syracuse, NY: Carrier Corporation, 1969.
Carrier Corporation. *Carrier System Design Manuals, Part 8—Auxiliary Equipment.* Syracuse, NY: Carrier Corporation, 1966.
Carrier Corporation. *Carrier System Design Manuals, Part 9—Systems and Applications.* Syracuse, NY: Carrier Corporation, 1971.
Carrier Corporation. *Carrier System Design Manuals, Part 10—Air-Air Systems.* Syracuse, NY: Carrier Corporation, 1975.
Carrier Corporation. *Carrier System Design Manuals, Part 11—Air-Water Systems.* Syracuse, NY: Carrier Corporation, 1966.
Carrier Corporation. *Carrier System Design Manuals, Part 12—Water and DX Systems.* Syracuse, NY: Carrier Corporation, 1975.

G. Cleaver Brooks Manuals

Cleaver Brooks. *The Boiler Book, A Complete Guide to Advanced Boiler Technology for the Specifying Engineer.* 1st Ed., Milwaukee, WI: Cleaver Brooks, 1993.
Cleaver Brooks. *Hot Water Systems, Components, Controls, and Layouts.* Milwaukee, WI: Cleaver Brooks, 1972.

Cleaver Brooks. *Application . . . and Misapplication of Hot Water Boilers.* Milwaukee, WI: Cleaver Brooks, 1976.

H. Johnson Controls Manuals

Johnson Controls. *Fundamentals of Pneumatic Control.* Milwaukee, WI: Johnson Controls.
Johnson Controls. *Johnson Field Training Handbook, Fundamentals of Electronic Control Equipment.* Milwaukee, WI: Johnson Controls.
Johnson Controls. *Johnson Field Training Handbook, Fundamentals of Systems.* Milwaukee, WI: Johnson Controls.

I. Honeywell Manual

Honeywell. *Engineering Manual of Automatic Control for Commercial Buildings, Heating, Ventilating, and Air Conditioning.* Inch-Pound Edition, Minneapolis, MN: Honeywell, 1991.

J. Industrial Ventilation Manual

American Conference of Governmental and Industrial Hygentists. *Industrial Ventilation, A Manual of Recommended Practice.* 21st Ed., Cincinnati, OH: American Conference of Governmental and Industrial Hygentists, 1992.

K. SMACNA (Sheet Metal and Air-Conditioning Contractors' National Association, Inc.) Manuals

SMACNA. *Fibrous Glass Duct Construction Standards.* 5th Ed., Vienna, VA: SMACNA, 1979.
SMACNA. *Fire, Smoke, and Radiation Damper Installation Guide for HVAC Systems.* 4th Ed., Vienna, VA: SMACNA, 1992.
SMACNA. *HVAC Air Duct Leakage Test Manual.* 1st Ed., Vienna, VA: SMACNA, 1985.
SMACNA. *HVAC Duct Construction Standards—Metal and Flexible.* 1st Ed., Vienna, VA: SMACNA, 1985.
SMACNA. *HVAC Duct Construction Standards—Metal and Flexible.* 2nd Ed., Vienna, VA: SMACNA, 1995.
SMACNA. *HVAC Duct Construction Standards—Metal and Flexible.* 3rd Ed., Vienna, VA: SMACNA, 2005.
SMACNA. *HVAC Systems—Duct Design.* 2nd Ed., Vienna, VA: SMACNA, 1981.
SMACNA. *HVAC Systems—Testing, Adjusting, and Balancing.* 1st Ed., Vienna, VA: SMACNA, 1986.
SMACNA. *Rectangular Industrial Duct Construction Standards.* 1st Ed., Vienna, VA: SMACNA, 1989.
SMACNA. *Round Industrial Duct Construction Standards.* 1st Ed., Vienna, VA: SMACNA, 1989.
SMACNA. *Seismic Restraint Manual Guidelines for Mechanical Systems.* 1st Ed., Vienna, VA: SMACNA, 1991.
SMACNA. *Thermoplastic Duct (PVC) Construction Manual.* 1st Ed., Vienna, VA: SMACNA, 1974.

L. Trane Manuals

The Trane Company. *Trane Air-Conditioning Manual.* LaCross, WI: The Trane Company, 1988.
The Trane Company. *Psychrometry.* LaCross, WI: The Trane Company, 1988.

M. United McGill Corporation

United McGill Corporation. *Engineering Design reference Manual for Supply Air Handling Systems.* Westerville, OH: United McGill Corporation, 1989.
United McGill Corporation. *Underground Duct Installation (No. 95).* Westerville, OH: United McGill Corporation, 1992.
United McGill Corporation. *Flat Oval vs. Rectangular Duct (No. 150).* Westerville, OH: United McGill Corporation, 1989.

United McGill Corporation. *Flat Oval Duct—The Alternative to Rectangular (No. 151).* Westerville, OH: United McGill Corporation, 1989.

United McGill Corporation. *Underground Duct Design (No. 155).* Westerville, OH: United McGill Corporation, 1992.

N. Manufacturers Standardization Society of the Valve and Fitting Industry

Manufacturers Standardization Society of the Valve and Fitting Industry. *Standard Marking System for Valves, Fittings, Flanges and Unions (Standard SP-25-1988).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1988.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Pipe Hangers and Supports—Materials, Design, and Manufacturers (Standard SP-58-1988).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1988.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Pipe Hangers and Supports—Selection and Application (Standard SP-69-1983).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1983.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Pipe Hangers and Supports—Fabrication and Installation Practices (Standard SP-89-1985).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1985.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Guidelines on Terminology for Pipe Hangers and Supports (Standard SP-90-1986).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1986.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Guidelines for Manual Operation of Valves (Standard SP-91-1984).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1984.

Manufacturers Standardization Society of the Valve and Fitting Industry. *MSS Valve User Guide (Standard SP-92-1987).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1987.

Manufacturers Standardization Society of the Valve and Fitting Industry. *Guidelines on Terminology for Valves and Fittings (Standard SP-96-1986).* Vienna, VA: Manufacturers Standardization Society of the Valve and Fitting Industry, 1986.

O. Miscellaneous

Armstrong. *Steam Conservation Guidelines for Condensate Drainage.* Three Rivers, MI: Armstrong Machine Works, 1976.

Avallone, Eugene A. and Baumeister, III Theodore. *Mark's Standard Handbook for Mechanical Engineers.* 9th Ed., New York, NY: McGraw-Hill Book Co., 1986.

Bolz, D. and Tuve, George L. *CRC Handbook of Tables for Applied Engineering Science.* 2nd. Ed., Boca Raton, FL: CRC Press, Inc., 1980.

Clough, Richard H. *Construction Contracting.* 4th Ed., New York, NY: John Wiley and Sons, Inc., 1981.

Dryomatic, Div. Airflow, Co. *Dehumidification Engineering Manual.* Frederick, MD: Dryomatic, Div. Airflow, Co., 1965.

Haines, Roger W. *Control Systems for Heating, Ventilating, and Air Conditioning.* 4th Ed., New York, NY: Van Nostrand Reinhold Company, 1987.

Hansen, Erwin G. *Hydronic System Design and Operation, A Guide to Heating and Cooling with Water.* New York, NY: McGraw-Hill Companies, Inc., College Customs Series, 1996.

Harris, Norman C. *Modern Air Conditioning Practice.* 3rd Ed., New York, NY: Glencoe Div. of Macmillan/McGraw-Hill, 1992.

Hauf, Harold D. *Architectural Graphic Standards.* 6th Ed., New York, NY: John Wiley and Sons, Inc., 1970.

Heald, C. C. *Cameron Hydraulic Data.* 17th Ed., Woodcliff Lake, NJ: Ingersoll Rand, 1988.

Leslie Control, Inc. *Steam Pressure Control Systems.* Tampa, FL: Leslie Controls, Inc.

The Marley Cooling Tower Co. *Cooling Tower Fundamentals.* 2nd Ed., Kansas City, MO: The Marley Cooling Tower Co., 1985.

McGuinness, William J. *Mechanical and Electrical Equipment for Buildings.* 6th Ed., New York, NY: John Wiley and Sons, Inc., 1980.

Nayyar, Mohinder L. *Piping Handbook.* 6th Ed., New York, NY: McGraw Hill, Inc. 1992.
The Singer Company. *Designing the Installation of the Electro-Hydronic Energy Conservation System.* Auburn, NY: The Singer Company, Climate Control Div., 1978.
Spence Engineering Co. *Steam Pressure Reducing Station Noise Treatment.* Walden, NY: Spence Engineering Co.
Spirax/Sarco. *Design of Fluid Systems, Steam Utilization.* Allentown, PA: Spirax/Sarco, 1991.
Spirax/Sarco. *Design of Fluid Systems, Hook-ups.* Allentown, PA: Spirax/Sarco, 1992.
Strock, Clifford. *Handbook of Air Conditioning, Heating, and Ventilating.* 1st Ed., New York, NY: The Industrial Press, 1959.
Systecon, Inc. *Distributed Pumping (Pressure Gradient Control) for Chilled Water and Hot Water Systems.* Cincinnati, OH: Systecon, Inc., 1992.

52.02 Building Codes

A. 2003 International Code Council Series of Codes (ICC)

1. ICC. *2003 International Building Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
2. ICC. *2003 International Mechanical Code*. 2003 Ed., Country Club Hills, IL: ICC, 2003.
3. ICC. *2003 International Mechanical Code Commentary*. 2003 Ed., Country Club Hills, IL: ICC, 2004.
4. ICC. *2003 International Energy Conservation Code*. 2003 Ed., Country Club Hills, IL: ICC, 2003.
5. ICC. *2003 International Energy Conservation Code Commentary*. 2003 Ed., Country Club Hills, IL: ICC, 2004.
6. ICC. *2003 International Plumbing Code*. 2003 Ed., Country Club Hills, IL: ICC, 2003.
7. ICC. *2003 International Fire Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
8. ICC. *2003 International Electric Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
9. ICC. *2003 International Fuel Gas Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
10. ICC. *2003 International Residential Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
11. ICC. *2003 International Existing Building Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
12. ICC. *2003 International Performance Code.* 2003 Ed., Country Club Hills, IL : ICC, 2003.
13. ICC. *2003 International Private Sewage Disposal Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
14. ICC. *2003 International Property Maintenance Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
15. ICC. *2003 International Zoning Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.
16. ICC. *2003 International Wildland-Urban Interface Code.* 2003 Ed., Country Club Hills, IL: ICC, 2003.

B. 2006 International Code Council Series of Codes (ICC)

1. ICC. *2006 International Building Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
2. ICC. *2006 International Mechanical Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
3. ICC. *2006 International Energy Conservation Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
4. ICC. 2006 *International Plumbing Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
5. ICC. *2006 International Fire Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
6. ICC. *2006 International Electric Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
7. ICC. *2006 International Fuel Gas Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
8. ICC. *2006 International Residential Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
9. ICC. *2006 International Existing Building Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
10. ICC. *2006 International Performance Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.

11. ICC. *2006 International Private Sewage Disposal Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
12. ICC. *2006 International Property Maintenance Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
13. ICC. *2006 International Zoning Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.
14. ICC. *2006 International Wildland-Urban Interface Code.* 2006 Ed., Country Club Hills, IL: ICC, 2006.

C. National Fire Protection Association (NFPA)

NFPA. *NFPA 1 Uniform Fire Code.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 10 Portable Fire Extinguishers.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 13 Installation of Sprinkler Systems.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 13 Installation of Sprinkler Systems Handbook.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 14 Installation of Standpipe and Hose systems.* Quincy, MA: NFPA, 2003.
NFPA. *NFPA 16 Deluge Foam-Water Sprinkler Systems and Foam-Water Spray Systems.* Quincy, MA: NFPA, 2003.
NFPA. *NFPA 17 Dry Chemical Extinguishing Systems.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 17A Wet Chemical Extinguishing Systems.* Quincy, MA: NFPA, 2001.
NFPA. *NFPA 20 Installation of Stationary Pumps.* Quincy, MA: NFPA, 2003.
NFPA. *NFPA 24 Installation of Private Fire Service Mains.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 30 Flammable and Combustible Liquids Code.* Quincy, MA: NFPA, 2003.
NFPA. *NFPA 31 Installation of Oil Burning Equipment.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 45 Fire Protection for Laboratories Using Chemicals.* Quincy, MA: NFPA, 2004.
NFPA. *NFPA 52 Vehicular Fuel Systems.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 54 National Fuel Gas Code.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 54 National Fuel Gas Code Handbook.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 55 Compressed Gases and Cryogenic Fluids.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 58 Liquefied Petroleum Gas Code.* Quincy, MA: NFPA, 2004.
NFPA. *NFPA 70 National Electrical Code.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 70 National Electrical Code Handbook.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 72 National Fire Alarm Code.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 75 Protection of Information Technology Equipment.* Quincy, MA: NFPA, 2003.
NFPA. *NFPA 76 Telecommunications Facilities.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 88A Parking Structures.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 90A Installation of Air Conditioning and Ventilating Systems.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 90B Installation of Warm Air Heating and Air Conditioning Systems.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 91 Exhaust Systems for Air Conveying of Gases.* Quincy, MA: NFPA, 2004.
NFPA. *NFPA 92A Smoke Control Systems.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 92B Smoke Management Systems in Malls, Atria, Large Areas.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 96 Ventilation Control and Fire Protection of Commercial Cooking Operations.* Quincy, MA: NFPA, 2004.
NFPA. *NFPA 99 Health Care Facilities.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 101 Life Safety Code.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 110 Emergency and Standby Power Systems.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 204 Smoke and Heat Venting.* Quincy, MA: NFPA, 2002.
NFPA. *NFPA 211 Chimneys, Fireplaces, Vents and Solid Fuel Burning Appliances.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 214 Water Cooling Towers.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 318 Protection of Semiconductor Fabrication Facilities.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 418 Heliports.* Quincy, MA: NFPA, 2006.

NFPA. *NFPA 750 Water Mist Fire Protection Systems.* Quincy, MA: NFPA, 2006.
NFPA. *NFPA 900 Building Energy Code.* Quincy, MA: NFPA, 2004.
NFPA. *NFPA 909 Protection of Cultural Resource Properties.* Quincy, MA: NFPA, 2005.
NFPA. *NFPA 914 Fire Protection in Historic Structures.* Quincy, MA: NFPA, 2001.
NFPA. *NFPA 5000 Building Construction and Safety Code.* Quincy, MA: NFPA, 2006.

D. Miscellaneous

The American Institute of Architects Committee on Architecture for Health. *Guidelines for Design and Construction of Health Care Facilities.* Washington, D.C: The American Institute of Architects' Press, 2006.
The American Institute of Architects Center for Advanced Technology Facilities Design. *Guidelines and Planning and Design of Biomedical Research Laboratory Facilities*. Washington, D.C: The American Institute of Architects' Press, 1999.
American Industrial Hygiene Association and The American National Standards Institute. *American National Standard—Laboratory Ventilation*. Fairfax, VA: American Industrial Hygiene Association, 2003.
Air Conditioning Contractors' Association. *Manual J Residential Load Calculations*. 8th Ed., Arlington, VA: Air Conditioning Contractors' Association, 2004.
Mower, Joe. *Updating Your Old Steam Heating System Using Modern Components*. Shippensburg, PA: Burd Street Press, 2003.
Associated Air Balance Council. *AABC Commissioning Guideline for Building Owners, Design Professionals, and Commissioning Service Providers*. Washington, D.C.: Associated Air Balance Council, 2002.
The Pennsylvania Housing Research/Resource Center (PHRC). *Pennsylvania's Alternative Residential Energy Provisions*. University Park, PA: PHRC, 2003.