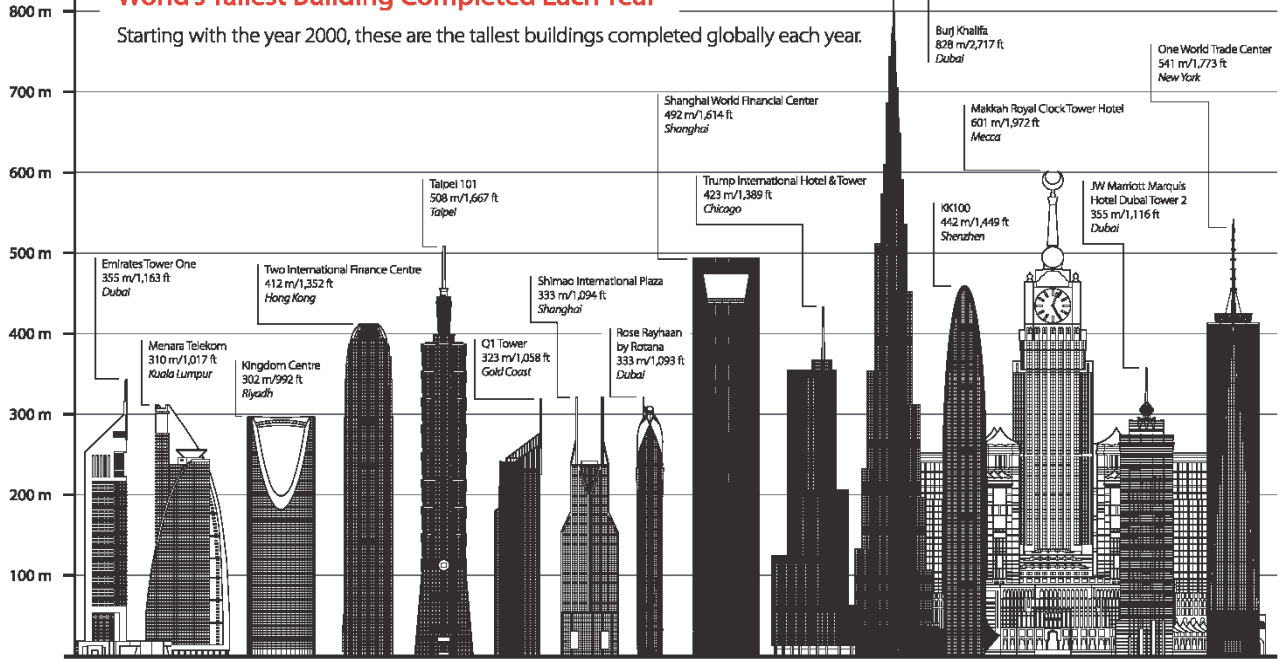
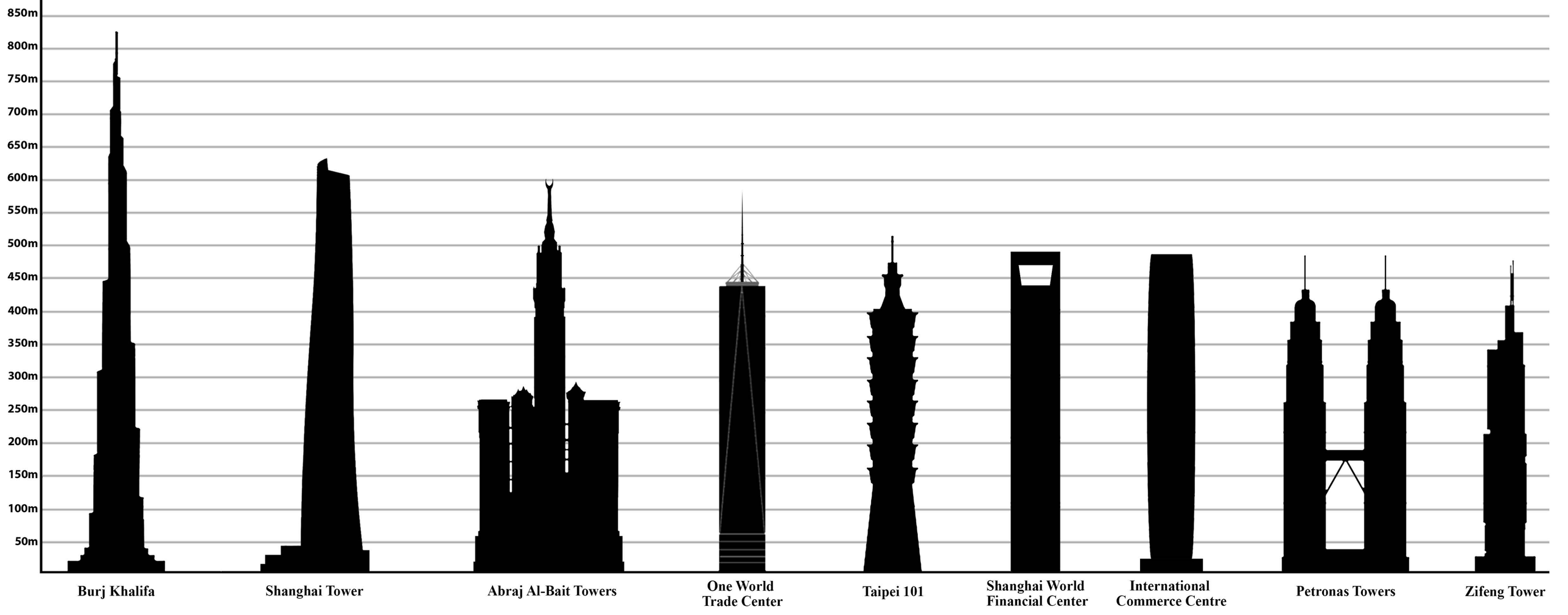
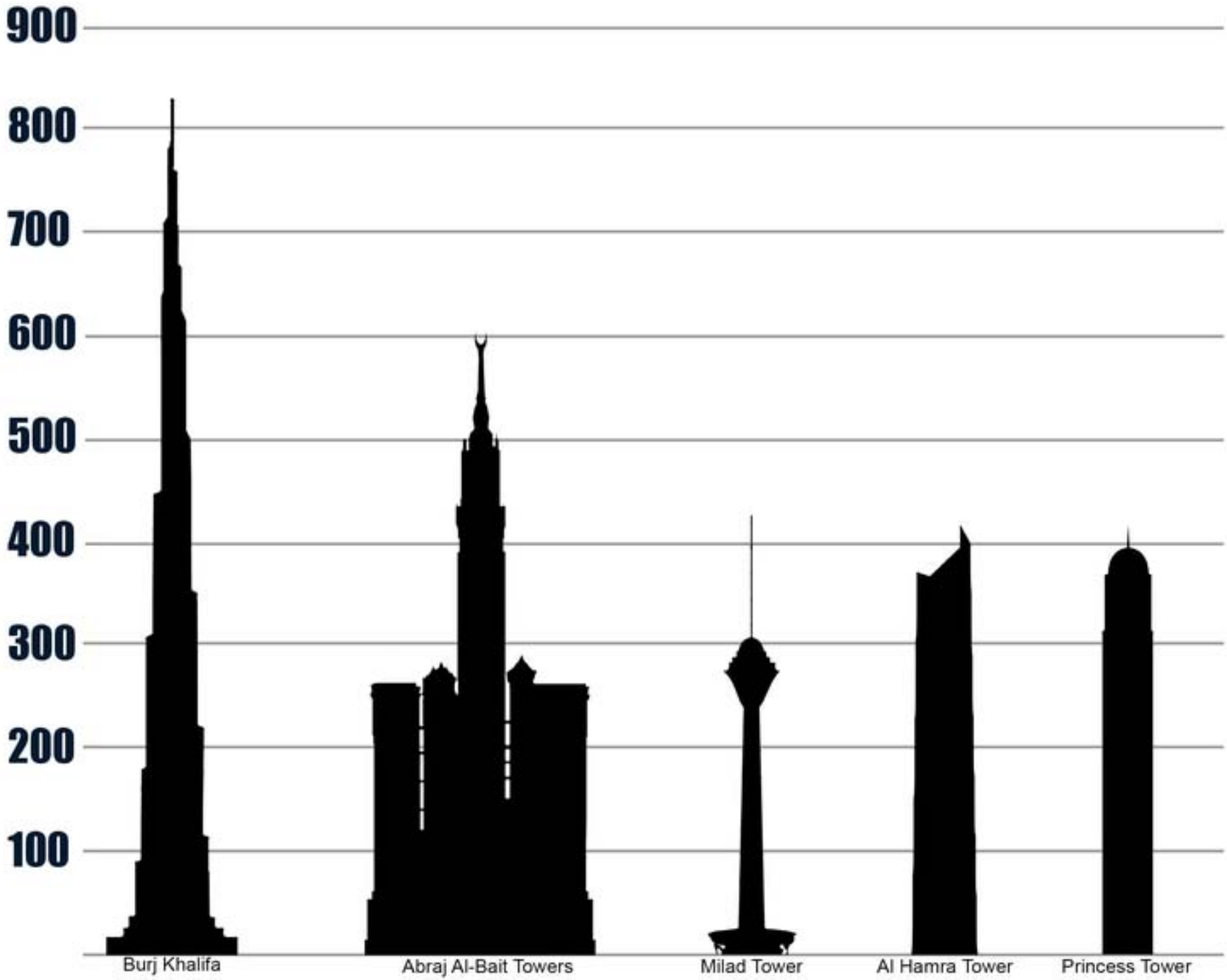
World's Tallest Building Completed Each Year

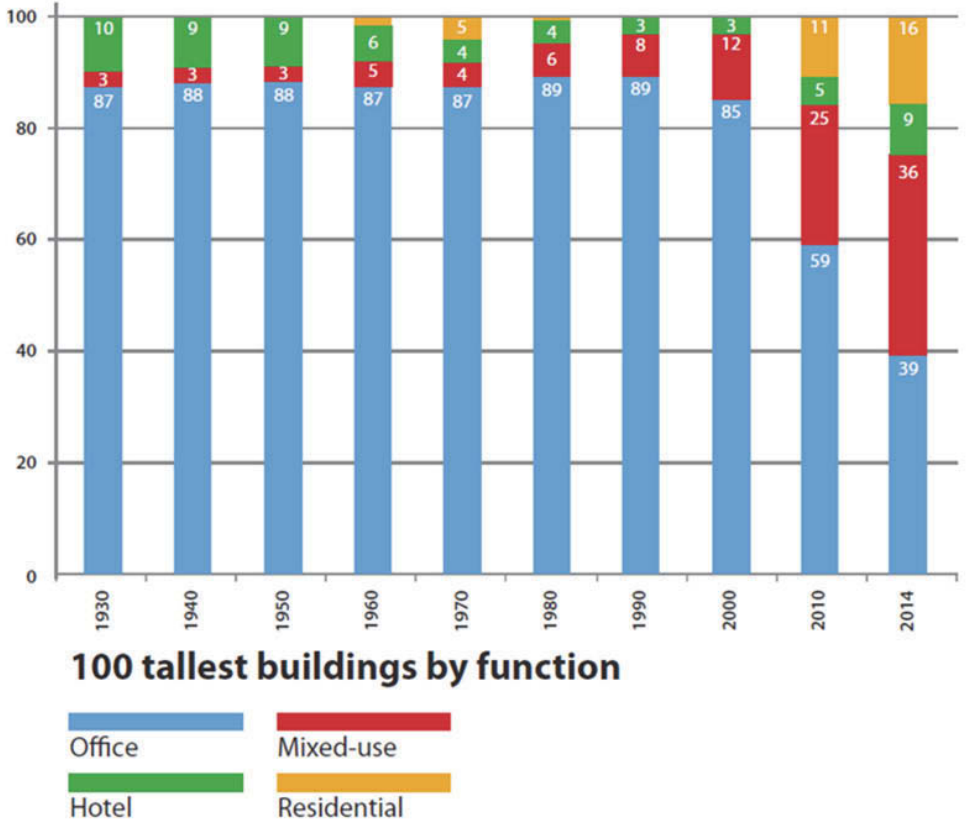
Starting with the year 2000, these are the tallest buildings completed globally each year.



© Council On Tall Buildings and Urban Habitat


850m
800m
750m
700m
650m
600m
550m
500m
450m
400m
350m
300m
250m
200m
150m
100m
50m
Burj Khalifa
Shanghai Tower
Abraj Al-Bait Towers
One World Trade Center
Taipei 101
Shanghai World Financial Center
International Commerce Centre
Petronas Towers
Zifeng Tower

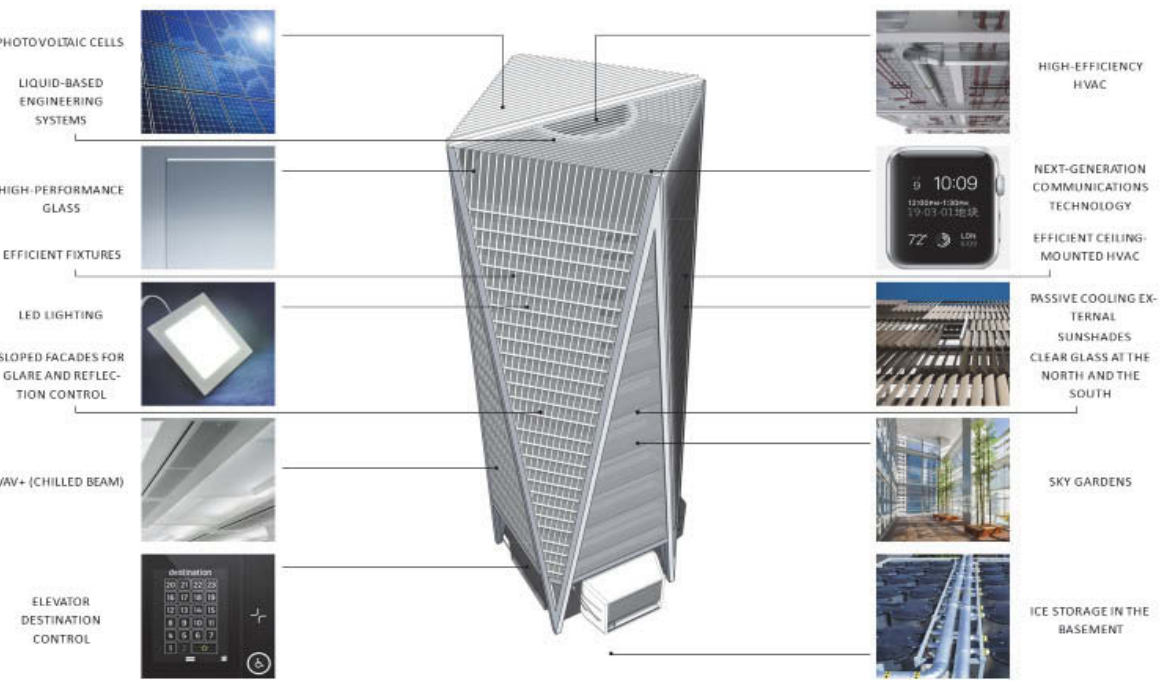

900
800
700
600
500
400
300
200
100
Burj Khalifa
Abraj Al-Bait Towers
Milad Tower
Al Hamra Tower
Princess Tower



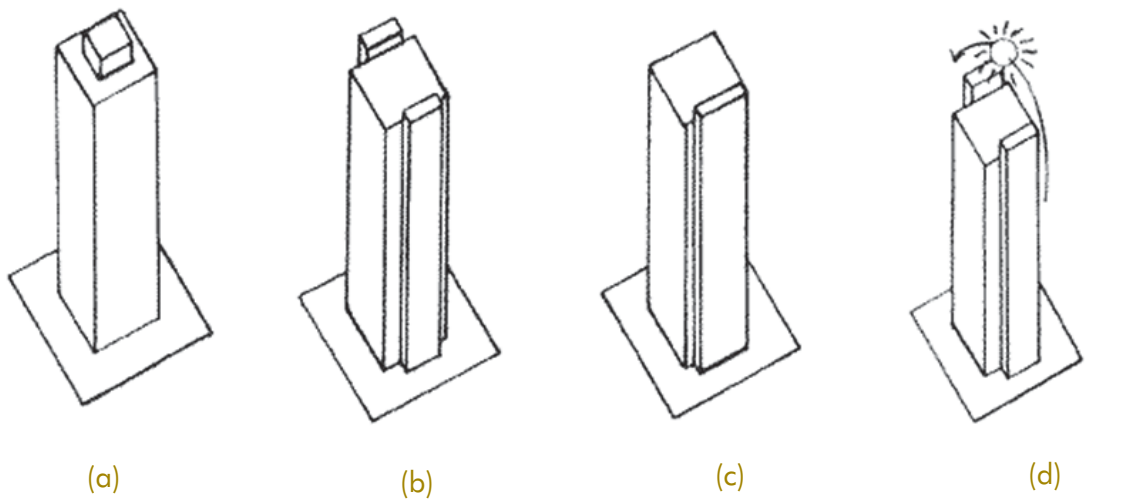
The world's 100 tallest buildings by function.

Rank	Building[A]	City	Country	Height[9]		Floors	Built
1	**Burj Khalifa**	Dubai	United Arab Emirates	828 m	2,717 ft	163	2010
2	Shanghai Tower	Shanghai	China	632 m[10]	2,073 ft	128	2015
3	Abraj Al-Bait Clock Tower	Mecca	Saudi Arabia	601 m[11]	1,971 ft	120	2012
4	Ping An Finance Centre	Shenzhen	China	599 m	1,965 ft	115	2017
5	Lotte World Tower	Seoul	South Korea	554.5 m	1,819 ft	123	2016
6	One World Trade Center	New York City	United States	541.3 m	1,776 ft	104	2014
7	Guangzhou CTF Finance Centre	Guangzhou	China	530 m[12]	1,739 ft	111	2016
7	Tianjin CTF Finance Centre	Tianjin	China	530 m	1,739 ft	98	2018
9	China Zun	Beijing	China	528 m	1,732 ft	108	2018
10	**Taipei 101**	Taipei	Taiwan	508 m[13]	1,667 ft	101	2004
11	Shanghai World Financial Center	Shanghai	China	492 m	1,614 ft	101	2008
12	International Commerce Centre	Hong Kong	China	484 m	1,588 ft	118	2010
13	Lakhta Center[14]	St. Petersburg	Russia	462 m	1,516 ft	86	2018
14	Landmark 81	Ho Chi Minh City	Vietnam	461.2 m	1,513 ft	81	2018
15	Changsha IFS Tower T1	Changsha	China	452.1 m	1,483 ft	88	2017
16	**Petronas Tower 1**	Kuala Lumpur	Malaysia	451.9 m	1,483 ft	88	1998
16	**Petronas Tower 2**	Kuala Lumpur	Malaysia	451.9 m	1,483 ft	88	1998
16	The Exchange 106	Kuala Lumpur	Malaysia	451.9 m	1,483 ft	97	2018
19	Zifeng Tower	Nanjing	China	450 m	1,476 ft	89	2010
19	Suzhou IFS	Suzhou	China	450 m	1,476 ft	92	2017
21	**Willis Tower** (formerly the **Sears Tower**)	Chicago	United States	442.1 m	1,450 ft	108	1974
22	KK100	Shenzhen	China	442 m	1,449 ft	100	2011
23	Guangzhou International Finance Center	Guangzhou	China	440 m	1,440 ft	103	2010
24	Wuhan Center	Wuhan	China	438 m	1,437 ft	88	2016[B]
25	432 Park Avenue	New York City	United States	425.5 m	1,396 ft	88	2015
26	Marina 101	Dubai	United Arab Emirates	425 m	1,394 ft	101	2015[B]
27	Trump International Hotel and Tower[15]	Chicago	United States	423.2 m	1,388 ft	98	2009
28	Jin Mao Tower	Shanghai	China	421 m	1,380 ft	88	1999
29	Princess Tower	Dubai	United Arab Emirates	414 m	1,358 ft[16]	101	2012
30	Al Hamra Tower	Kuwait City	Kuwait	413 m	1,354 ft	80	2011
31	Two International Finance Centre	Hong Kong	China	412 m	1,352 ft	88	2003
32	Guangxi China Resources Tower	Nanning	China	402.7 m	1,321 ft	85	2018
33	China Resources Headquarters	Shenzhen	China	392.5 m	1,288 ft	67	2017
34	23 Marina	Dubai	United Arab	392.4 m	1,287 ft	89	2012

Rank	Building[A]	City	Country	Height[9]		Floors	Built
			Emirates				
35	CITIC Plaza	Guangzhou	China	390.2 m	1,280 ft	80	1996
36	Shum Yip Upperhills Tower 1	Shenzhen	China	388.1 m	1,273 ft	80	2017
37	30 Hudson Yards	New York City	United States	386.6 m	1,268 ft	73	2018
38	Capital Market Authority Headquarters	Riyadh	Saudi Arabia	385 m	1,263 ft	77	2016
39	Shun Hing Square	Shenzhen	China	384 m	1,260 ft	69	1996
40	Eton Place Dalian Tower 1	Dalian	China	383 m	1,257 ft	81	2015
41	Logan Century Center 1	Nanning	China	381.3 m	1,251 ft	82	2017
42	Burj Mohammed bin Rashid	Abu Dhabi	United Arab Emirates	381 m	1,251 ft	88	2014
43	**Empire State Building**	New York City	United States	381 m	1,250 ft	102	1931
44	Elite Residence	Dubai	United Arab Emirates	381 m	1,248 ft	87	2012
45	Central Plaza	Hong Kong	China	373.9 m	1,226 ft	78	1992
46	Federation Tower (East Tower)[17]	Moscow	Russia	373.7 m	1,226 ft	95	2016
47	Dalian International Trade Center	Dalian	China	370.2 m	1,214 ft	86	2018
48	The Address the BLVD	Dubai	United Arab Emirates	370 m	1,214 ft	72	2017
49	Golden Eagle Tiandi Tower A	Nanjing	China	368.1 m	1,208 ft	76	2018
50	Bank of China Tower	Hong Kong	China	367 m	1,205 ft	70	1990
51	Bank of America Tower	New York City	United States	365.8 m	1,200 ft	54	2009
52	Almas Tower	Dubai	United Arab Emirates	363 m	1,191 ft	68	2009
53	Hanking Center	Shenzhen	China	358.9 m	1,177 ft	65	2017
54	Gevora Hotel	Dubai	United Arab Emirates	356.3 m	1,169 ft	75	2017
55	JW Marriott Marquis Dubai Tower 1	Dubai	United Arab Emirates	355 m	1,166 ft	82	2012
55	JW Marriott Marquis Dubai Tower 2	Dubai	United Arab Emirates	355 m	1,166 ft	82	2012
57	Emirates Office Tower	Dubai	United Arab Emirates	355 m	1,163 ft	54	2000
58	Raffles City Chongqing T3N[18]	Chongqing	China	354.5 m	1,163 ft	79	2018
58	Raffles City Chongqing T4N[18]	Chongqing	China	354.5 m	1,163 ft	79	2019
60	OKO Tower - South Tower	Moscow	Russia	354 m	1,160 ft	85	2015
61	The Marina Torch	Dubai	United Arab Emirates	352 m	1,155 ft	86	2011
62	Forum 66 Tower 1	Shenyang	China	350.6 m	1,150 ft	68	2015
63	The Pinnacle	Guangzhou	China	350.3 m	1,149 ft	60	2012
64	Xi An Glory International Financial Center[19]	Xi'an	China	350 m	1,148 ft	75	2017



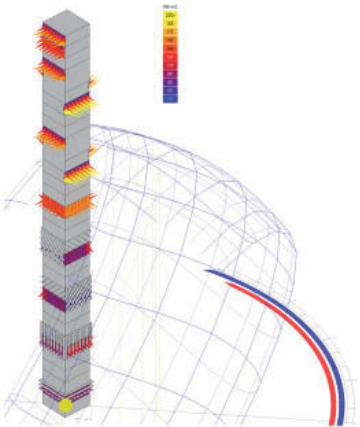
1.5 Various sustainable systems that can be applied to tall, supertall, and megatall buildings.



2.8 (a) Central core, (b) double core, (c) single-sided core, and (d) east and west sides.

Sensitivity analysis for facade orientation and solar radiation

Facade System



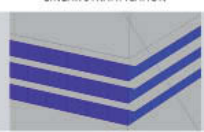
SHADING SYSTEMS tested for a building orientation of 48.5 deg

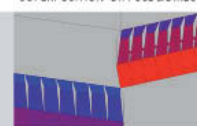
LINEAR STRATIFICATION

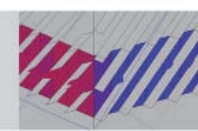
SUPERPOSITION DIFFUSE & DIRECT

DIAGONAL INTERFERENCE

	Direct solar radiation W/m² / (Diffuse solar radiation W/m²)			
shading system	**North-East**	**South-East**	**South-West**	**North-West**
None	14.2 / (100.4)	42.0 / (100.4)	56.0 / (100.4)	38.0 / (100.4)
Horizontal	2.3 / (70.3)	9.6 / (79.8)	18.3 / (70.3)	17.2 / (70.6)
Vertical	3.5 / (75.7)	36.2 / (75.7)	36.3 / (75.4)	21.0 / (75.9)
diagonal +45deg	0.0 / (59.1)	12.2 / (58.5)	3.5 / (58.4)	25.8 / (85.0)
diagonal -45deg	6.4 / (58.5)	6.3 / (59.1)	26.0 / (59.1)	4.4 / (58.3)







Typical solar radiation analysis of a building's façade.

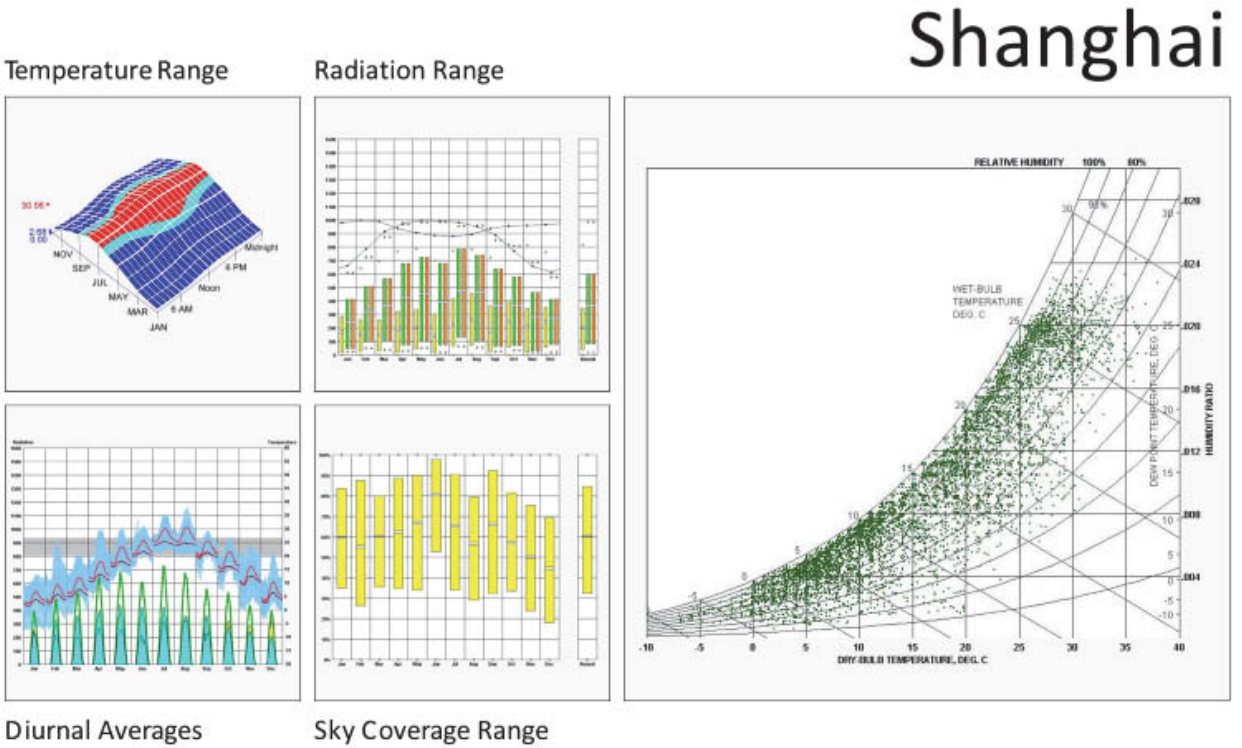
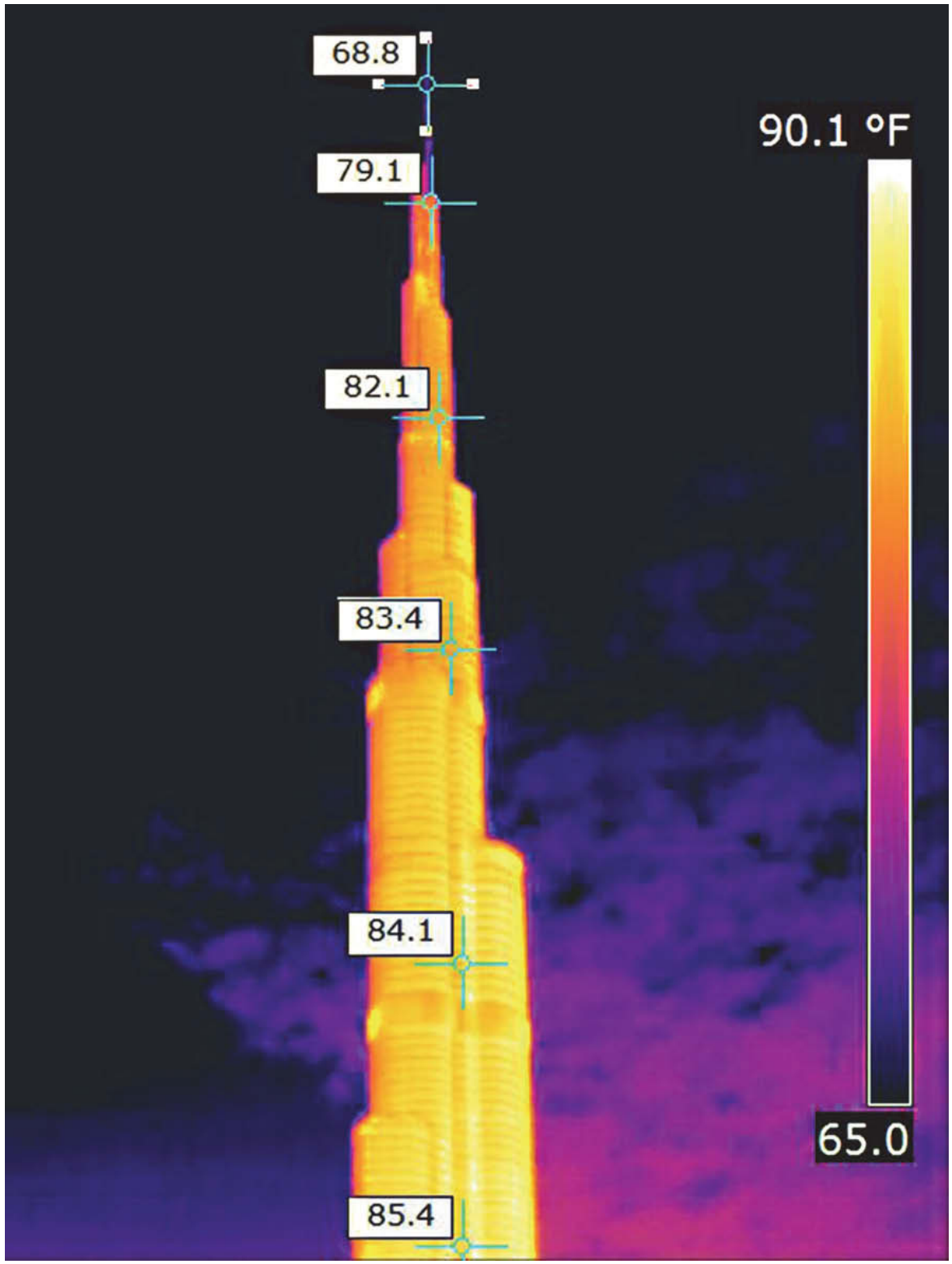


Figure 4.4 Example of a climate analysis.



The vertical temperature distribution over the height of the Burj Khalifa.

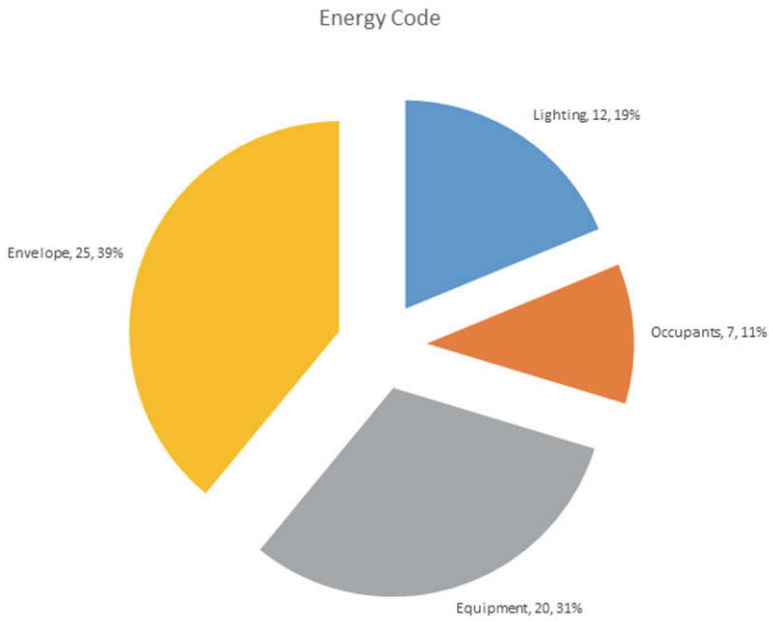


Figure 3.4 Breakdown of energy components for energy code building.

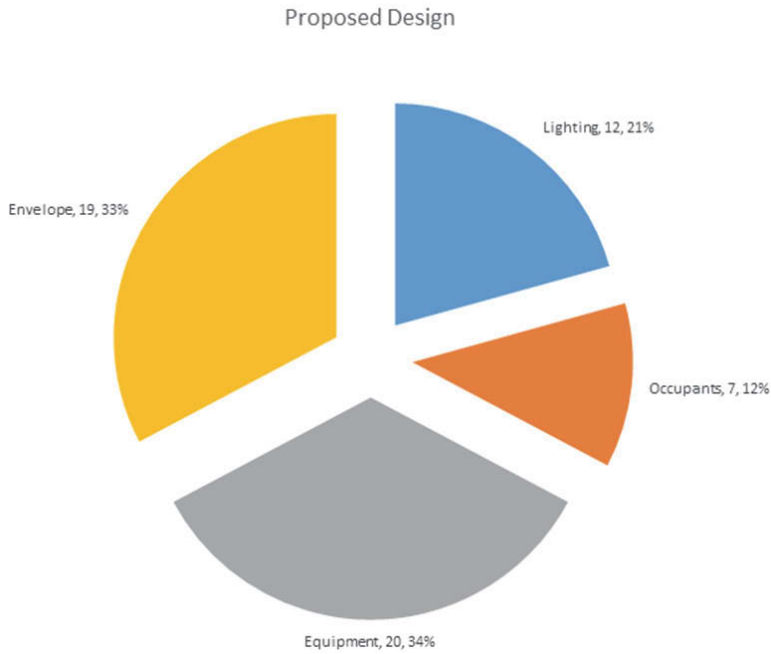


Figure 3.5 Breakdown of energy components for proposal design.

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.

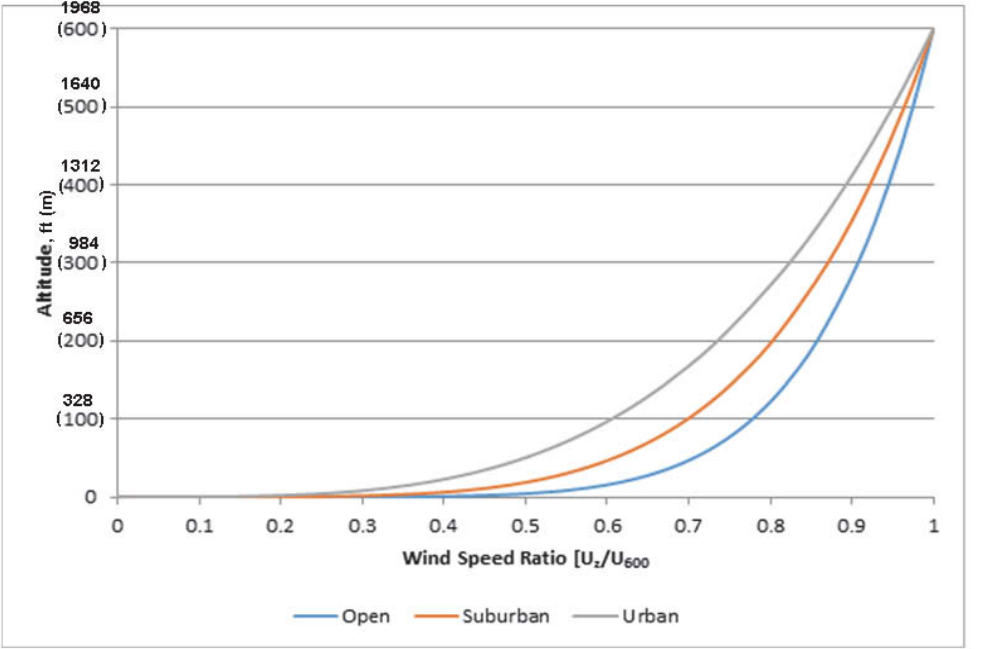
B. Cooling infiltration values are generally taken as 1/2 of the values listed earlier for heating infiltration.

Heat loss calculations for high buildings

Floor	*Addition to infiltration rate*	*Designation of U-valve*
Ground, 1st	nil	Normal
2nd to 4th	25%	Normal
5th to 11th	50%	Normal
Above 11th	100%	Severe

Infiltration heat loss

Heat loss for 1 air change per hour = 0.34 W/m^3 K (0.018 Btu/hr ft^3 °F).



Wind speed profile for different ground roughness.

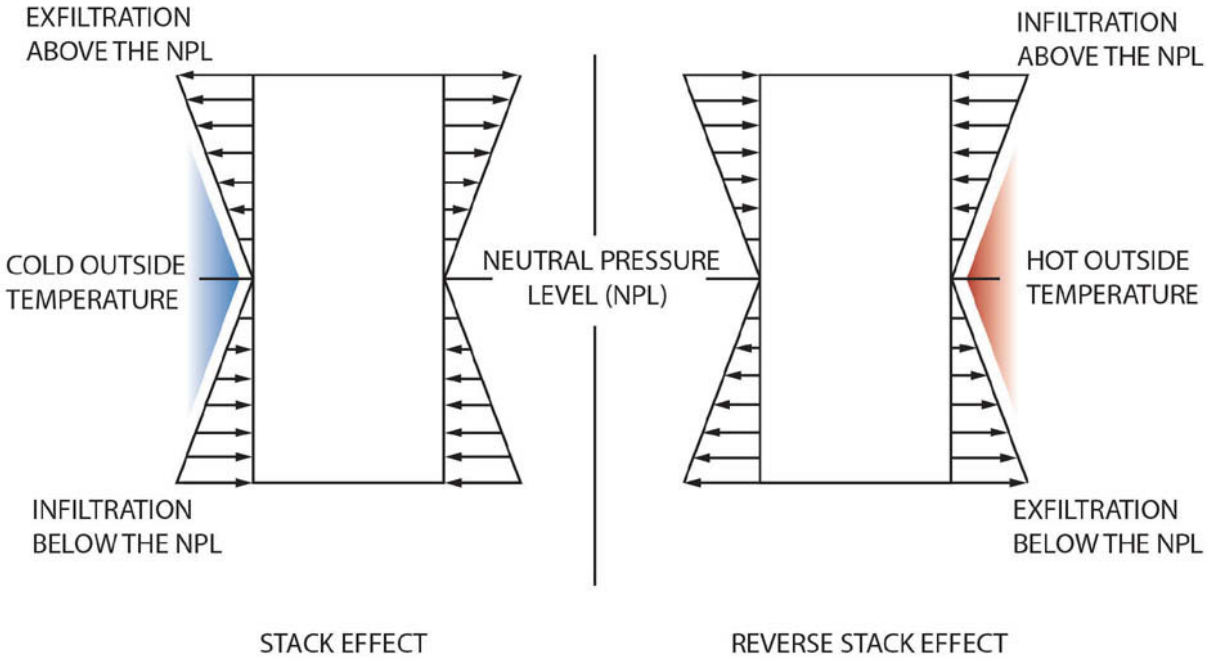


Figure 4.7 The airflow caused by stack effect and reverse stack effect.

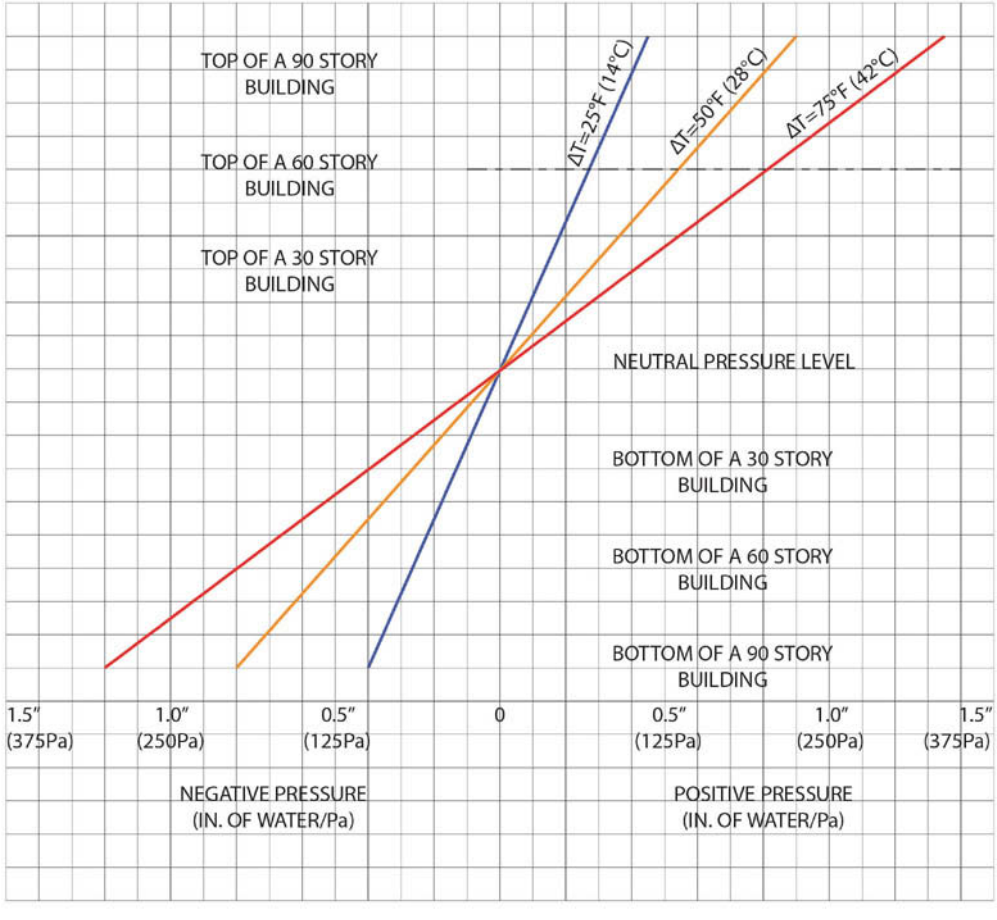
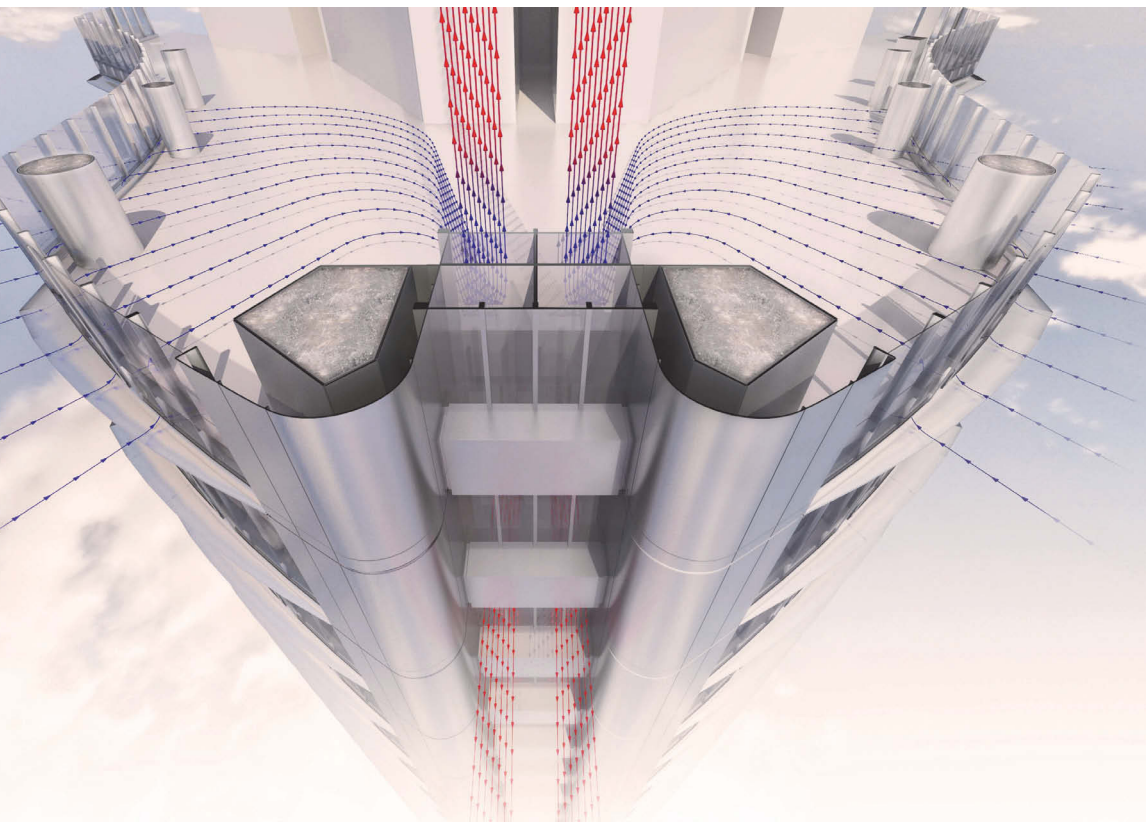


Figure 4.8 Theoretical stack effect pressure gradient for various building heights at alternative temperature differences.



Natural ventilation concept for a supertall building.

STANDARD

ANSI/ASHRAE Standard 62.1-2013
(Supersedes ANSI/ASHRAE Standard 62.1-2010)
Includes ANSI/ASHRAE addenda listed in Appendix J

Ventilation for Acceptable Indoor Air Quality

See Appendix J for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE Web site (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multiuse assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	7	3.5	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.

3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.

5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.

6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.

B Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").

D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.

F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

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TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Coffee stations	5	2.5	0.06	0.3		20	8	4	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	—	—	0.06	0.3		—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.

3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.

5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.

6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.

B Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").

D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.

F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

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TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Freezer and refrigerated spaces (<50°F)	10	5	0	0	E	0	0	0	2
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	10	5	0.12	0.6	B	2	70	35	2
Sorting, packing, light assembly	7.5	3.8	0.12	0.6		7	25	12.5	2
Telephone closets	—	—	0.00	0.0		—			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	10	5	0.06	0.3	B	—			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	—	—	0.06	0.3					1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.

3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.

5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.

6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.

B Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").

D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.

F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

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TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.12	0.6		20	14	7.0	2
Sports and Entertainment									
Gym, sports arena (play area)	20	10	0.18	0.9	E	7	45	23	2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	—	—	0.48	2.4	C	—			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	2
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.

3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.

5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.

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D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.

F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

vided such value is the product of the net occupiable area of the ventilation zone and the default occupant density listed in Table 6.2.2.1.

6.2.2.2 Zone Air Distribution Effectiveness. The zone air distribution effectiveness (E_z) shall be no greater than the default value determined using Table 6.2.2.2.

Note: For some configurations, the default value depends upon space and supply air temperature.

6.2.2.3 Zone Outdoor Airflow. The zone outdoor airflow (V_{oz}), i.e., the outdoor airflow rate that must be provided to the ventilation zone by the supply air distribution system, shall be determined in accordance with Equation 6.2.2.3.

$$V_{oz} = V_{bz}/E_z \qquad (6.2.2.3)$$

6.2.3 Single-Zone Systems. For ventilation systems wherein one or more air handlers supply a mixture of outdoor air and recirculated air to only one ventilation zone, the

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TABLE 6.5 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, L/s·m^2	Air Class
Arenas	—	0.50	B	—	—	1
Art classrooms	—	0.70		—	3.5	2
Auto repair rooms	—	1.50	A	—	7.5	2
Barber shops	—	0.50		—	2.5	2
Beauty and nail salons	—	0.60		—	3.0	2
Cells with toilet	—	1.00		—	5.0	2
Copy, printing rooms	—	0.50		—	2.5	2
Darkrooms	—	1.00		—	5.0	2
Educational science laboratories	—	1.00		—	5.0	2
Janitor closets, trash rooms, recycling	—	1.00		—	5.0	3
Kitchenettes	—	0.30		—	1.5	2
Kitchens—commercial	—	0.70		—	3.5	2
Locker/dressing rooms	—	0.25		—	1.25	2
Locker rooms	—	0.50		—	2.5	2
Paint spray booths	—	—	F	—	—	4
Parking garages	—	0.75	C	—	3.7	2
Pet shops (animal areas)	—	0.90		—	4.5	2
Refrigerating machinery rooms	—	—	F	—	—	3
Residential kitchens	50/100	—	G	25/50	—	2
Soiled laundry storage rooms	—	1.00	F	—	5.0	3
Storage rooms, chemical	—	1.50	F	—	7.5	4
Toilets—private	25/50	—	E, H	12.5/25	—	2
Toilets—public	50/70	—	D, H	25/35	—	2
Woodwork shop/classrooms	—	0.50		—	2.5	2

NOTES:

A Stands where engines are run shall have exhaust systems that directly connect to the engine exhaust and prevent escape of fumes.

B When combustion equipment is intended to be used on the playing surface additional dilution ventilation and/or source control shall be provided.

C Exhaust not required if two or more sides comprise walls that are at least 50% open to the outside.

D Rate is per water closet and/or urinal. Provide the higher rate where periods of heavy use are expected to occur, e.g., toilets in theatres, schools, and sports facilities. The lower rate may be used otherwise.

E Rate is for a toilet room intended to be occupied by one person at a time. For continuous system operation during normal hours of use, the lower rate may be used. Otherwise use the higher rate.

F See other applicable standards for exhaust rate.

G For continuous system operation, the lower rate may be used. Otherwise use the higher rate.

H Exhaust air that has been cleaned to meet Class 1 criteria from Section 5.16.1 shall be permitted to be recirculated.

6.4.3 Control and Accessibility. The means to open required operable openings shall be readily accessible to building occupants whenever the space is occupied. Controls shall be designed to properly coordinate operation of the natural and mechanical ventilation systems.

6.5 Exhaust Ventilation. The Prescriptive Compliance Path or the Performance Compliance Path shall be used to meet the requirements of this section. Exhaust makeup air may be any combination of outdoor air, recirculated air, and transfer air.

6.5.1 Prescriptive Compliance Path. The design exhaust airflow shall be determined in accordance with the requirements in Table 6.5.

6.5.2 Performance Compliance Path. The exhaust airflow shall be determined in accordance with the following subsections.

6.5.2.1 Contaminant Sources. Contaminants or mixtures of concern for purposes of the design shall be identified. For each contaminant or mixture of concern, indoor sources

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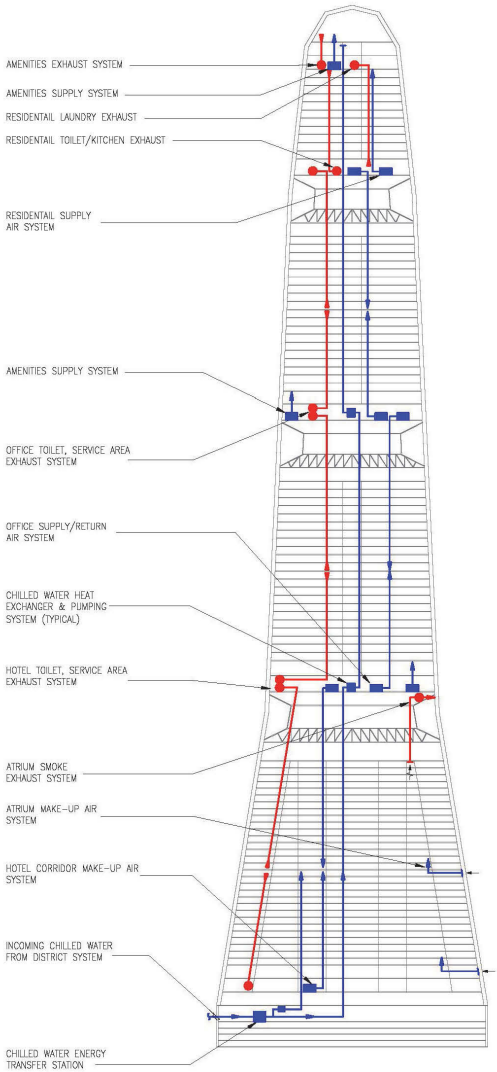
تلفن: ۰۲۱-۸۶۰۲۰۱۱۴
۰۲۱-۸۶۰۲۰۱۷۳
سامانه پیامک: ۱۰۰۰۶۶۴۲۲۱۲۲
دورنگار: ۰۲۱-۸۸۴۴۶۳۸۱
ارتباط مستقیم با هیات مدیره:
۰۲۱-۲۲۹۲۰۲۹۵
آدرس: تهران - خ مطهری
بین سهروردی و شریعتی
خ وزوائی - کوچه بخشایش
پلاک ۲ - واحد ۱ - خانه تاسیسات

ناشر ماهنامه خانه تاسیسات
ناشر تخصصی کتاب‌های فنی - مهندسی و تاسیسات
برگزارکننده سمینارها و دوره‌های تاسیسات مکانیکی، الکتریکی و انرژی

- تاسیسات
  - تاسیسات مکانیکی
    - HVAC – R
      - تجهیزات انتقال و توزیع
        - هوا
          - کانال + فن
            - آکسیال(جریان محوری)
            - سانتریفیوژ(گریز از مرکز)
        - مبرد
          - لوله + کمپرسور
        - آب
          - لوله + پمپ
            - خطی
            - زمینی
            - سیرکولاسیون(گردشی)
            - بوسترپمپ(پمپ تامین فشار)
      - تجهیزات تبادل حرارت
        - تک فصلی
          - رادیاتور
          - کنوکتور
          - گرمایش از کف
          - یونیت هیتر
        - دو فصلی
          - فن کویل
            - زمینی
            - ایستاده
            - سقفی
            - کانالی
          - هواساز
      - تجهیزات مولد
        - گرما
          - دیگ ها
            - چدنی
            - فولادی
          - کوره های هوای گرم
          - پکیج های آب گرم
          - گرمایش تابشی
        - سرما
          - سرمایش تراکمی
            - مولد هوای سرد
              - انواع کولر گازی
              - پکیج ها با کویل DX
            - مولد آب سرد (چیلرهای تراکمی)
              - چیلرهای رفت و برگشتی یا سیلندر - پیستونی یا ضربه ای (Reciprocating)
              - چیلرهای اسکرو یا پیچی یا چرخ گوشتی (Screw)
              - چیلرهای اسکرال یا اسکرول (Scroll)
              - چیلرهای سانتریفیوژ یا گریز از مرکز (Centrifugal)
          - سرمایش جذبی
            - چیلرهای تک اثره (Single Effect)
            - چیلرهای جذبی دو اثره (Double Effect)
            - چیلرهای جذبی شعله مستقیم (Direct Fire)
          - سرمایش تبخیری
            - ایرواشرها
              - کولرهای آبی
              - ایرواشرهای صنعتی
            - برج های خنک کننده
              - برج های مکعب فلزی یا گالوانیزه یا سانتریفیوژ
              - برج های مارلی یا ذوزنقه ای
              - برج های فایبرگلاس
              - برج های بتنی
    - آب و فاضلاب
    - تاسیسات الکتریکی



MECHANICAL

A typical distribution of water systems for a megatall building.

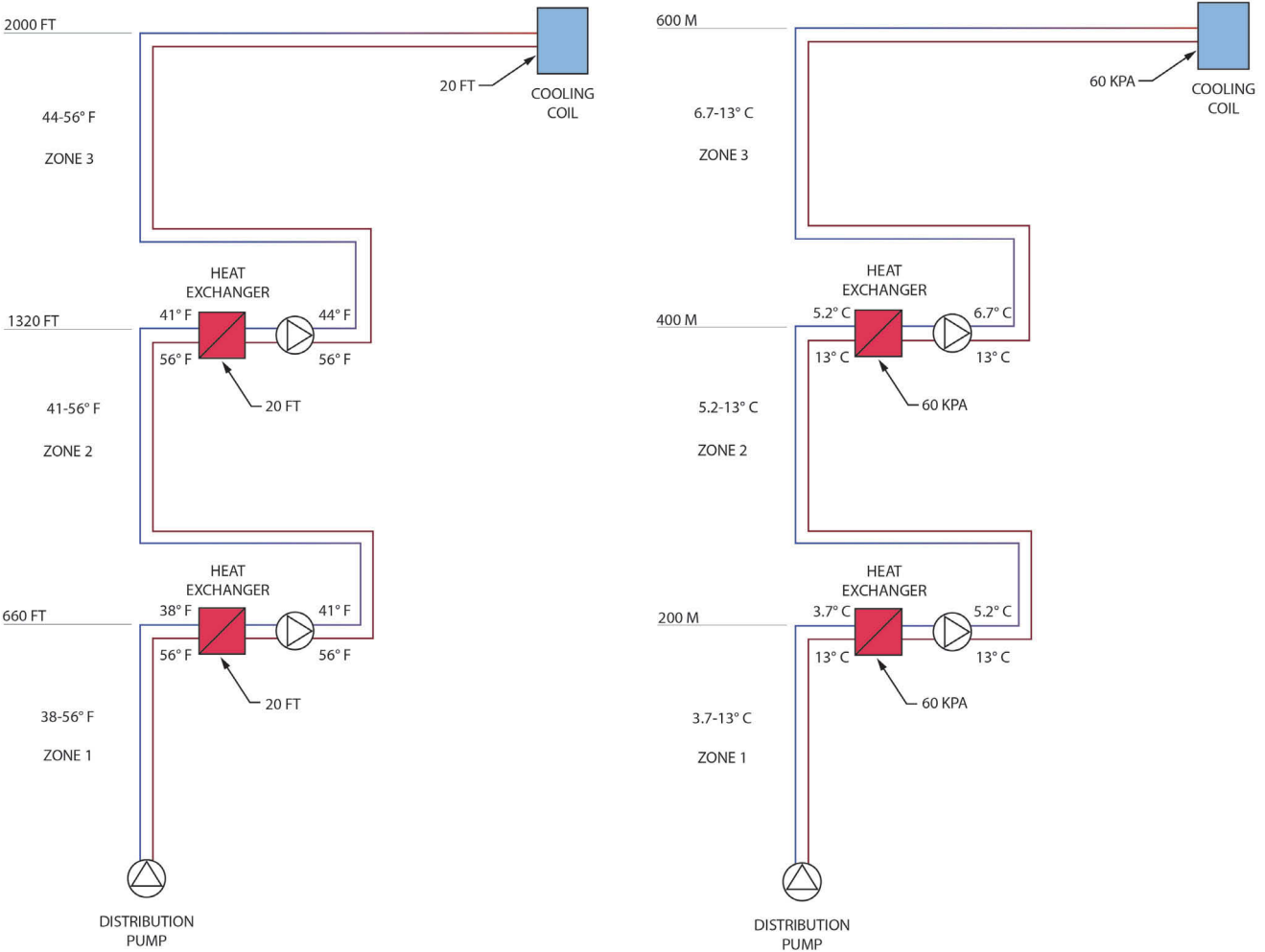


Figure 9.5 Zoned chilled water for 2000 ft (600 m) tall building.

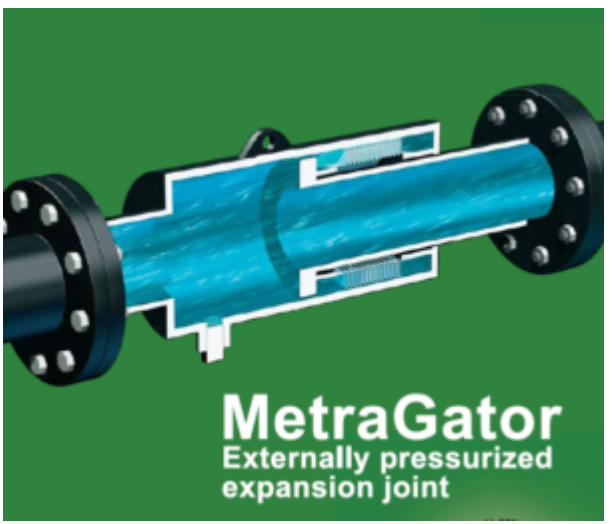
160 and above	Mechanical
156–159	Communication and broadcast
155	Mechanical
139–154	Corporate suites
136–138	Mechanical
125–135	Corporate suites
124	*At the Top* observatory
123	Sky lobby
122	*At.mosphere* restaurant
111–121	Corporate suites
109–110	Mechanical
77–108	Residential
76	Sky lobby
73–75	Mechanical
44–72	Residential
43	Sky lobby
40–42	Mechanical
38–39	Armani Hotel suites
19–37	Armani Residences
17–18	Mechanical
9–16	Armani Residences
1–8	Armani Hotel
Ground	Armani Hotel
Concourse	Armani Hotel
B1–B2	Parking, mechanical

The different floor levels of the Burj-Khalifa in Dubai.

Expansion Joints for HVAC Steam Systems

Monday Morning Minutes | by Norm Hall, September 4, 2017

Steel expands when you heat it. This is a fact of nature and shouldn't be overlooked when designing the HVAC steam piping system. One way of accommodating the expansion of the pipe is to use an expansion joint. Today, the R. L. Deppmann Monday Morning Minutes offers a solution for steam piping expansion joints.



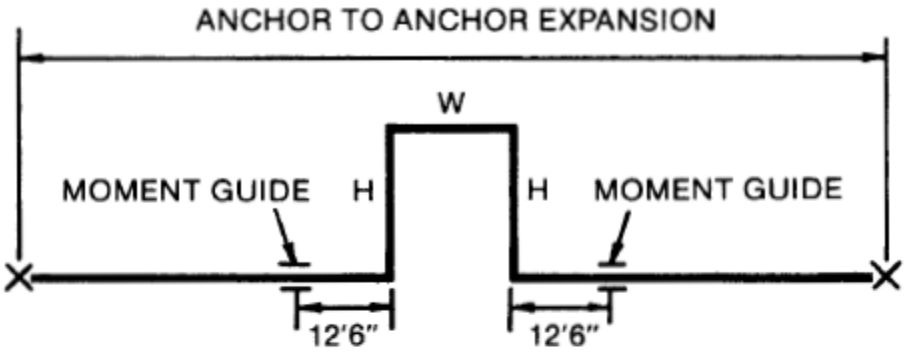
Expansion of Steel Pipe

There are many ways to control the expansion of steel pipe in steam distribution systems. One obvious solution often used is the natural flexibility of the pipe by installing a hard-piped expansion loop. Let's look at a quick example. Let's assume the project has 50 PSIG saturated steam in a 10" supply pipe which is 150 feet between anchors. The steam temperature is about300°F. If the project is in Michigan and the pipe is 0°F when installed, how much will the pipe expand?

	Carbon Steel	Copper	304 Stainless Steel
Change in	Linear Thermal Expansion	Linear Thermal Expansion	Linear Thermal Expansion
Temperature °F	in / 100 Feet	in / 100 Feet	in / 100 Feet
0	0	0	0
10	0.08	0.12	0.11
20	0.15	0.24	0.22
32	0.24	0.37	0.36
40	0.3	0.45	0.45
50	0.38	0.57	0.56
60	0.46	0.68	0.67
70	0.53	0.79	0.78
80	0.61	0.9	0.9
90	0.68	1.02	1.02
100	0.76	1.13	1.13
120	0.91	1.37	1.37
140	1.06	1.59	1.59
160	1.22	1.8	1.8
180	1.37	2.05	2.05
200	1.52	2.3	2.3
212	1.62	2.43	2.43
220	1.69	2.52	2.52
240	1.85	2.76	2.76
260	2.02	2.99	2.99
280	2.18	3.22	3.22
300	2.35	3.46	3.46

From the chart above, with a 300°F difference, we see that the steel pipe will expand 2.35” per 100 feet or a bit over 3.5” for 150 feet. The engineer may apply a safety factor to the numbers and ask for 4” of expansion in the piping system. Using the chart below from the Metraflex MEJ97 expansion joint guide, the engineer identifies the hard piped expansion loop must be 16’ long by 8 feet wide. Sometimes that required area for the loop or the installed cost becomes a hindrance and the engineer chooses to use an expansion joint.

Loops



Pipe Size		Anchor to Anchor Expansion									
		1"	2"	3"	4"	5"	6"	7"	8"	9"	10"
2"	W	2'0"	2'6"	3'6"	4'0"	4'6"	5'0"	5'6"	6'0"	6'6"	7'0"
	H	4'0"	5'0"	7'0"	8'0"	9'0"	10'0"	11'0"	12'0"	13'0"	14'0"
2½"	W	2'0"	3'0"	3'6"	4'0"	4'6"	5'0"	5'6"	6'0"	6'6"	7'0"
	H	4'0"	6'0"	7'0"	8'0"	9'0"	10'0"	11'0"	12'0"	13'6"	14'0"
3"	W	2'0"	3'0"	4'0"	4'6"	5'6"	6'0"	6'6"	7'0"	7'6"	8'0"
	H	4'0"	6'0"	8'0"	9'0"	11'0"	12'0"	13'0"	14'0"	15'0"	16'0"
4"	W	2'6"	3'6"	4'6"	5'6"	6'0"	7'0"	7'6"	8'0"	9'0"	9'6"
	H	5'0"	7'0"	9'0"	11'0"	12'0"	14'0"	15'0"	16'0"	18'0"	19'0"
5"	W	2'6"	4'0"	5'0"	6'0"	7'0"	8'0"	8'6"	9'6"	10'0"	11'0"
	H	5'0"	8'0"	10'0"	12'0"	14'0"	16'0"	17'0"	19'0"	20'0"	22'0"
6"	W	2'6"	4'6"	5'6"	6'6"	7'6"	8'6"	9'6"	10'6"	11'0"	12'0"
	H	5'0"	9'0"	11'0"	13'0"	15'0"	17'0"	19'0"	21'0"	22'0"	24'0"
8"	W	3'0"	4'6"	6'0"	7'6"	8'6"	8'6"	10'6"	11'6"	12'6"	13'6"
	H	6'0"	9'0"	12'0"	15'0"	17'0"	19'0"	21'0"	23'0"	25'0"	27'0"
10"	W	3'0"	4'6"	6'6"	8'0"	9'6"	10'6"	11'6"	12'6"	13'6"	14'6"
	H	6'0"	9'0"	13'0"	16'0"	19'0"	21'0"	23'0"	25'0"	27'0"	29'0"
12"	W	3'0"	5'0"	6'6"	8'6"	10'0"	11'0"	12'6"	13'6"	14'6"	15'0"
	H	6'0"	10'0"	13'0"	17'0"	20'0"	22'0"	25'0"	27'0"	29'0"	31'0"

فهرست سازه‌های بلند ایران به ترتیب ارتفاع:

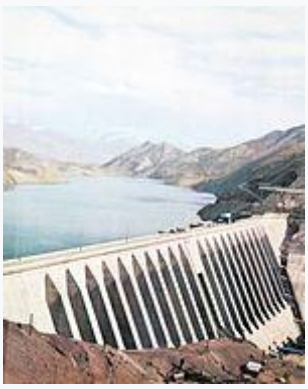
رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۱	برج میلاد[۱]	تهران	۴۳۵	
۲	دکل تلویزیونی زیباکنار	گیلان	۳۶۵	
۳	سد کارون ۴[۲]	اردل		
۴	سد کارون ۳	ایذه	۲۰۵	
۵	سد دز	اندیمشک	۲۰۳	
۶	نیروگاه شازند دودکش[۳]	شازند	۲۰۰	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۷	سد امیرکبیر	کرج	۱۸۰	
۸	سد سیمره	بدره	۱۸۰	
۹	برج بین‌المللی تهران[۴]	تهران	۱۶۲	
۱۰	مرکز تجارت جهانی تبریز	تبریز	۱۵۲	
۱۱	برج پاژ[۵]	مشهد	۱۵۰	
۱۲	هتل فارس[۶]	شیراز	۱۵۰	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۱۳	متل قو[۷]	سلمان شهر	۱۵۰	
۱۴	نیروگاه شهید رجایی برج‌های خنک‌کننده	قزوین	۱۵۰	
۱۵	مصلای تهران گلدسته‌های	تهران	۱۴۰	
۱۶	برج یاس[۸]	مشهد	۱۴۰	
۱۷	سد شهید رجایی	ساری	۱۳۸	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۱۸	سد جیرفت	جیرفت	۱۳۴	
۱۹	برج سفید	تهران	۱۳۲	
۲۰	سد کرخه	اندیمشک	۱۲۷	
۲۱	برج مرجان نیروی دریایی	تهران	۱۲۵	
۲۲	برج بی۳ مهستان	تهران	۱۲۰	
۲۳	برج دماوند	تهران	۱۲۰	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۲۴	برج آسمان[۷]	تهران	۱۲۰	
۲۵	برج هزاره سوم	تهران	۱۱۸	
۲۶	نیروگاه شهید منتظری برج‌های خنک‌کننده	اصفهان	۱۱۸	
۲۷	برج سپهر[۹]	تهران	۱۱۵	
۲۸	برج نگار	تهران	۱۱۴	
۲۹	برج مجلل لکسون	تهران	113	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۳۰	هتل چمران شیراز[۱۰]	شیراز	۱۱۰	
۳۵	مصلای اصفهان گلدسته‌های	اصفهان	۱۱۰	
۳۶	برج باران ۲[۷]	مشهد	۱۱۰	
۳۷	برج تجاری و تفریحی ائل گلی	تبریز	۱۱۰	
۳۸	برج ققنوس[۱۱]	سمنان	۱۱۰	
۳۹	سد لتیان	لواسان	۱۰۷	
۴۰	سد سفیدرود	منجیل	۱۰۶	
۴۱	برج الیزه ۱	مشهد	۱۰۵	
۴۲	مجتمع مسکونی سامان	تهران	۱۰۵	
۴۳	برج‌های سیتی سنتر اصفهان[۱۲]	اصفهان	۱۰۳	
۴۴	برج الیزه ۱	مشهد	۱۰۳	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۴۵	برج تجارت قزوین[۱۳]	قزوین	۱۰۳	
۴۶	سد رئیس علی دلواری	برازجان	۱۰۲	
۴۷	برج شهران[۱۴]	تبریز	۱۰۰	
۴۸	برج باران ۳	مشهد	۱۰۰	
۴۹	برج مینیاتور	مشهد	۱۰۰	
۵۰	سد زاینده رود	چادگان	۱۰۰	
۵۱	برج‌های دوقلوی الهیه	تهران	۱۰۰	
۵۲	برج نگین رضا	تهران	۹۸	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۵۳	برج بهشهر	تهران	۹۵	
۵۴	مسجد مکی گلدسته‌های[۱۵]	زاهدان	۹۴	
۵۵	آرامگاه سید روح‌الله خمینی گلدسته‌های	تهران	۹۱	
۵۶	هتل الماس ۲[۱۶]	مشهد	۹۰	
۵۷	هتل نرگس رضوی ۲	مشهد	۹۰	
۵۸	برج تجاری گل شرق	تبریز	۸۴	
۵۹	پل غدیر اهواز[۱۷]	اهواز	۸۱	
۶۰	بوستان ملت چرخ و فلک[۱۸]	مشهد	۸۰	
۶۱	برج آبشار کوثر	مشهد	۸۰	
۶۲	برج عدالت	مشهد	۸۰	
۶۳	هتل درویشی	مشهد	۸۰	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۶۴	برجهای مهر کوهسنگی	مشهد	۷۸	
۶۵	برج های دوقلوی روناک(درحال ساخت)	اردبیل	۷۸	
۶۶	هتل قصر طلایی	مشهد	۷۵	
۶۷	برج بانک مرکزی	تهران	۷۴	
۶۸	ساختمان اسکان	تهران	۷۲	
۶۹	برج مروارید گوهرشاد	مشهد	۷۲	
۷۰	برج گنبد قابوس	گنبد کاووس	۷۲	
۷۱	برج سلمان	مشهد	۷۰	
۷۲	برج مسکونی یاس	مشهد	۷۰	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۷۳	برج آلتون[۱۹]	مشهد	۷۰	
۷۴	ساختمان مرکزی بانک صادرات	مشهد	۷۰	
۷۵	مجتمع تجاری صدر	مشهد	۷۰	
۷۶	هتل سی نور	مشهد	۷۰	
۷۷	برج‌های دوقلوی سامان	تهران	۷۰	
۷۸	ساختمان بورس اوراق بهادار تهران	تهران	۶۸	
۷۹	زیست خاور	مشهد	۶۷	

رتبه	نام سازه	مکان	ارتفاع (متر)	تصویر
۸۰	برج مسکونی امام رضا	مشهد	۶۵	
۸۱	برج مسکونی آترین	مشهد	۶۵	
۸۲	هتل کایا لاله پارک	تبریز	۶۴	
۸۳	بیمارستان میلاد	تهران	۶۳	
۸۴	برج گرگان[۲۰]	گرگان	۵۷	
۸۵	هتل پارس ایل گلی	تبریز	۵۵	
۸۶	مناره مسجد امام	اصفهان	۵۲	
۸۷	برج لوکس مهتاب	اردبیل	۵۱	