Ch. 11 Passive heating
Ch. 12 Passive cooling

11.2 Degree-Days
11.5 Estimating the Balance-Point Temperature

12.1 Brief history
12.2 Design strategies for cooling
12.3 Summer heat gain guidelines
12.4 Passive cooling guidelines
12.5 Reintegrating daylighting, passive solar heating, and cooling
12.6 Approximate Method for Calculating Heat Gain (Cooling Load)
12.7 Detailed Hourly Heat Gain (Cooling Load) Calculations
12.8 Detailed calculations: Passive Cooling performance

End-use energy

1.3.6 1995 Commercial *Delivered* End-Use Energy Consumption Intensities, by Principal Building Type (1)

Building Type	Space Heating	Space Cooling	Water Heating	Lighting	Total (2)	Percent of Total Consumption
	Consumption (10^3 Btu/SF)					
Office	24.3	9.1	8.7	28.1	97.2	19%
Mercantile and Service	30.6	5.8	5.1	23.4	76.4	18%
Education	32.8	4.8	17.4	15.8	79.3	12%
Health Care	55.2	9.9	63.0	39.3	240.4	11%
Lodging	22.7	8.1	51.4	23.2	127.3	9%
Public Assembly	53.6	6.3	17.5	21.9	113.7	8%
Food Service	30.9	19.5	27.5	37.0	245.5	6%
Warehouse and Storage	15.7	0.9	2.0	9.8	38.3	6%
Food Sales	27.5	13.4	9.1	33.9	213.5	3%
Vacant (3)	38.0	1.4	5.5	4.5	30.1	3%
Public Order and Safety	27.8	6.1	23.4	16.4	97.2	2%
Other (4)	59.6	9.3	15.3	26.7	172.2	3%
All Buildings	29.0	6.0	13.8	20.4	90.5	100%

Note(s): 1) Further detail can be found in Table 7.4.1. Parking garages and commercial buildings on multibuilding manufacturing facilities are excluded from CBECS 1995. 2) Includes all end-uses. 3) Includes vacant and religious worship. 4) Includes mixed uses, hangars, crematoriums, laboratories, and other.

Source(s): EIA, Commercial Building Energy Consumption and Expenditures 1995, April 1998, Table EU-2, p. 311.

From Buildings energy databook (2002), Pacific Northwest National Laboratory

Energy breakdown (Residential)

Skin load dominated building

1.2.9 Aggregate Residential Building Component Loads (1)

	Loads (quads) and Percent of Total Loads			
Component	Heating		Cooling	
Roof	-0.65	12%	0.16	14%
Walls	-1.00	19%	0.11	10%
Foundation	-0.76	15%	-0.07	-
Infiltration	-1.47	28%	0.19	16%
Windows (conduction)	-1.34	26%	0.01	1%
Windows (solar gain)	0.43	-	0.37	32%
Internal Gains	0.79	-	0.31	27%
NET Load	-3.99	100%	1.08	100%

Note(s): 1) "Loads" represents the thermal energy losses/gains that when combined will be offset by a building's heating/cooling system to maintain a set interior temperature (which then equals *site* energy).

Source(s): LBNL, Residential Heating and Cooling Loads Component Analysis, November 1998, Figure P-1, P-1 and Appendix C: Component Loads Data Tables.

A quad is a unit of energy equal to 10^{15} BTU, or 1.055×10^{18} joules in SI units.

Energy breakdown (Commercial)

Internal load dominated building

1.3.9 Aggregate Commercial Building Component Loads (1)

	Loads (quads) and Percent of Total Loads			
	Heating		Cooling	
Component				
Roof	-0.103	12%	0.014	1%
Walls (2)	-0.174	21%	-0.008	-
Foundation	-0.093	11%	-0.058	-
Infiltration	-0.152	18%	-0.041	-
Ventilation	-0.129	15%	-0.045	-
Windows (conduction)	-0.188	22%	-0.085	-
Windows (solar gain)	0.114	-	0.386	32%
Internal Gains				
Lights	0.196	-	0.505	42%
Equipment (electrical)	0.048	-	0.207	17%
Equip. (non-electrical)	0.001	-	0.006	1%
People	0.038	-	0.082	7%
NET Load	-0.442	100%	0.963	100%

Note(s): 1) "Loads" represents the thermal energy losses/gains that, when combined, will be offset by a building's heating/cooling system to maintain a set interior temperature (which then equals *site* energy). 2) Includes common interior walls between buildings.

Source(s): LBNL, Commercial Heating and Cooling Loads Component Analysis, June 1998, Table 24, p. 45 and Figure 3, p. 61.

A quad (quadrillion) is a unit of energy equal to 10^{15} BTU, or 1.055×10^{18} joules in SI units.

11.5 Estimating Balance-Point Temperature

- Balance point temperature
  - When the "heat losses through the envelope and infiltration" equals the "heat gains to the building from solar radiation and internal sources (people, lights, equipment)", this particular outdoor temperature is called 'balance point temperature'.
- It represents the beginning of the need for space heating equipment.

Balance point

$$Q_{gain} = Q_{solar} + Q_{internal}\ (W)$$
$$Q_{loss} = Q_{envelope} + Q_{infiltration}\ (W)$$
$$Q_{envelope} = UA(t_i - t_b)$$
$$Q_{infiltration} = 1.2V(t_i - t_b)$$

Find t_b when $Q_{gain} = Q_{loss}$

$$Q_{gain} = Q_{solar} + Q_{internal} = UA(t_i - t_b) + 1.2V(t_i - t_b)$$

t_b = balance point temperature
t_i = average interior temperature over 24 hours, winter

UA_{total} = total heat loss rate envelope plus infiltration; in (Btu/h °F or W/°C)

Rewriting this equation to solve for the balance point temperature:

$$t_b = t_i - \frac{Q_i}{UA_{total}}$$

From MEEB 12th Ed.

People: Two adults and two children (average times of occupancy): 23,000 to 24,500 Btu/day (6.7 to 7.2 kWh/day)

Lights and equipment: See Table 9.3 for individual heat sources, but if actual appliances are unknown, then:

53,000 Btu/day (15.5 kWh/day) for standard-efficiency equipment

100,000 Btu/day (29.3 kWh/day) for old and inefficient equipment

TABLE 9.3 Typical Residential Daily Internal Heat Gains from Appliances and Lighting

PART A. ELECTRIC APPLIANCES		
Heat Source	**Btu/day**	**kWh/day**
Frost-free refrigerator	16,000	4.7
Freezer	10,900–15,700	3.2–4.6
Dryer[a]	8,900–11,600	2.6–3.4
Range[a]	6,500–11,300	1.9–3.3
Television[b]	3,400–4,400	1.0–1.3
Dishwasher	2,400	0.7
Lighting and miscellaneous[c]	9,500–18,800	2.8–5.5
Water heater[d]	13,700–27,400	4.0–8.0
PART B. GAS APPLIANCES		
Heat Source	**Btu/day**	
Water heater	13,700–27,400	
Dryer[a]	12,000–19,000	
Range[a]	12,000–27,000	

Source: A New Prosperity: Building a Sustainable Energy Future, The SERI Solar Conservation Study. Brick House Publishing. Andover, MA, 1981. Previously adapted, with the permission of ASHRAE, from the *1989 ASHRAE Handbook—Fundamentals.* This citation to an older version of the *Handbook* is intentional and provides access to historic reference information of ongoing interest.

[a]These are for the appliance's consumption per day; heat gain to a house is less, depending on the amount of heated exhaust air.

[b]Total daily use of TV per household.

[c]These figures are for an average 1350-ft² house; the rate per square foot of floor area may be extrapolated.

[d]Standby heat loss from water heater to house.

Example

- $Q_{gain} = 300(W)$, $A = 10m^2$, $U = 3(W/m^2K)$, $t_i = 20^\circ C$
- Find t_b? $t_b = 10^\circ C$

11.2 Calculation of Degree Days

- To derive HDD_{XX}, each day's mean temperature (halfway between high and low) is subtracted from the base temperature (or balance point temperature)
- HDD are totaled (added up) for an entire year
- HDD data in most cities can be found in Appendices Tables B.3 & Tables C.20. HDD data are published for each climate station and are calculated to various *base* temperatures
- Why multiple base temperatures like HDD50, HDD55, HDD60, HDD65?
- Interpolation between the various base DDs.
- Conversion: $DD_{SI} = 0.56\ DD_{IP}$ (5/9=0.56)
- What if the mean temperature is greater than the base temperature?

For example, assume that a day in Troy, New York, had a high of 60°F and a low of 34°F. The mean temperature was (60+34)/2=47˚F

65 – 47 = 18 DD65

60 – 47 = 13 DD60

55 – 47 = 8 DD55

50 – 47 = 3 DD50

Calculation of Degree Days (sample)

Month	Jan			
balance T	10			
Day	High ('C)	Low ('C)	Mean T	DD_{10}
1	4	2	3	7
2	5	1	3	7
3	6	0	3	7
4	7	-1	3	7
5	8	-2	3	7
6	5	2	3.5	6.5
7	9	4	6.5	3.5
8	7	5	6	4
9	6	3	4.5	5.5
10	4	-5	-0.5	10.5
11	5	-3	1	9
12	6	4	5	5
13	7	5	6	4
14	8	3	5.5	4.5
15	2	-5	-1.5	11.5
16	3	-3	0	10
17	4	2	3	7
18	4	2	3	7
19	5	-2	1.5	8.5
20	6	2	4	6
21	7	4	5.5	4.5
22	8	5	6.5	3.5
23	5	3	4	6
24	3	0	1.5	8.5
25	4	-1	1.5	8.5
26	5	-2	1.5	8.5
27	6	2	4	6
28	7	4	5.5	4.5
29	8	5	6.5	3.5
30	6	3	4.5	5.5
31	5	-2	1.5	8.5
				205

TABLE C.20 Average Insolation, Temperature, and DD Data (SI units)

Elevation in meters; latitude in degrees north latitude; HS (horizontal surface) and VS (vertical surface) insolation in W/day m^2; TA in degrees C; D10.0, D12.8, D15.6, and D18.3 in degree days C (for these various "base" temperatures).

United States

MONTGOMERY, ALABAMA Elev 62 Lat 32.3

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	2373	2827	9	82	142	219	309
Jul	5808	2587	27	0	0	0	0
Yr	4385	2985	18	247	481	819	1261

PHOENIX, ARIZONA Elev 339 Lat 33.4

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	3221	4613	11	43	90	158	238
Jul	7843	3041	33	0	0	0	0
Yr	4326	4184	21	104	255	511	862

TUCSON, ARIZONA Elev 779 Lat 32.1

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	3467	4856	11	44	92	162	246
Jul	7386	2909	30	0	0	0	0
Yr	5912	4124	20	119	292	576	973

FORT SMITH, ARKANSAS Elev 141 Lat 35.3

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	2347	3142	4	192	276	362	448
Jul	6515	2865	28	0	0	0	0
Yr	4436	3196	16	553	901	1336	1853

FRESNO, CALIFORNIA Elev 100 Lat 36.8

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	2073	2795	7	98	171	254	339
Jul	8471	3395	27	0	0	0	0
Yr	5408	3818	17	282	567	967	1472

GRAND JUNCTION, COLORADO Elev 1475 Lat 39.1

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	2496	4089	−3	403	489	575	661
Jul	7777	3452	26	0	0	0	0
Yr	5240	4247	12	1397	1896	2463	3114

HARTFORD, CONNECTICUT Elev 55 Lat 41.9

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	1505	2190	−4	434	520	606	692
Jul	5203	2716	23	0	0	1	3
Yr	3344	2634	9	1651	2193	2819	3528

WASHINGTON, DC Elev 88 Lat 38.9

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	1805	2502	0	308	394	481	567
Jul	5733	2786	24	0	0	0	0
Yr	3818	2877	12	1113	1594	2147	2783

MIAMI, FLORIDA Elev 2 Lat 25.8

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	3335	3537	19	1	2	10	29
Jul	5562	2483	28	0	0	0	0
Yr	4650	2969	24	2	8	31	114

ORLANDO, FLORIDA Elev 36 Lat 28.5

	HS	VS	TA	D10.0	D12.8	D15.6	D18.3
Jan	3152	3631	16	7	23	58	109
Jul	5682	2508	27	0	0	0	0
Yr	4695	3105	22	22	70	193	407

Monthly HDDs

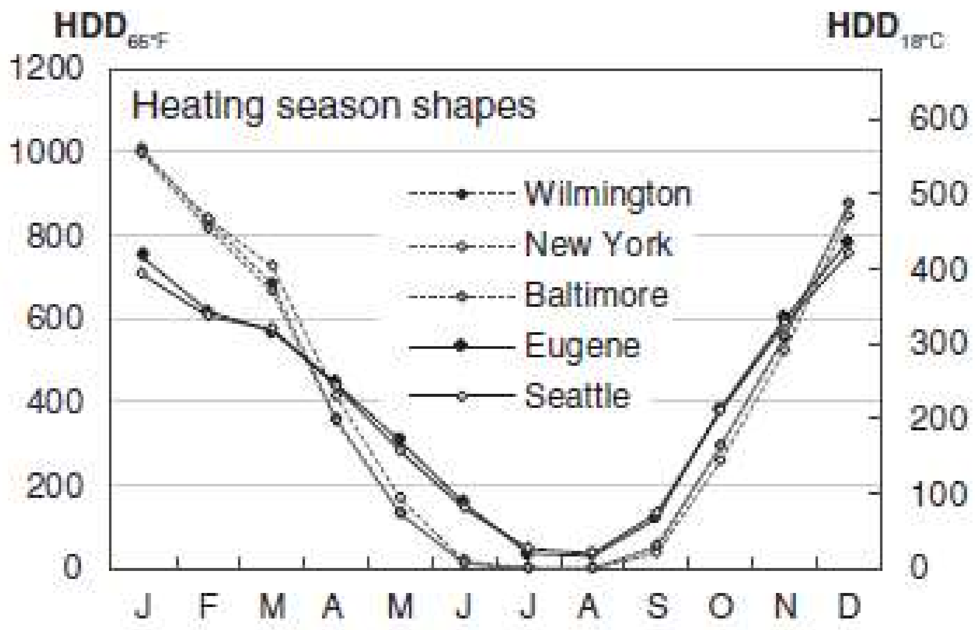

Fig. 11.7 *Contrasting heating season length and severity, as shown by monthly heating degree-days in Wilmington, DE; New York, NY; Baltimore, MD; Eugene, OR; and Seattle, WA, all with about 4800 annual* HDD_{65F} *(2650* $HDD_{18.3C}$*). (Data from 1981–2010 Climate Normals; Arguez et al., 2010.)*

ANNUAL HEATING DEGREE DAYS

BASED ON NORMAL PERIOD 1961-1990

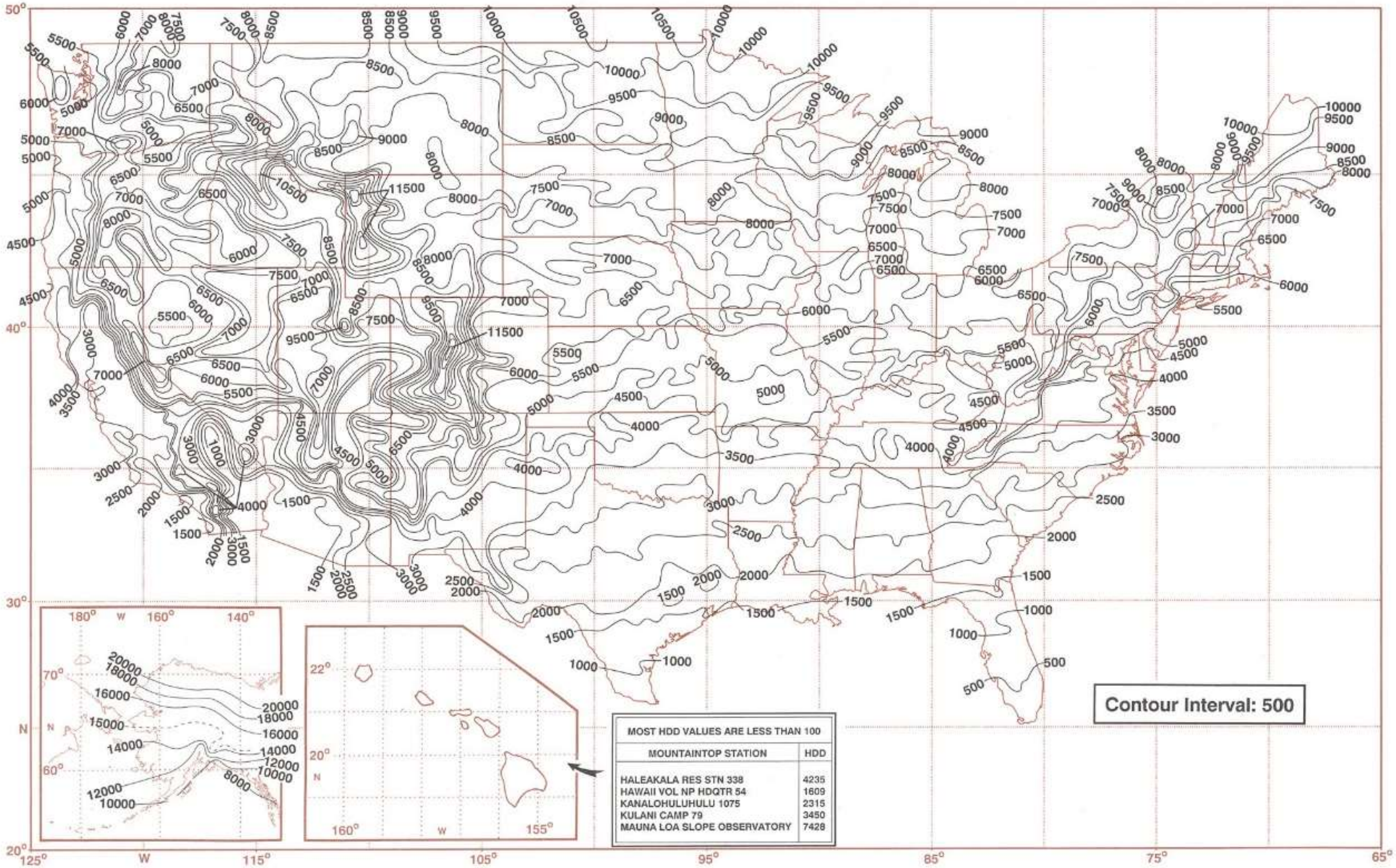

Image source: https://commons.wikimedia.org/wiki/File:United_States_Heating_Degree_Day_map,_1961-1990.jpg

12.6 Approximate method for calculating heat gain (cooling load)

- Why is it so complicated?
  - ΔT is not so influential in summer
  - Solar and internal heat gains must be included. (not safety margins as for heating)
  - Hourly change in sun's position and intensity
  - Thermal mass (walls, ceilings, furniture) delays the impact of the radiant component of heat gain.

A simplified approach (1)

- Sensible heat gains through opaque parts (roofs, walls, floor)
  - Q=UA*DETD (DETD: Design Equivalent Temperature Difference)
    - From Table G.2 (Notes: For lightweight frame walls and doors, the DETD varies by orientation)
    - or DETD = Sol-air temperature – room air temperature
    - DETD values for roofs are considerably higher than other components due to the sol-air temperature.
- Sensible heat gains through glass
  - Q=A*DCLF (DCLF: design cooling load factor. DCLF includes U factors as well as the equivalent temperature difference)
    - From Table G.3: glass shaded by external shading devices which exclude all direct sun: assume "north glass protected by awnings"
- Sensible and latent gains from outdoor air
  - Approach 1: Use Table G.4
    - Infiltration: $q_{\_inf}$= ($A_{\_exposed}$)(infiltration factor)
    - Ventilation: $q_{\_vent}$= (Q)(ventilation factor)
  - Approach 2: Use calculated or estimated ventilation rate (V)
    - $Q=1.2V\Delta T$ (Q= sensible heat loss only, V[L/s])
    - $Q=3010V\Delta W$ (W:kg/kg[DA])

G.2 DESIGN TEMPERATURE DIFFERENCES FOR OPAQUE ENVELOPE ASSEMBLIES

Table G.2 Design Equivalent Temperature Differences (DETD)

Appendix Table B.3

Part A. Mass Walls, Roofs, and Floors																								
SI Units												***Outdoor Design Temperature***	*I-P Units*											
29.4°C		32.2			35.0			37.7		40.5	43.3	***Daily Temperature***	85°F		90			95			100		105	110
L	M	L	M	H	L	M	H	M	H	H	H	***Range***[3]	L	M	L	M	H	L	M	H	M	H	H	H
												Walls												
5.7	3.5	8.5	6.3	3.5	11.3	9.1	6.3	11.8	9.1	11.8	14.6	1. Masonry walls, 200-mm (8-in.) block or brick	10.3	6.3	15.3	11.3	6.3	20.3	16.3	11.3	21.3	16.3	21.3	26.3
5.0	2.7	7.7	5.5	2.7	10.5	8.3	5.5	11.1	8.3	11.1	13.8	2. Partitions, frame	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
~~1.4~~	~~0.0~~	~~4.2~~	~~1.9~~	~~0.0~~	~~6.9~~	~~4.7~~	~~1.9~~	~~7.5~~	~~4.7~~	~~7.5~~	~~10.3~~	~~masonry~~	~~2.5~~	~~0~~	~~7.5~~	~~3.5~~	~~0~~	~~12.5~~	~~8.5~~	~~3.5~~	~~13.5~~	~~8.5~~	~~13.5~~	~~18.5~~
												Ceilings and Roofs												
												1. Ceilings under naturally vented attic or vented flat roof												
21.1	18.8	23.8	21.6	18.8	26.6	24.4	21.6	27.2	24.4	27.2	30.0	—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
16.6	14.9	19.4	17.2	14.4	22.2	20.0	17.2	22.7	20.0	22.7	25.5	—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
												2. Built-up roof, no ceiling												
21.1	18.8	23.3	21.6	18.8	26.6	24.4	21.6	27.2	24.4	27.2	30.0	—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
16.6	14.9	19.4	17.2	14.4	22.2	20.2	17.2	22.7	20.0	22.7	25.5	—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
5.0	2.7	7.7	5.5	2.7	10.5	8.3	5.5	11.1	8.3	11.1	13.8	3. Ceilings under unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
												Floors												
5.0	2.7	7.7	5.5	2.7	10.5	8.3	5.5	11.1	8.3	11.1	13.8	1. Over unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2. Over basement, enclosed crawl space, or concrete slab on ground	0	0	0	0	0	0	0	0	0	0	0	0
5.0	2.7	7.7	5.5	2.7	10.5	8.3	5.5	11.1	8.3	11.1	13.8	3. Over open crawl space	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0

Table G.2 Design Equivalent Temperature Differences (DETD) (*Continued*)

Part B. Frame Walls and Doors																								
SI Units												***Outdoor Design Temperature Daily Temperature Range***[a]	***I-P Units***											
29.4°C		**32**			**35**			**38**		**41**	**43**		**85°F**		**90**			**95**			**100**		**105**	**110**
L	**M**	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**H**	**H**	**Orientation**	**L**	**M**	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**H**	**H**
4	2	7	4	2	10	7	4	10	7	10	13	North	8	3	13	8	3	18	13	8	18	13	18	23
8	5	11	8	5	13	11	8	13	11	13	16	NE and NW	14	9	19	14	9	24	19	14	24	19	24	29
10	7	13	10	7	16	13	10	16	13	16	18	East and West	18	13	23	18	13	28	23	18	28	23	28	33
9	6	12	9	6	14	12	9	14	12	14	17	SE and SW	16	11	21	16	11	26	21	16	26	21	26	31
6	3	9	6	3	12	9	6	12	9	12	14	South	11	6	16	11	6	21	16	11	21	16	21	26

Source: Part A, Previously adapted, with the permission of ASHRAE, from the *1981 ASHRAE Handbook—Fundamentals*; Part B, Previously adapted, with the permission of ASHRAE, from the *1997 ASHRAE Handbook—Fundamentals*. This citation to an older version of the *Handbook* is intentional and provides access to historic reference information of ongoing interest.

[a]Daily temperature range: L (low), M (medium), H (high).

From *Mechanical and Electrical Equipment for Buildings* Appendix B, mean daily range column: L is less than 16°F (9°C); M is 16 to 25°F (9 to 14°C); H is greater than 25°F (14°C).

G.3 HEAT GAINS (COOLING LOADS) THROUGH GLASS

Table G.3 Design Cooling Load Factors through Glass

Part A. SI: W/m^2

Outdoor Design Temp.[a]	*Regular Single Glass*						*Regular Double Glass*						*Heat-Absorbing Double Glass*						*Clear Triple Glass*		
	29.4	**32.2**	**35.0**	**37.7**	**40.5**	**43.3**	**29.4**	**32.2**	**35.0**	**37.7**	**40.5**	**43.3**	**29.4**	**32.2**	**35.0**	**37.7**	**40.5**	**43.3**	**29.4**	**32.2**	**35.0**
No Awnings or Inside Shading																					
North	72.6	85.2	97.8	110.4	123.0	138.8	59.9	66.2	75.8	82.0	88.3	94.7	37.9	44.1	53.7	60.0	66.2	72.6	53.7	60.0	63.1
NE and NW	176.6	189.3	202.0	214.6	227.1	243.0	145.1	151.4	161.0	167.2	173.6	179.9	85.1	91.4	101.0	107.2	113.6	119.9	132.6	135.7	138.9
East and west	255.5	268.1	280.8	293.4	306.0	321.9	214.6	220.9	230.3	236.7	243.0	249.2	132.6	138.9	148.2	154.6	160.9	167.2	195.7	198.8	202.6
SE and SW	220.9	233.4	246.0	258.8	271.3	287.1	186.1	192.4	202.0	208.2	214.6	220.9	110.4	116.8	126.2	132.6	138.9	145.1	167.2	173.6	176.7
South	126.2	138.9	151.4	164.0	176.7	192.4	104.1	110.4	119.9	126.2	132.6	138.9	66.0	75.8	75.8	82.0	88.3	94.7	94.7	97.9	104.1
Horiz. skylight	504.8	517.4	530.0	542.7	555.2	571.0	438.6	444.9	454.3	460.7	467.0	473.2	280.8	296.6	296.6	302.9	309.1	315.6	397.6	400.7	407.0
Draperies or Venetian Blinds																					
North	47.3	60.0	72.6	85.1	97.9	113.6	37.9	44.1	53.7	60.0	66.2	72.6	28.3	34.7	44.1	50.4	56.8	63.1	34.7	37.9	44.2
NE and NW	101.0	113.6	126.2	138.9	151.4	167.2	85.1	91.4	101.0	107.2	113.6	119.9	63.1	69.4	78.9	85.1	91.4	97.9	75.8	82.0	85.1
East and west	151.4	164.0	176.7	189.3	202.0	217.7	132.6	138.9	148.2	154.6	161.0	167.2	94.7	101.0	110.4	116.8	123.0	129.3	119.9	123.0	129.3
SE and SW	126.2	138.9	151.4	164.0	176.7	192.4	110.4	116.8	126.2	132.6	138.9	145.1	75.8	82.0	91.4	97.9	104.1	110.4	101.0	104.1	107.2
South	72.5	85.1	97.9	110.4	123.0	138.9	63.1	69.4	78.9	85.1	91.4	97.9	47.3	53.7	63.1	75.8	75.8	82.0	56.8	60.0	66.2
Roller Shades Half-Drawn																					
North	56.8	69.4	82.0	92.7	102.2	123.0	47.3	53.7	63.1	69.4	75.8	82.0	31.6	37.9	47.3	53.7	60.0	66.2	41.0	44.2	47.3
NE and NW	126.2	138.9	151.4	164.0	176.7	192.4	119.9	126.2	135.7	142.0	148.2	154.6	75.8	82.0	91.4	97.9	104.1	110.4	107.2	110.4	110.4
East and west	192.5	205.0	217.7	230.3	243.0	258.8	170.3	176.7	186.1	192.4	198.8	205.0	110.4	116.8	126.2	132.5	138.9	145.1	154.6	154.6	157.8
SE and SW	164.0	176.7	189.3	202.0	214.6	230.3	145.1	151.4	161.0	167.2	173.6	179.9	94.7	101.0	110.4	123.0	123.0	129.3	129.3	132.6	135.7
South	91.4	104.1	116.8	129.3	142.0	157.8	85.1	91.4	101.0	107.2	113.6	119.9	56.8	63.1	72.6	78.9	85.1	91.4	78.9	82.0	82.0
Awnings[b]																					
North	63.1	75.8	88.3	101.0	113.6	129.3	41.0	47.3	56.8	63.1	69.4	75.8	31.6	37.9	47.3	53.7	60.0	66.2	34.7	37.9	41.0
NE and NW	66.2	78.9	91.4	104.1	116.8	132.6	44.2	50.4	60.0	66.2	72.6	78.9	34.7	41.0	50.4	56.8	63.1	69.4	37.9	41.0	44.2
East and west	69.4	82.0	94.7	107.2	119.9	135.7	44.2	50.4	60.0	66.2	72.6	78.9	37.9	44.2	53.6	60.0	66.2	72.6	37.9	41.0	44.2
SE and SW	66.2	78.9	91.4	104.1	116.8	132.6	44.2	50.4	60.0	66.2	72.6	78.9	34.7	41.0	50.4	56.8	63.1	69.4	37.9	41.0	44.2
South	66.2	75.8	88.3	101.0	113.6	129.3	41.0	47.3	56.8	63.1	69.4	75.8	34.7	41.0	50.4	56.8	63.1	69.4	34.7	37.9	41.0

A simplified approach (2)

- Sensible and latent gains from people
  - Table G.5
- Sensible heat gains from lights
  - 1.1 or 1.2 times the total bulb wattage of such lights for discharge lamps (because of ballasts)
  - 1.0 for incandescent lamps
- Sensible heat gains from equipment
  - Tables G.6, G.7

G.4 HEAT GAINS (COOLING LOADS) DUE TO INFILTRATION/VENTILATION

Table G.4 Sensible Cooling Load Factors Due to Infiltration and Ventilation

Design Temperature °C:									Design temperature °F:					
29.4	32.2	35.0	37.7	41.5	43.3	Units	Condition	Units	85	90	95	100	105	110
2.2	3.5	4.7	6.0	6.9	8.2	W/m²	Infiltration, per gross exposed wall area	Btu/h ft²	0.7	1.1	1.5	1.9	2.2	2.6
6.8	9.9	13.6	16.7	19.8	23.6	W per L/s	Mechanical ventilation	Btu/h per cfm	11.0	16.0	22.0	27.0	32.0	38.0

Source: Previously adapted, with the permission of ASHRAE, from the *1981 ASHRAE Handbook—Fundamentals*. This citation to an older version of the *Handbook* is intentional and provides access to historic reference information of ongoing interest.

G.5 HEAT GAINS FROM BUILDING OCCUPANTS

Table G.5 Rates of Heat Gain from Occupants of Conditioned Spaces

		Heat Gain							
		W				*Btu/h*			
Activity	Location	Adult Male	Adjusted[b]	Sensible[a] Heat	Latent[a] Heat	Adult Male	Adjusted[b]	Sensible[a] Heat	Latent[a] Heat
Seated at theater	Theater, matinee	115	95	65	30	390	330	225	105
Seated at theater, night	Theater, night	115	105	70	35	390	350	245	105
Seated, very light work	Offices, hotels, apartments	130	115	70	45	450	400	245	155
Moderately active office work	Offices, hotels, apartments	140	130	75	55	475	450	250	200
Standing, light work; walking	Department or retail store	160	130	75	55	550	450	250	200
Walking, standing	Drug store, bank	160	145	75	70	550	500	250	250
Sedentary work	Restaurant[c]	170	160	80	80	590	550	275	275
Light bench work	Factory	235	220	80	140	800	750	275	475
Moderate dancing	Dance hall	265	250	90	160	900	850	305	545
Walking 4.8 km/h (3 mph), light machine work	Factory	295	295	110	185	1000	1000	375	625
Bowling[d]	Bowling alley	440	425	170	255	1500	1450	580	870
Heavy work	Factory	440	425	170	255	1500	1450	580	870
Heavy machine work, lifting	Factory	470	470	185	285	1600	1600	635	965
Athletics	Gymnasium	585	525	210	315	2000	1800	710	1090

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[a] All values are rounded to the nearest 5 W (and 5 Btu/h). Based on 75°F (24°C) room dry-bulb temperature. For 80°F (27°C) room dry-bulb temperature, the total heat remains the same but the sensible heat values should be decreased by approximately 20% and the latent heat values increased accordingly.

[b] Adjusted heat gain based on the normal percentage of men, women, and children for the application listed, assuming that the gain from an adult female is 85% (and from children 75%) of that from an adult male.

[c] Adjusted heat gain includes 60 Btu/h (18 W) for food per individual: 50% sensible, 50% latent.

[d] Assume only one person per alley actually bowling and all others as sitting, standing, or walking slowly.

G.6 HEAT GAINS FROM OFFICE EQUIPMENT

Table G.6 Heat Gains from Office Equipment Recommended for Use in Design Calculations

Equipment Description	Nameplate Power,[a] W	Peak Heat Gain,[b] W
Desktop computer		
Manufacturer 1, 3.5 GHz processor, 8 GB RAM, *n* = *2*	NA	42
Manufacturer 1, 3.6 GHz processor, 16 GB RAM, *n* = *2*	NA	66
Manufacturer 1, 3.3 GHz processor, 16 GB RAM, *n* = *2*	NA	52
Manufacturer 1, 3.7 GHz processor, 32 GB RAM, *n* = *1*	NA	84
Manufacturer 2, 3.6 GHz processor, 32 GB RAM, *n* = *8*	NA	80
Manufacturer 2, 3.6 GHz processor, 16 GB RAM, *n* = *1*	NA	78
Manufacturer 2, 3.4 GHz processor, 32 GB RAM, *n* = *1*	NA	72
Manufacturer 2, 3.4 GHz processor, 24 GB RAM, *n* = *1*	NA	76
Laptop computer		
Manufacturer 1, 2.6 GHz processor, 8 GB RAM, *n* = *1*	NA	46
Manufacturer 2, 2.4 GHz processor, 4 MB RAM, *n* = *1*	NA	59
Average 15-min peak power consumption (range)	**53 (46–59)**	
Flat-panel monitor[c]		
Manufacturer 1, 27 in. (686 mm) LED flat screen, *n* = *2*	40	26
Manufacturer 1, 22 in. (546 mm) LED flat screen, *n* = *2*	29	25
Manufacturer 3, 23 in. (584 mm) LED flat screen, *n* = *3*	50	17
Manufacturer 3, 23 in. (584 mm) LED flat screen, *n* = *1*	38	21
Manufacturer 4, 24 in. (610 mm) LED flat screen, *n* = *1*	42	25
Average 15-min peak power consumption (range)	**21 (14–26)**	
Multifunction printer (copy, print, scan), multiuser, office type		
Max. printing speed up to 40 pages per minute	1010	540 (idle 29W)
Max. printing speed up to 30 pages per minute	1300	303 (idle 116W)
Max. printing speed up to 28 pages per minute	1500	433 (idle 28W)
Average 15-min peak power consumption (range)	**425 (303–540)**	
Vending machine		
Drinks, 280 to 400 items	NA	940
Snacks	NA	54
Food (e.g., sandwiches)	NA	465
Microwave oven	1000–1500	713 to 822
Coffee maker, 12 cups	950	780
Refrigerator, 18 to 28 ft^3 (0.5 to 0.80 m^3)	NA	387 to 430

Source: Excerpted and reprinted with permission; ©ASHRAE, www.ashrae.org. 2017 *ASHRAE Handbook—Fundamentals*.

n = number of tested equipment of same configuration.

[a]Nameplate power for **desktop computers** is present on its power supply, which is mounted inside desktop, hence not accessible for most computers, where NA = not available. **Screens** with atypical size and shape are excluded for calculating average 15-minute peak power consumption. Voltage and amperage information for **laptop computer** is available on power supply nameplates.

[b]For equipment peak heat gain value, highest 15-minute interval of recorded data is listed in tables.

[c]Approximately 60% convective heat gain and 40% radiative heat gain.

Table G.7 Recommended Rates of Heat Gain from Miscellaneous Appliances (*Continued*)

PART B. SI Units: W

	Energy Rate		*Rate of Heat Gain*			
	Rated	Standby	Sensible Radiant	Sensible Convective	Latent	Total
Cabinet: hot serving (large), insulated	1993	352	117	234	0	352
hot serving (large), uninsulated	1993	1026	205	821	0	1026
proofing (large)	5099	410	352	0	59	410
proofing (small 15-shelf)	4191	1143	0	264	879	1143
Coffee brewing urn	3810	352	59	88	205	352
Drawer warmers, 2-drawer (moist holding)	1202	147	0	0	59	59
Egg cooker	3194	205	88	117	0	205
Espresso machine	2403	352	117	234	0	352
Food warmer: steam table (2-well-type)	1495	1026	88	176	762	1026
Freezer (small)	791	322	147	176	0	322
Hot dog roller	996	703	264	440	0	703
Hot plate: single burner, high speed	1114	879	264	615	0	879
Hot-food case (dry holding)	9115	733	264	469	0	733
Hot-food case (moist holding)	9115	967	264	528	176	967
Microwave oven: commercial (heavy duty)	3194	0	0	0	0	0
Oven: countertop conveyorized bake/finishing	6008	3693	645	3048	0	3693
Panini	1700	938	352	586	0	938
Popcorn popper	586	59	29	29	0	59
Rapid-cook oven (quartz-halogen)	12,016	0	0	0	0	0
Rapid-cook oven (microwave/convection)	7297	1202	293	909	0	293
Reach-in refrigerator	1407	352	88	264	0	352
Refrigerated prep table	586	264	176	88	0	264
Steamer (bun)	1495	205	176	29	0	205
Toaster: 4-slice pop up (large): cooking	1788	879	59	410	293	762
contact (vertical)	3312	1553	791	762	0	1553
conveyor (large)	9613	3019	879	2139	0	3019
small conveyor	1700	1084	117	967	0	1084
Tortilla grill	2200	1055	264	791	0	1055
Waffle iron	909	352	234	117	0	352

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[a]For details on energy use from residential appliances, see the Energy Efficiency and Renewable Energy Clearinghouse (EREC).

For Recommended Rates of Radiant Heat Gain from Hooded Electric Appliances During Idle (Ready-to-Cook) Conditions; Recommended Rates of Radiant Heat Gain from Hooded Gas Appliances During Idle (Ready-to-Cook) Conditions; and Recommended Rates of Radiant and Convective Heat Gain from Warewashing Equipment During Idle (Standby) or Washing Conditions—Refer to 2017 ASHRAE Handbook—Fundamentals.

A simplified approach (3)

- Latent heat gains
  - Assumption: the latent heat gains are closely associated with infiltration
  - Estimate additional latent heat as a percentage of total sensible heat gain
  - Use design DB and mean coincident WB temperatures from Appendix Table B.3
  - Use Figure 12.23

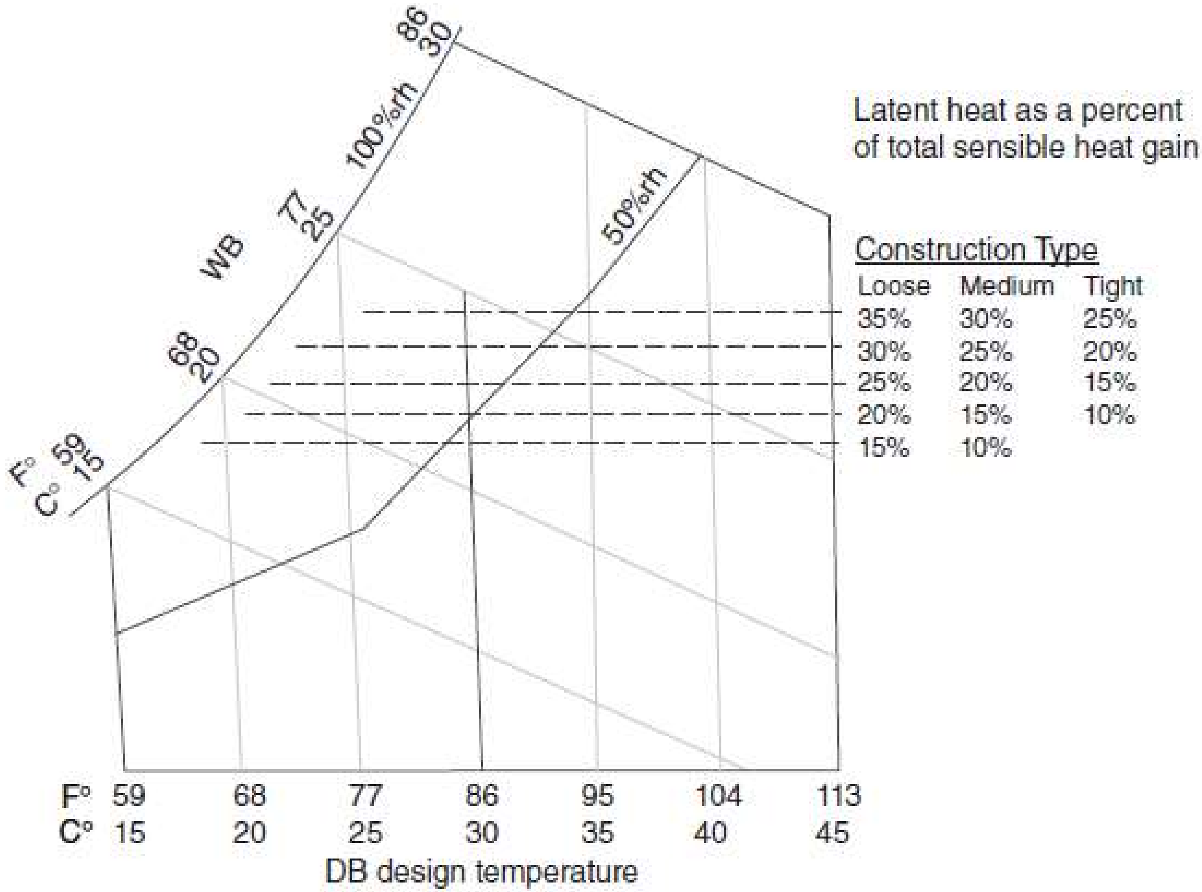


Fig. 12.23 *Estimating latent heat gain as a percentage of total sensible heat gain, assuming that these additional latent gains are closely associated with outdoor air infiltration. Relative tightness of building construction is included as a variable. Design DB and mean coincident WB temperatures may be found in Appendix B.*

EXAMPLE 12.8 A one-story office building (Fig. 12.24) is located in the eastern United States near 40°N latitude. The adjoining buildings on the north and west are not conditioned, and their inside air temperatures are, for simplicity, assumed equal to the outdoor air temperature at any time of day. This is an unusual building both for its uninsulated walls and for very high lighting loads. What are the heat gains, hence the cooling load?

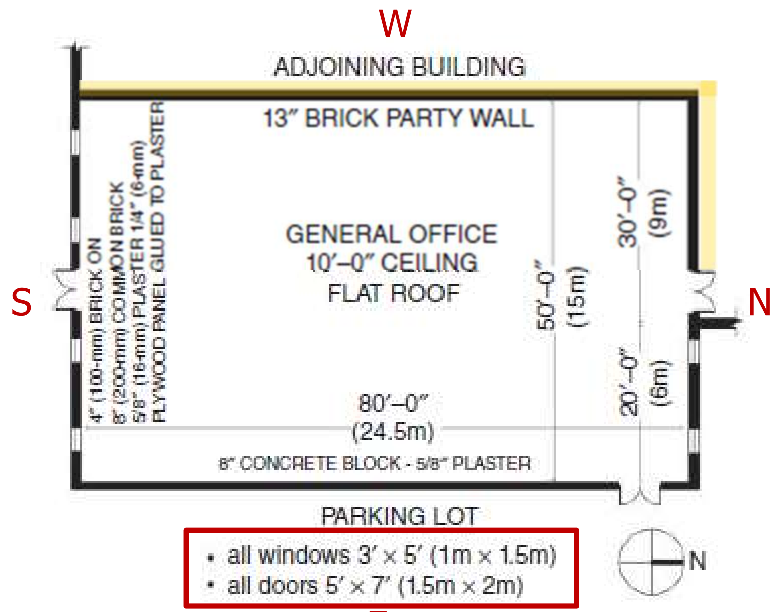


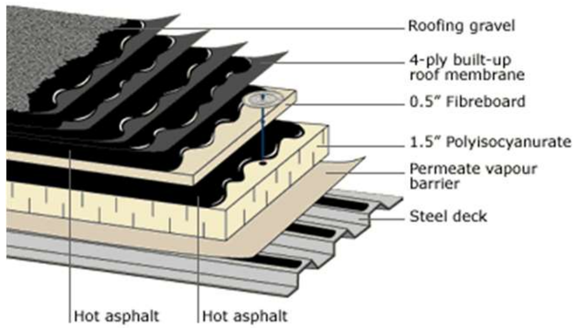
Fig. 12.24 *Plan of the office building for which heat gain calculations are shown in 12.8 (and in Table 12.3). (Drawn by Tyler Mavichien.)*

Roof construction: 4.5-in. (115-mm) flat roof deck of 2-in. (50-mm) gypsum slab on metal roof deck, 2-in. (50-mm) rigid above-deck roof insulation, surfaced with two layers of mopped felt vapor-seal built-up roofing having dark-colored gravel surface, no false ceiling. Summer U = 0.09 Btu/h ft^2 °F (0.51 W/m^2 °C).

South wall construction: 4-in. (100-mm) face brick, 8-in. (200-mm) common brick, 0.625-in. (16-mm) plaster, 0.25-in. (6-mm) plywood panel glued on plaster. Summer U = 0.24 Btu/h ft^2 °F (1.36 W/m^2 °C).

West wall and adjoining north party wall construction: 13-in. (325-mm) solid brick, no plaster. Interior partition U = 0.25 Btu/h ft^2 °F (1.40 W/m^2 °C).

Built-up= increased in height by the addition of parts



Example of built up roofing

= occasionally parti-wall or parting wall, also known as common wall, is a dividing partition between two adjoining buildings

North exposed wall and east wall construction: 8-in. (200-mm) concrete block and 0.625-in. (16-mm) plaster. Summer U = 0.48 Btu/h ft^2 °F (2.73 W/m^2 °C).

Floor construction: 4-in. (100-mm) concrete slab-on-grade

Fenestration: 3-ft × 5-ft (1-m × 1.5-m) nonoperable windows of regular plate glass with light-colored venetian blinds. Summer U = 0.81 Btu/h ft^2 °F (4.6 W/m^2 °C).

single

Front doors: Two, 2.5 × 7 ft (1.5 m × 2 m)

Side doors: Two, 2.5 × 7 ft (1.5 m × 2 m)

Rear doors: Two, 2.5 × 7 ft (1.5 m × 2 m), interior

Door construction: Light-colored 1.75-in. (45-mm) steel door with solid urethane core and thermal break. Summer U = 0.18 Btu/h ft^2 °F (1.08 W/m^2 °C).

(U-factors for all doors and outside walls were calculated assuming a wind speed of 7.5 mph [12 km/h]. For party and inside walls, still air was assumed.)

Outdoor design conditions: Dry-bulb temperature, 94°F (35°C); daily range, 20F° (11C°). Wet-bulb temperature, 77°F (25°C).

Indoor design conditions: Dry-bulb temperature, 75°F (24°C); wet-bulb temperature, 62.5°F (18°C)

Occupancy: 85 office workers from 8:00 A.M. to 5:00 P.M.

Lighting: 17,500 W fluorescent, from 8:00 A.M. to 5:00 P.M.; and 4000 W tungsten, continuous

Equipment: This example does not include any office equipment.

Ventilation: The ventilation rate is 15 cfm (7 L/s) per person, for a total of 1275 cfm (595 L/s).

The conditioning equipment is located in the adjoining building to the north.

Determine the sensible, latent, and total space cooling load at design conditions.

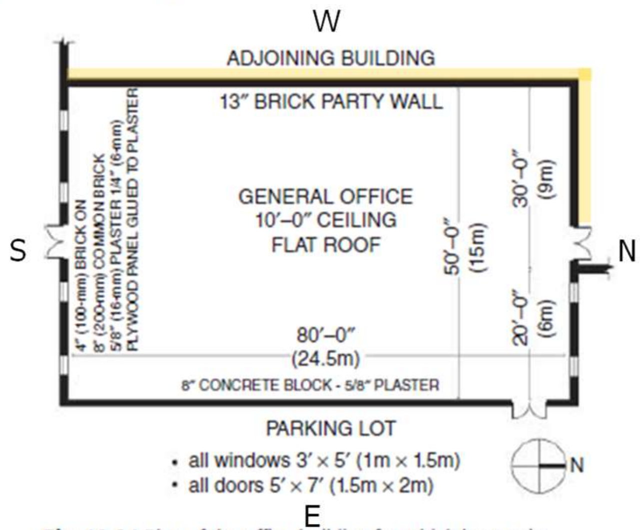
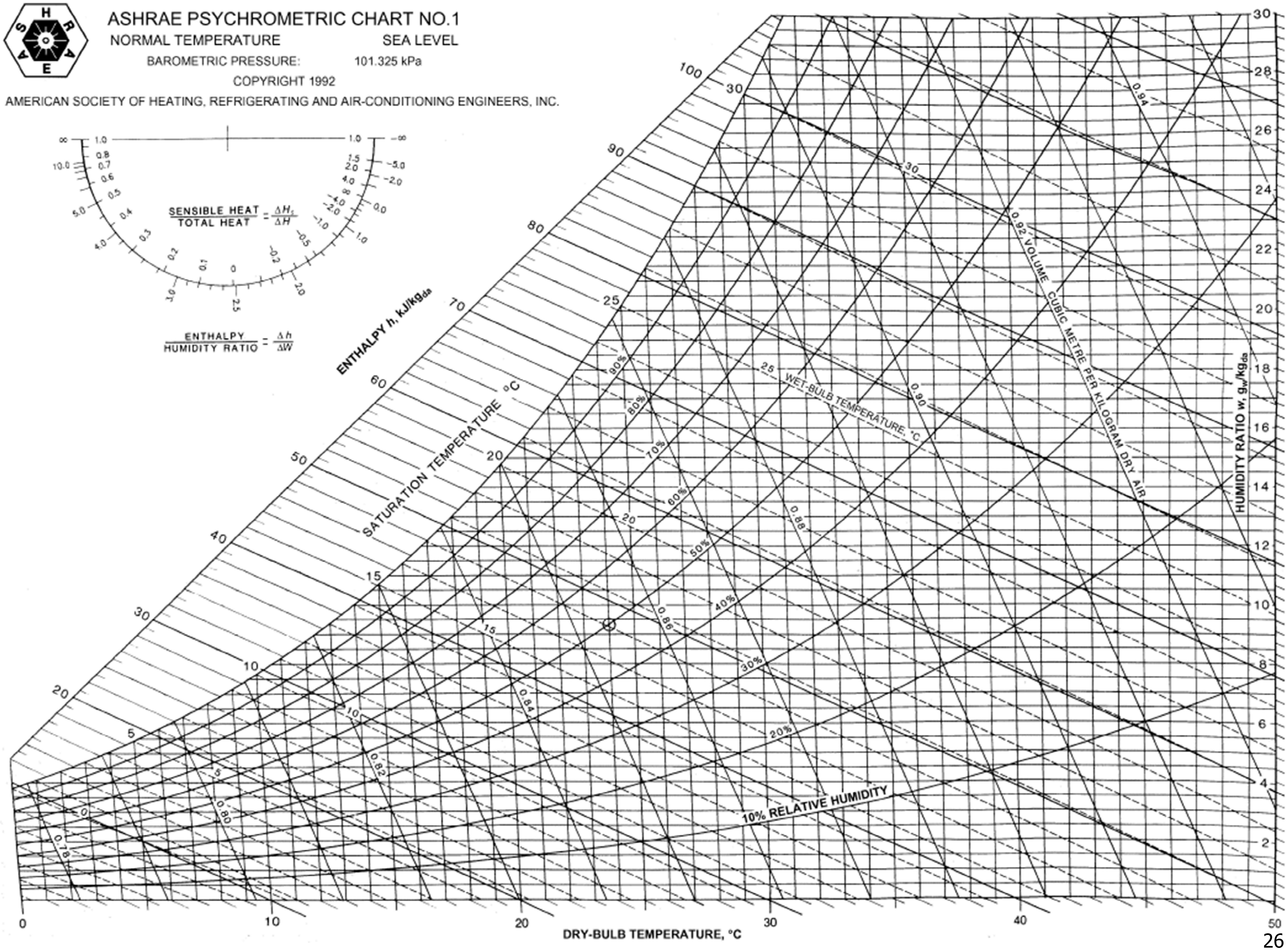


Fig. 12.24 *Plan of the office building for which heat gain calculations are shown in 12.8 (and in Table 12.3). (Drawn by Tyler Mavichien.)*



ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO w, gw/kgda
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C

TABLE 12.3 Cooling Load through Building Envelope (Example 12.8)

Net Area (m^2)	U-factor (W/m^2 K)	Δt (C°)	DETD (C°)	DCLF	Cooling Load (W)	Section	Reference	Net Area (ft^2)	DETD (F°)	U-factor (Btu/h ft^2 F°)	Δt (F°)	DCLF	Cooling Load (Btu/h)
371.6	0.51		24.4		**4620**	Roof	Table F.5	4000	0.09		44.0		**15,840**
37.6[a]	1.36		9.1		**470**	South wall	Table F.5	405[a]	0.24		16.3		**1,580**
71.1[a]	2.7		9.1		**1750**	East wall	Table F.5	765[a]	0.48		16.3		**5,990**
15.8[a]	2.7		9.1		**390**	North wall exposed	Table F.5	170[a]	0.48		16.3		**1,330**
98.9[a]	1.41	11.2[2]			**1560**	Party walls		1065[a]	0.25	20[b]			**5,330**
3.25	1.08		13.1		**50**	Doors: S	Table F.5	35	0.19		23.6		**160**
3.25	1.08	11.2[2]			**40**	N	Table F.5	35	0.19	20[b]			**130**
3.25	1.08		13.1		**50**	E	Table F.5	35	0.19		23.6		**160**
						Windows:							
5.6	(4.6)[c]			97.9	**550**	S	Table F.6	60	(0.81)[c]			31	**1,860**
2.8	(4.6)[c]			72.6	**200**	N	Table F.6	30	(0.81)[c]			23	**690**
				Total:	**9680**							Total:	**33,070**

[a]Calculated from gross wall area less windows and door areas.

[b]Design temperature difference, inside to outside.

[c]DCLF for glass includes the U-factor.

Latent heat gains: The climate description suggests a typical northeastern U.S. climate at 40°N latitude. Newark, New Jersey (91°F DB, 73°F WB [32.8°C, 22.8°C]), and Philadelphia, Pennsylvania (90 DB, 74 WB [32.2°C, 22.3°C]), are examples. From Fig. 12.23, estimate latent gain as about 20% of the total sensible load.

	W	Btu/h
Sensible gains, envelope	9680	33,070
Sensible gains, lights and people	31,380	106,550
Sensible gains, ventilation	8090	28,050
Sensible gains, total	49,150	167,670
Latent gains (20%, this example)	9830	33,530
Total latent and sensible heat gains	58,980	201,200

12.7 Detailed hourly heat gain (cooling load) calculations

- Much more detailed calculation than section 12.6 (Ex.12.8) → that can account for thermal storage
  - TFM, TETD/TA: hourly calculation
  - CLTD/CLF: 1hour calc.
  - HB (Heat Balance Method)
  - RTS (Radiant Time Series)

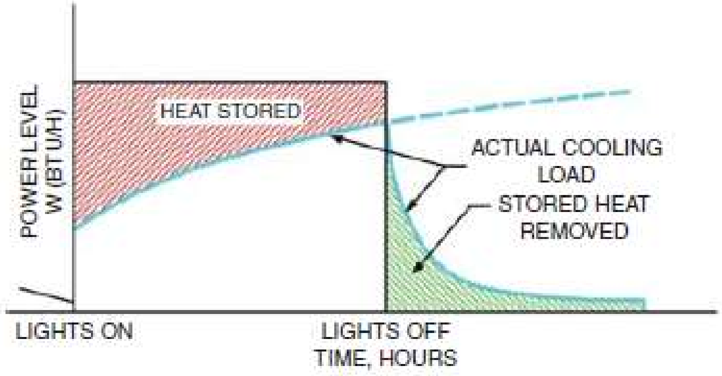


Fig. 12.25 *Thermal storage effect in the cooling load caused by electric lighting. (Reprinted with permission of ASHRAE, from the 1997* ASHRAE Handbook—Fundamentals. *This citation to an older version of the Handbook is intentional and provides access to historic reference information of ongoing interest.)*

TABLE 12.4 Comparison of Methods of Heat Gain Calculation (Example 12.8)

	Maximum Hourly Gain (W)			24-h Average Gain (W/m^2)			Maximum Hourly Gain (Btu/h)			24-h Average Gain (Btu/h ft^2)		
Method	Sensible	Latent	Total	Sensible	Latent	Total	Sensible	Latent	Total	Sensible	Latent	Total
Design guideline (Table G.1)	($118/m^2$)						($37.5/ft^2$)					
Approximate[a] (Section 12.6)	49,150 ($131/m^2$)	9830	58,980				167,670 ($41.9/ft^2$)	33,530	201,200			
Transfer Function[b] (worst hour 4:00 p.m.)	41,415 ($110/m^2$)	15,040	56,455	68.3	32.0	100.3	149,623 ($37.4/ft^2$)	61,168	210,791	21.3	12.5	33.8
CLTD/CLF[b] (for 4:00 p.m. only)	53,499 ($143/m^2$)	15,040	68,489				179,140 ($44.8/ft^2$)	63,208	242,348			
TETD/TA[b] (worst hour 4:00 p.m.)	50,096 ($134/m^2$)	15,040	65,136	68.3	32.0	100.3	169,082 ($42.3/ft^2$)	61,168	230,250	21.3	12.5	33.8

[a]See Table 12.3 and Example 12.8 for calculations.

[b]Previously extracted, with permission of ASHRAE, from 1997 *ASHRAE Handbook—Fundamentals,* Chapter 28. This table is maintained for the purpose of this example; recently ASHRAE has developed a more complex calculation.