12. AIR-CONDITIONING LOAD DATA

Cooling Loads

Obtain appropriate weather data and select design conditions. In addition to the conventional dry-bulb with mean coincident wet-bulb, also consider dew-point with mean coincident dry-bulb, particularly with spaces requiring large amounts of outdoor air or close control of moisture. Select indoor dry-bulb, wet-bulb, and ventilation rate, including permissible variations and control limits. Consider proposed schedules of occupancy, lighting, and processes that contribute to the internal load. Several different times of day and months must frequently be analyzed to determine the peak load time.

ANSI/ASHRAE/ACCA Standard 183-2007 sets the minimum standards for nonresidential load calculations.

Currently there are two ASHRAE cooling load calculation methods. The first is the Heat Balance (HB) method, whose equations are coded in a generic computer program linked to a user interface program. The source code for these programs is in the ASHRAE Load Calculation Toolkit.

The second method is the Radiant Time Series (RTS) method, a simplification of the heat balance method, still requiring a complex computer program for a multiroom building.

Due to the variation in heat transfer coefficients, precision of construction, and manner of actual building operation, a cooling load calculation can never be more than a good estimate of the actual load.

For preliminary estimation of the cooling load, the figures herein are a very rough guide. The approximate cooling load calculation methods presented here are useful to the experienced designer.

To design and size components of central air-conditioning systems, more than the cooling load is needed. Type of system, fan energy and location, direct heat loss and gain, duct leakage, heat extracted from lights, and type of return system must all be considered.

Heating Loads

Similar calculations to cooling load are made, but temperatures outside conditioned spaces are usually lower than space temperatures maintained. Solar heat gains, and internal heat gains are not included and thermal storage of building structure or content is usually ignored. This is usually sufficient to cope with a worst-case situation. There is very often need for cooling in cold months, for perimeter spaces with high solar heat gain and interior spaces with significant heat gain.

Previous Cooling Load Calculation Methods

Procedures described in Chapters 17 and 18 of the 2013 *ASHRAE Handbook–Fundamentals* are the most current and scientifically derived means for estimating cooling load for a defined building space, but methods in earlier editions of the ASHRAE Handbook are valid for many applications. These earlier procedures are simplifications of the Heat Balance principles, and their use requires experience to deal with atypical or unusual circumstances. In fact, any cooling or heating load estimate is no better than the assumptions used to define conditions and parameters such as physical makeup of the various envelope surfaces, conditions of occupancy and use, and ambient weather conditions. Experience of the practitioner can never be ignored.

The primary difference between the HB and RTS methods and the older methods is the newer methods' direct approach, compared to the simplifications necessitated by the limited computer capability available previously.

The **transfer function method (TFM)**, for example, required many calculation steps. It was originally designed for energy analysis with emphasis on daily, monthly, and annual energy use, and thus was more oriented to average hourly cooling loads than peak design loads.

The **total equivalent temperature differential method with time averaging (TETD/TA)** has been a highly reliable (if subjective) method of load estimating since its initial presentation in the 1967 *Handbook of Fundamentals*. Originally intended as a manual method of calculation, it proved suitable only as a computer application because of the need to calculate an extended profile of hourly heat gain values, from which radiant components had to be averaged over a time representative of the general mass of the building involved. Because perception of thermal storage characteristics of a given building is almost entirely subjective, with little specific information for the user to judge variations, the TETD/TA method's primary usefulness has always been to the experienced engineer.

The **cooling load temperature differential method with solar cooling load factors (CLTD/CLF)** attempted to simplify the two-step TFM and TETD/TA methods into a single-step technique that proceeded directly from raw data to cooling load without intermediate conversion of radiant heat gain to cooling load. A series of factors were taken from cooling load calculation results (produced by more sophisticated methods) as "cooling load temperature differences" and "cooling load factors" for use in traditional conduction ($q = UA\Delta t$) equations. The results are approximate cooling load values rather than simple heat gain values. The simplifications and assumptions used in the original work to derive those factors limit this method's applicability to those building types and conditions for which the CLTD/CLF factors were derived; the method should not be used beyond the range of applicability.

The TFM, TETD/TA, and CLTD/CLF procedures have not been invalidated or discredited. Experienced engineers have successfully used them in millions of buildings around the world. The accuracy of cooling load calculations in practice depends primarily on the availability of accurate information and the design engineer's judgment in the assumptions made in interpreting the available data. Those factors have much greater influence on a project's success than does the choice of a particular cooling load calculation method.

The primary benefit of HB and RTS calculations is their somewhat reduced dependency on purely subjective input (e.g., determining a proper time-averaging period for TETD/TA; ascertaining appropriate safety factors to add to the rounded-off TFM results; determining whether CLTD/CLF factors are applicable to a specific unique application). However, using the most up-to-date techniques in real-world design still requires judgment on the part of the design engineer and care in choosing appropriate assumptions, just as in applying older calculation methods.

Table 12.1 Cooling Load Check Figures

Classifications	Occupancy ft²/Person			Lights and Other Electrical W/ft²			Refrigeration ft²/ton†			Supply Air Rate cfm/ft² East-South-West			North			Internal		
	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi
Apartment, High Rise	325	175	100	0.7	0.9	1.1	450	400	350	0.8	1.2	1.7	0.5	0.8	1.3	—	—	—
Auditoriums, Churches, Theaters	15	11	6	0.5	0.7	0.9	400	250	90	—	—	—	—	—	—	1.0	2.0	3.0
Educational Facilities	30	25	20	0.75	1.0	1.1	240	185	150	1.0	1.6	2.2	0.9	1.3	2.0	0.8	1.2	1.9
Schools, Colleges, Universities																		
Factories Assembly Areas	50	35	23	2.5†	4.0†	5.5†	240	150	90	—	—	—	—	—	—	2.0	3.6	5.5
Light Manufacturing	200	150	100	7.5†	9†	11†	200	150	100	—	—	—	—	—	—	1.6	2.5	3.8
Heavy Manufacturing*	200	250	300	12†	25†	30†	100	80	60	—	—	—	—	—	—	2.5	4.0	6.5
Hospitals Patient Rooms	70	50	25	0.5	0.75	1.0	275	220	165	1.0	1.5	2.0	0.8	1.2	1.4	0.7	1.0	1.3
Public Areas	100	80	50	0.5	0.75	1.0	175	140	110	1.0	1.25	1.45	1.0	1.1	1.2	0.95	1.0	1.1
Hotels, Motels, Dormitories	200	150	100	0.5	0.75	1.0	350	300	220	1.0	1.40	1.5	0.9	1.2	1.4	—	—	—
Libraries and Museums	80	60	40	0.5	0.75	1.0	340	280	200	1.0	1.6	2.1	0.9	1.1	1.3	0.9	1.0	1.1
Office Buildings (General)	130	110	80	2†	2.5†	4†	360	280	190	1.0	1.6	2.2	0.9	1.3	2.0	0.8	1.0	1.2
Private Offices	150	125	100	0.5	0.75	1.0	—	—	—	1.2	1.8	2.4	1.1	1.5	1.8	0.8	1.2	1.4
Stenographic Department	100	85	70	1.0	1.25	1.5	—	—	—	—	—	—	—	—	—	0.9	1.3	2.0
Residential Large	600	400	200	0.5	1.0	1.5	600	500	380	0.8	1.2	1.6	0.5	0.8	1.3	—	—	—
Medium	600	360	200	0.5	1.0	1.5	700	550	400	0.7	1.1	1.4	0.5	0.7	1.2	—	—	—
Restaurants Large	17	15	13	0.5	1.0	1.5	135	100	80	1.8	2.4	3.7	1.2	1.6	2.1	0.9	1.1	1.4
Medium							150	120	100	1.5	2.0	3.0	1.1	1.4	1.8	0.9	1.0	1.3
Shopping Centers, Department Stores and Specialty Shops																		
Beauty and Barber Shops	45	40	25	3.0†	5.0†	9.0†	240	160	105	1.5	2.6	4.2	1.1	1.7	2.6	0.9	1.3	2.0
Malls	100	75	50	1.0	1.5	2.0	365	230	160	—	—	—	—	—	—	1.1	1.8	2.5
Refrigeration for Central Heating and Cooling Plant																		
Urban Districts						475	380	285										
College Campuses						400	320	240										
Commercial Centers						330	265	200										
Residential Centers						625	500	375										

Refrigeration and air quantities for applications listed in this table of cooling load check figures are based on all-air system and normal outdoor air quantities for ventilation except as noted.
†Refrigeration loads are for entire application
*Air quantities for heavy manufacturing areas are based on supplementary means to remove excessive heat.

Table 12.2 Summary of Load Sources and Equations for Estimating Space Design Cooling Load

Load Source	Equation	Reference, Table, Description
External		
Roof	$q = UA$(CLTD)	Design heat transmission coefficients, pp. 179–84 Areas calculated from plans CLTD, pp. 185–86
Walls	$q = UA$(CLTD)	Design heat transmission coefficients, pp. 179–84
		Areas calculated from plans CLTD, pp. 187–89
Glass Conduction	$q = UA$(CLTD)	Glass area calculated from plans U-factors p. 174 CLTD for conduction load through glass, p. 174
Glass Solar	$q = A$(SC)SCL	Solar Cooling Load factors, pp. 190–91 Net glass area from plans Shading coefficients for combination of glass and internal shading, p. 192 Compute shaded area from building projections Externally shaded glass: use north orientation data
Partitions, Ceilings, Floors	$q = UA$(TD)	Design heat transmission coefficients, pp. 179–84 Area calculated from plans
Internal		
Lights	q = INPUT	Input rating from electrical plans or lighting fixture data, pp. 194–96
People		
Sensible	q_s = No. (Sens. H.G.)	Number of people in space Sensible heat gain from occupants, p. 193
Latent	q_l = No. (Lat. H.G.)	Latent heat gain from occupants
Equipment and Appliances	q_s = HEAT GAIN	Recommended rate of heat gain, pp. 197–210
Power	q = HEAT GAIN	pp. 198–99
Infiltration Air		
Sensible	$q_s = 1.10\ (\text{CFM})\ \Delta t$	Inside-outside air temperature difference, °F
Latent	$q_l = 4840\ (\text{CFM})\ \Delta W$	Inside-outside air humidity ratio difference, grains/lbda
Total	$q = 4.5\ (\text{CFM})\ \Delta h$	Inside-outside air enthalpy difference, Btu/lbda

CAUTION: Approximate data—Use for preliminary computations only. See *ASHRAE Cooling and Heating Load Calculation Applications Manual* (Spitler 2008), and *ASHRAE Load Calculation Toolkit.*

Heat Flow *Q* Through Building Materials

(In addition to heat flow through building materials the resistance of surfaces and air spaces must be included in calculating U-factors.)

$$Q \text{ (Btu/h)} = U \times \text{Area (ft}^2\text{)} \times \text{temperature difference (°F)}$$

where U = overall coefficient of heat transmission, Btu/h·ft^2·°F, of materials + interior and exterior resistances:

$$1/U = \Sigma R \text{ (resistance of components)}$$

For multiple layers of homogeneous materials, R values are added in series:

$$1/U = R_{cold\ surface} + R_1 + R_2 + R_n ... + R_{warm\ surface}$$

For wood stud walls, studs 16 in. on center (series and parallel):

$$1/U = R_{cold\ surface} + \left\{ \frac{+\ 0.25\ R_{stud}}{+\ 0.75\ R_{stud\ space}} \right\} + R_{warm\ surface}$$

(Plus, in series, $R_{insulation}$, R_{siding}, $R_{wallboard}$, etc.)

For metal framed construction, heat flow through the metal causes thermal bridging, increasing the U-factor significantly.

Conductive Heat Flow Through Glazing

Solar radiation gain through glazing is usually more significant in cooling load calculations than conductive heat gain. Solar heat gain is neglected in heating load calculations.

Conductive heat flow through glazing including surface resistance (approximate data)

Single glazing	$U = 1.1$
Double glazing	$U = 0.55$
Triple glazing	$U = 0.33$

Table 12.3 Effective Thermal Resistance of Plane Air Spaces,[a,b,c] h·ft²·°F/Btu
[2013F, Ch 26, Tbl 3]

Position of Air Space	Direction of Heat Flow	Air Space: Mean Temp.[d], °F	Air Space: Temp. Diff.,[d] °F	Effective Emittance ε_{eff}[d,e]: 0.5 in. Air Space[c]					0.75 in. Air Space[c]				
				0.03	0.05	0.2	0.5	0.82	0.03	0.05	0.2	0.5	0.82
Horiz.	Up ↑	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		50	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		–50	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
		–50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
Vertical	Horiz. →	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		–50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		–50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
Horiz.	Down ↓	90	10	2.48	2.34	1.67	1.06	0.77	3.55	3.29	2.10	1.22	0.85
		50	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02
		50	10	2.67	2.55	1.89	1.25	0.92	3.84	3.59	2.41	1.45	1.02
		0	20	2.94	2.83	2.20	1.53	1.15	4.18	3.96	2.83	1.81	1.30
		0	10	2.96	2.85	2.22	1.53	1.16	4.25	4.02	2.87	1.82	1.31
		–50	20	3.25	3.15	2.58	1.89	1.47	4.60	4.41	3.36	2.28	1.69
		–50	10	3.28	3.18	2.60	1.90	1.47	4.71	4.51	3.42	2.30	1.71

[a] See Chapter 25 of *ASHRAE Handbook—Fundamentals* (2013). Thermal resistance values were determined from $R = 1/C$, where $C = h_c + \varepsilon_{eff} h_r$, h_c is conduction/convection coefficient, $\varepsilon_{eff} h_r$ is radiation coefficient $\approx 0.0068\varepsilon_{eff}[(t_m + 460)/100]^3$, and t_m is mean temperature of air space.

[b] Values apply for ideal conditions (i.e., air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no air leakage to or from the space). **This table should not be used for hollow siding or profiled cladding.**

[c] A single resistance value cannot account for multiple air spaces; each air space requires a separate resistance calculation that applies only for established boundary conditions. Resistances of horizontal spaces with heat flow downward are substantially independent of temperature difference.

[d] Interpolation is permissible for other values of mean temperature, temperature difference, and effective emittance ε_{eff}. Interpolation and moderate extrapolation for air spaces greater than 3.5 in. are also permissible.

[e] Effective emittance ε_{eff} of air space is given by $1/\varepsilon_{eff} = 1/\varepsilon_1 + 1/\varepsilon_2 - 1$, where ε_1 and ε_2 are emittances of surfaces of air space (see Table 2). **Also, oxidation, corrosion, and accumulation of dust and dirt can dramatically increase surface emittance. Emittance values of 0.05 should only be used where the highly reflective surface can be maintained over the service life of the assembly.**

Table 12.4 Surface Film Coefficients/Resistances [2013, Ch 26, Tbl 10]

Position of Surface	Direction of Heat Flow	Surface Emittance, ε					
		Nonreflective ε = 0.90		Reflective			
				ε = 0.20		ε = 0.05	
Indoor		h_i	R_i	h_i	R_i	h_i	R_i
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping at 45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping at 45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
Outdoor (any position)		h_o	R_o				
15 mph wind (for winter)	Any	6.00	0.17	—	—	—	—
7.5 mph wind (for summer)	Any	4.00	0.25	—	—	—	—

Notes:
1. Surface conductance h_i and h_o measured in Btu/h·ft^2·°F; resistance R_i and R_o in h·ft^2·°F/Btu.
2. No surface has both an air space resistance value and a surface resistance value.
3. Conductances are for surfaces of the stated emittance facing virtual blackbody surroundings at same temperature as ambient air. Values based on surface/air temperature difference of 10°F and surface temperatures of 70°F.
4. See Chapter 4 for more detailed information.
5. Condensate can have significant effect on surface emittance (see Table 2). Also, oxidation, corrosion, and accumulation of dust and dirt can dramatically increase surface emittance. Emittance values of 0.05 should only be used where highly reflective surface can be maintained over the service life of the assembly.

Table 12.5 European Surface Film Coefficients/Resistances [2013, Ch 26, Tbl 11]

Position of Surface	Direction of Heat Flow	*h*, Btu/h·ft^2·°F	*R*, h·ft^2·°F/Btu
Indoors			
Horizontal, sloping to 45°	Upward	1.76	0.57
	Downward	1.06	0.97
Vertical, sloping beyond 45°	Any direction	1.36	0.74
Outdoors		4.4	0.23

Table 12.6 Emissivity of Various Surfaces and Effective Emittances of Facing Air Spaces[a] [2013F, Ch 26, Tbl 2]

Surface	Average Emissivity ε	Effective Emittance ε_{eff} of Air Space	
		One Surface's Emittance ε; Other, 0.9	Both Surfaces' Emittance ε
Aluminum foil, bright	0.05	0.05	0.03
Aluminum foil, with condensate just visible (>0.7 g/ft^2)	0.30[b]	0.29	—
Aluminum foil, with condensate clearly visible (>2.9 g/ft^2)	0.70[b]	0.65	—
Aluminum sheet	0.12	0.12	0.06
Aluminum-coated paper, polished	0.20	0.20	0.11
Brass, nonoxidized	0.04	0.038	0.02
Copper, black oxidized	0.74	0.41	0.59
Copper, polished	0.04	0.038	0.02
Iron and steel, polished	0.2	0.16	0.11
Iron and steel, oxidized	0.58	0.35	0.41
Lead, oxidized	0.27	0.21	0.16
Nickel, nonoxidized	0.06	0.056	0.03
Silver, polished	0.03	0.029	0.015
Steel, galvanized, bright	0.25	0.24	0.15
Tin, nonoxidized	0.05	0.047	0.026
Aluminum paint	0.50	0.47	0.35
Building materials: wood, paper, masonry, nonmetallic paints	0.90	0.82	0.82
Regular glass	0.84	0.77	0.72

[a]Values apply in 4 to 40 μm range of electromagnetic spectrum. Also, oxidation, corrosion, and accumulation of dust and dirt can dramatically increase surface emittance. Emittance values of 0.05 should only be used where the highly reflective surface can be maintained over the service life of the assembly. Except as noted, data from VDI (1999).

[b]Values based on data in Bassett and Trethowen (1984).

Table 12.7 Effective Thermal Resistance of Ventilated Attics[a] (Summer Condition)

Ventilation Air Temp., °F	Sol-Air[e] Temp., °F	Not Ventilation[b]		Natural Ventilation		Power Ventilation[c]					
		Ventilation Rate, cfm/ft²									
		0		0.1		0.5		1.0		1.5	
		Ceiling Resistance *R*[d], °F·ft²·h/Btu									
		10	20	10	20	10	20	10	20	10	20
		Part A. Nonreflective Surfaces									
80	120	1.9	1.9	2.8	3.4	6.3	9.3	9.6	16	11	20
	140	1.9	1.9	2.8	3.5	6.5	10	9.8	17	12	21
	160	1.9	1.9	2.8	3.6	6.7	11	10	18	13	22
100	120	1.9	1.9	2.2	2.3	3.3	4.4	4.0	6.0	4.1	6.9
	140	1.9	1.9	2.4	2.7	4.2	6.1	5.8	8.7	6.5	10
	160	1.9	1.9	2.6	3.2	5.0	7.6	7.2	11	8.3	13
		Part B. Reflective Surfaces[f]									
80	120	6.5	6.5	8.1	8.8	13	17	17	25	19	30
	140	6.5	6.5	8.2	9.0	14	18	18	26	20	31
	160	6.5	6.5	8.3	9.2	15	18	19	27	21	32
100	120	6.5	6.5	7.0	7.4	8.0	10	8.5	12	8.8	12
	140	6.5	6.5	7.3	7.8	10	12	11	15	12	16
	160	6.5	6.5	7.6	8.2	11	14	13	18	15	20

[a]Although the term effective resistance is commonly used when there is attic ventilation, this table includes values for situations with no ventilation. The effective resistance of the attic added to the resistance (1/U) of the ceiling yields the effective resistance of this combination based on sol-air and room temperatures. These values apply to wood frame construction with a roof deck and roofing that has a conductance of 1.0 Btu/h·ft²·°F.

[b]This condition cannot be achieved in the field unless extreme measures are taken to tightly seal the attic.

[c]Based on air discharging outward from attic.

[d]When determining ceiling resistance, do not add the effect of a reflective surface facing the attic, as it is accounted for in part B of this table.

[e]Roof surface temperature rather than sol-air temperature can be used if 0.25 is subtracted from the attic resistance shown.

[f]Surfaces with effective emittance ε_{eff} = 0.05 between ceiling joists facing attic space.

Table 12.8 Building and Insulating Materials: Design Values[a]

[2013F, Ch 26, Tbl 1]

Description	Density, lb/ft³	Conductivity[b] k, Btu·in/h·ft²·°F	Resistance R, h·ft²·°F/Btu	Specific Heat c_p, Btu/lb·°F
Insulating Materials				
Blanket and batt[c,d]				
Glass-fiber batts				0.2
	0.47 to 0.51	0.32 to 0.33	—	—
	0.61 to 0.75	0.28 to 0.30	—	—
	0.79 to 0.85	0.26 to 0.27	—	—
	1.4	0.23	—	—
Rock and slag wool batts.	—	—	—	0.2
	2 to 2.3	0.25 to 0.26	—	—
	2.8	0.23 to 0.24	—	—
Mineral wool, felted	1 to 3	0.28	—	—
	1 to 8	0.24	—	—
Board and slabs				
Cellular glass	7.5	0.29	—	0.20
Cement fiber slabs, shredded wood with				
Portland cement binder	25 to 27	0.50 to 0.53	—	—
with magnesia oxysulfide binder	22	0.57	—	0.31
Glass fiber board	—	—	—	0.2
	1.5 to 6.0	0.23 to 0.24	—	—
Expanded rubber (rigid)	4	0.2	—	0.4
Extruded polystyrene, smooth skin	—	—	—	0.35
aged per Can/ULC Standard S770-2003	1.4 to 3.6	0.18 to 0.20	—	—
aged 180 days	1.4 to 3.6	0.20		
European product	1.9	0.21		
aged 5 years at 75°F	2 to 2.2	0.21	—	—
blown with low global warming potential (GWP) (<5) blowing agent		0.24 to 0.25	—	—
Expanded polystyrene, molded beads	—	—	—	0.35
	1.0 to 1.5	0.24 to 0.26	—	—
	1.8	0.23	—	—
Mineral fiberboard, wet felted	10	0.26	—	0.2
Rock wool board	—	—	—	0.2
floors and walls	4.0 to 8.0	0.23 to 0.25	—	—
roofing	10. to 11.	0.27 to 0.29	—	0.2
Acoustical tile[e]	21 to 23	0.36 to 0.37	—	0.14 to 0.19
Perlite board	9	0.36	—	—
Polyisocyanurate	—	—	—	0.35
unfaced, aged per Can/ULC Standard S770-2003	1.6 to 2.3	0.16 to 0.17	—	—
with foil facers, aged 180 days	—	0.15 to 0.16	—	—
Phenolic foam board with facers, aged	—	0.14 to 0.16	—	—
Loose fill				
Cellulose fiber, loose fill	—	—	—	0.33
attic application up to 4 in.	1.0 to 1.2	0.31 to 0.32	—	—
attic application > 4 in.	1.2 to 1.6	0.27 to 0.28	—	—
wall application, densely packed	3.5	0.27 – 0.28	—	—
Perlite, expanded	2 to 4	0.27 to 0.31	—	0.26
	4 to 7.5	0.31 to 0.36	—	—
	7.5 to 11	0.36 to 0.42	—	—
Glass fiber[d]				
attics, ~4 to 12 in.	0.4 to 0.5	0.36 to 0.38	—	—
attics, ~12 to 22 in.	0.5 to 0.6	0.34 to 0.36	—	—
closed attic or wall cavities	1.8 to 2.3	0.24 to 0.25	—	—
Rock and slag wool[d]				
attics, ~3.5 to 4.5 in.	1.5 to 1.6	0.34	—	—
attics, ~5 to 17 in.	1.5 to 1.8	0.32 to 0.33	—	—
closed attic or wall cavities	4.0	0.27 to 0.29	—	—
Vermiculite, exfoliated	7.0 to 8.2	0.47	—	0.32
	4.0 to 6.0	0.44	—	—
Spray applied				
Cellulose, sprayed into open wall cavities	1.6 to 2.6	0.27 to 0.28	—	—
Glass fiber, sprayed into open wall or attic cavities	1.0	0.27 to 0.29	—	—
	1.8 to 2.3	0.23 to 0.26	—	—
Polyurethane foam	—	—	—	0.35
low density, open cell	0.45 to 0.65	0.26 to 0.29	—	—
medium density, closed cell, aged 180 days	1.9 to 3.2	0.14 to 0.20	—	—

Table 12.8 Building and Insulating Materials: Design Values[a]

[2013F, Ch 26, Tbl 1] ***(Continued)***

Description	Density, lb/ft^3	Conductivity[b] k, $Btu \cdot in/h \cdot ft^2 \cdot °F$	Resistance R, $h \cdot ft^2 \cdot °F/Btu$	Specific Heat c_p, $Btu/lb \cdot °F$
Building Board and Siding				
Board				
Asbestos/cement board	120	4	—	0.24
Cement board	71	1.7	—	0.2
Fiber/cement board	88	1.7	—	0.2
	61	1.3	—	0.2
	26	0.5	—	0.45
	20	0.4	—	0.45
Gypsum or plaster board	40	1.1	—	0.21
Oriented strand board (OSB) 7/16 in.	41	—	0.62	0.45
1/2 in.	41	—	0.68	0.45
Plywood (douglas fir) 1/2 in.	29	—	0.79	0.45
5/8 in.	34	—	0.85	0.45
Plywood/wood panels 3/4 in.	28	—	1.08	0.45
Vegetable fiber board				
sheathing, regular density 1/2 in.	18	—	1.32	0.31
intermediate density 1/2 in.	22	—	1.09	0.31
nail-based sheathing 1/2 in.	25	—	1.06	0.31
shingle backer 3/8 in.	18	—	0.94	0.3
sound-deadening board 1/2 in.	15	—	1.35	0.3
tile and lay-in panels, plain or acoustic	18	0.4	—	0.14
laminated paperboard	30	0.5	—	0.33
homogeneous board from repulped paper	30	0.5	—	0.28
Hardboard				
medium density	50	0.73	—	0.31
high density, service-tempered and service grades	55	0.82	—	0.32
high density, standard-tempered grade	63	1.0	—	0.32
Particleboard				
low density	37	0.71	—	0.31
medium density	50	0.94	—	0.31
high density	62	1.18	0.85	—
underlayment 5/8 in.	44	0.73	0.82	0.29
Waferboard	37	0.63	0.21	0.45
Shingles				
Asbestos/cement	120	—	0.21	—
Wood, 16 in., 7 1/2 in. exposure	—	—	0.87	0.31
Wood, double, 16 in., 12 in. exposure	—	—	1.19	0.28
Wood, plus ins. backer board 5/16 in.	—	—	1.4	0.31
Siding				
Asbestos/cement, lapped 1/4 in.	—	—	0.21	0.24
Asphalt roll siding	—	—	0.15	0.35
Asphalt insulating siding (1/2 in. bed)	—	—	0.21	0.24
Hardboard siding 7/16 in.	—	—	0.15	0.35
Wood, drop, 8 in. 1 in.	—	—	0.79	0.28
Wood, bevel				
8 in., lapped 1/2 in.	—	—	0.81	0.28
10 in., lapped 3/4 in.	—	—	1.05	0.28
Wood, plywood, 3/8 in., lapped	—	—	0.59	0.29
Aluminum, steel, or vinyl,[h, i] over sheathing				—
hollow-backed	—	—	0.62	0.29[i]
insulating-board-backed 3/8 in.	—	—	1.82	0.32
foil-backed 3/8 in.	—	—	2.96	—
Architectural (soda-lime float) glass	158	6.9	—	0.21
Building Membrane				
Vapor-permeable felt	—	—	0.06	—
Vapor: seal, 2 layers of mopped 15 lb felt	—	—	0.12	—
Vapor: seal, plastic film	—	—	Negligible	—
Finish Flooring Materials				
Carpet and rebounded urethane pad 3/4 in.	7	—	2.38	—
Carpet and rubber pad (one-piece) 3/8 in.	20	—	0.68	—
Pile carpet with rubber pad 3/8 to 1/2 in.	18	—	1.59	—
Linoleum/cork tile 1/4 in.	29	—	0.51	—
PVC/rubber floor covering	—	2.8	—	—
rubber tile 1.0 in.	119	—	0.34	—
terrazzo 1.0 in.	—	—	0.08	0.19
Metals (See Chapter 33, Table 3 in 2013 *ASHRAE Handbook—Fundamentals*)				

Table 12.8 Building and Insulating Materials: Design Values[a]
[2013F, Ch 26, Tbl 1] ***(Continued)***

Description	Density, lb/ft^3	Conductivity[b] k, Btu·in/h·ft^2·°F	Resistance R, h·ft^2·°F/Btu	Specific Heat c_p, Btu/lb·°F
Roofing				
Asbestos/cement shingles	120	—	0.21	0.24
Asphalt (bitumen with inert fill)	100	2.98	—	—
	119	4.0	—	—
	144	7.97	—	—
Asphalt roll roofing	70	—	0.15	0.36
Asphalt shingles	70	—	0.44	0.3
Built-up roofing ... 3/8 in.	70	—	0.33	0.35
Mastic asphalt (heavy, 20% grit)	59	1.32	—	—
Reed thatch	17	0.62	—	—
Roofing felt	141	8.32	—	—
Slate ... 1/2 in.	—	—	0.05	0.3
Straw thatch	15	0.49	—	—
Wood shingles, plain and plastic-film-faced	—	—	0.94	0.31
Plastering Materials				
Cement plaster, sand aggregate	116	5.0	—	0.2
Sand aggregate ... 3/8 in.	—	—	0.08	0.2
... 3/4 in.	—	—	0.15	0.2
Gypsum plaster	70	2.63	—	—
	80	3.19	—	—
Lightweight aggregate ... 1/2 in.	45	—	0.32	—
... 5/8 in.	45	—	0.39	—
on metal lath ... 3/4 in.	—	—	0.47	—
Perlite aggregate	45	1.5	—	0.32
Sand aggregate	105	5.6	—	0.2
on metal lath ... 3/4 in.	—	—	0.13	—
Vermiculite aggregate	30	1.0	—	—
	40	1.39	—	—
	45	1.7	—	—
	50	1.8	—	—
	60	2.08	—	—
Perlite plaster	25	0.55	—	—
	38	1.32	—	—
Pulpboard or paper plaster	38	0.48	—	—
Sand/cement plaster, conditioned	98	4.4	—	—
Sand/cement/lime plaster, conditioned	90	3.33	—	—
Sand/gypsum (3:1) plaster, conditioned	97	4.5	—	—
Masonry Materials				
Masonry units				
Brick, fired clay	150	8.4 to 10.2	—	—
	140	7.4 to 9.0	—	—
	130	6.4 to 7.8	—	—
	120	5.6 to 6.8	—	0.19
	110	4.9 to 5.9	—	—
	100	4.2 to 5.1	—	—
	90	3.6 to 4.3	—	—
	80	3.0 to 3.7	—	—
	70	2.5 to 3.1	—	—
Clay tile, hollow				
1 cell deep ... 3 in.	—	—	0.80	0.21
... 4 in.	—	—	1.11	—
2 cells deep ... 6 in.	—	—	1.52	—
... 8 in.	—	—	1.85	—
... 10 in.	—	—	2.22	—
3 cells deep ... 12 in.	—	—	2.50	—
Lightweight brick	50	1.39	—	—
	48	1.51	—	—
Concrete blocks[f, g]				
Limestone aggregate				
8 in., 36 lb, 138 lb/ft^3 concrete, 2 cores	—	—	—	—
with perlite-filled cores	—	—	2.1	—
12 in., 55 lb, 138 lb/ft^3 concrete, 2 cores	—		—	—
with perlite-filled cores	—	—	3.7	—

Table 12.8 Building and Insulating Materials: Design Values[a]
[2013F, Ch 26, Tbl 1] ***(Continued)***

Description	Density, lb/ft³	Conductivity[b] k, Btu·in/h·ft²·°F	Resistance R, h·ft²·°F/Btu	Specific Heat c_p, Btu/lb·°F
Normal-weight aggregate (sand and gravel)				
8 in., 33 to 36 lb, 126 to 136 lb/ft³ concrete, 2 or 3 cores	—	—	1.11 to 0.97	0.22
with perlite-filled cores	—	—	2.0	—
with vermiculite-filled cores	—	—	1.92 to 1.37	—
12 in., 50 lb, 125 lb/ft³ concrete, 2 cores	—	—	1.23	0.22
Medium-weight aggregate (combinations of normal and lightweight aggregate)				
8 in., 26 to 29 lb, 97 to 112 lb/ft³ concrete, 2 or 3 cores	—	—	1.71 to 1.28	—
with perlite-filled cores	—	—	3.7 to 2.3	—
with vermiculite-filled cores	—	—	3.3	—
with molded-EPS-filled (beads) cores	—	—	3.2	—
with molded EPS inserts in cores	—	—	2.7	—
Lightweight aggregate (expanded shale, clay, slate or slag, pumice)				
6 in., 16 to 17 lb, 85 to 87 lb/ft³ concrete, 2 or 3 cores	—	—	1.93 to 1.65	—
with perlite-filled cores	—	—	4.2	—
with vermiculite-filled cores	—	—	3.0	—
8 in., 19 to 22 lb, 72 to 86 lb/ft³ concrete	—	—	3.2 to 1.90	0.21
with perlite-filled cores	—	—	6.8 to 4.4	—
with vermiculite-filled cores	—	—	5.3 to 3.9	—
with molded-EPS-filled (beads) cores	—	—	4.8	—
with UF foam-filled cores	—	—	4.5	—
with molded EPS inserts in cores	—	—	3.5	—
12 in., 32 to 36 lb, 80 to 90 lb/ft³, concrete, 2 or 3 cores	—	—	2.6 to 2.3	—
with perlite-filled cores	—	—	9.2 to 6.3	—
with vermiculite-filled cores	—	—	5.8	—
Stone, lime, or sand	180	72	—	—
Quartzitic and sandstone	160	43	—	—
	140	24	—	—
	120	13	—	0.19
Calcitic, dolomitic, limestone, marble, and granite	180	30	—	—
	160	22	—	—
	140	16	—	—
	120	11	—	0.19
	100	8	—	—
Gypsum partition tile				
3 by 12 by 30 in., solid	—	—	1.26	0.19
4 cells	—	—	1.35	—
4 by 12 by 30 in., 3 cells	—	—	1.67	—
Limestone	150	3.95	—	0.2
	163	6.45	—	0.2
Concretes[i]				
Sand and gravel or stone aggregate concretes	150	10.0 to 20.0	—	—
(concretes with >50% quartz or quartzite	140	9.0 to 18.0	—	0.19 to 0.24
sand have conductivities in higher end of range)	130	7.0 to 13.0	—	—
Lightweight aggregate or limestone concretes	120	6.4 to 9.1	—	—
expanded shale, clay, or slate; expanded slags; cinders;	100	4.7 to 6.2	—	0.2
pumice (with density up to 100 lb/ft³); scoria (sanded	80	3.3 to 4.1	—	0.2
concretes have conductivities in higher end	60	2.1 to 2.5	—	—
of range)	40	1.3	—	—
Gypsum/fiber concrete (87.5% gypsum, 12.5% wood chips)	51	1.66	—	0.2
Cement/lime, mortar, and stucco	120	9.7	—	—
	100	6.7	—	—
	80	4.5	—	—

Table 12.8 Building and Insulating Materials: Design Values[a]
[2013F, Ch 26, Tbl 1] ***(Continued)***

Description	Density, lb/ft³	Conductivity[b] k, Btu·in/h·ft²·°F	Resistance R, h·ft²·°F/Btu	Specific Heat c_p, Btu/lb·°F
Perlite, vermiculite, and polystyrene beads	50	1.8 to 1.9	—	—
	40	1.4 to 1.5	—	0.15 to 0.23
	30	1.1	—	—
	20	0.8	—	—
Foam concretes	120	5.4	—	—
	100	4.1	—	—
	80	3.0	—	—
	70	2.5	—	—
Foam concretes and cellular concretes	60	2.1	—	—
	40	1.4	—	—
	20	0.8	—	—
Aerated concrete (oven-dried)	27 to 50	1.4	—	0.2
Polystyrene concrete (oven-dried)	16 to 50	2.54	—	0.2
Polymer concrete	122	11.4	—	—
	138	7.14	—	—
Polymer cement	117	5.39	—	—
Slag concrete	60	1.5	—	—
	80	2.25	—	—
	100	3	—	—
	125	8.53	—	—
Woods (12% moisture content)[j]				
Hardwoods	—	—	—	0.39[k]
Oak	41 to 47	1.12 to 1.25	—	—
Birch	43 to 45	1.16 to 1.22	—	—
Maple	40 to 44	1.09 to 1.19	—	—
Ash	38 to 42	1.06 to 1.14	—	—
Softwoods	—	—	—	0.39[k]
Southern pine	36 to 41	1.00 to 1.12	—	—
Southern yellow pine	31	1.06 to 1.16	—	—
Eastern white pine	25	0.85 to 0.94	—	—
Douglas fir/larch	34 to 36	0.95 to 1.01	—	—
Southern cypress	31 to 32	0.90 to 0.92	—	—
Hem/fir, spruce/pine/fir	24 to 31	0.74 to 0.90	—	—
Spruce	25	0.74 to 0.85	—	—
Western red cedar	22	0.83 to 0.86	—	—
West coast woods, cedars	22 to 31	0.68 to 0.90	—	—
Eastern white cedar	23	0.82 to 0.89	—	—
California redwood	24 to 28	0.74 to 0.82	—	—
Pine (oven-dried)	23	0.64	—	0.45
Spruce (oven-dried)	25	0.69	—	0.45

Notes for Table 12.8

[a]Values are for mean temperature of 75°F. Representative values for dry materials are intended as design (not specification) values for materials in normal use. Thermal values of insulating materials may differ from design values depending on in-situ properties (e.g., density and moisture content, orientation, etc.) and manufacturing variability. For properties of specific product, use values supplied by manufacturer or unbiased tests.

[b]Symbol λ also used to represent thermal conductivity.

[c]Does not include paper backing and facing, if any. Where insulation forms boundary (reflective or otherwise) of airspace, see Tables 2 and 3 for insulating value of airspace with appropriate effective emittance and temperature conditions of space.

[d]Conductivity varies with fiber diameter (see Chapter 25). Batt, blanket, and loose-fill mineral fiber insulations are manufactured to achieve specified R-values, the most common of which are listed in the table. Because of differences in manufacturing processes and materials, the product thicknesses, densities, and thermal conductivities vary over considerable ranges for a specified R-value.

[e]Insulating values of acoustical tile vary, depending on density of board and on type, size, and depth of perforations.

[f]Values for fully grouted block may be approximated using values for concrete with similar unit density.

[g]Values for concrete block and concrete are at moisture contents representative of normal use.

[h]Values for metal or vinyl siding applied over flat surfaces vary widely, depending on ventilation of the airspace beneath the siding; whether airspace is reflective or nonreflective; and on thickness, type, and application of insulating backing-board used. Values are averages for use as design guides, and were obtained from several guarded hot box tests (ASTM Standard C1363) on hollow-backed types and types made using backing of wood fiber, foamed plastic, and glass fiber. Departures of ±50% or more from these values may occur.

[i]Vinyl specific heat = 0.25 Btu/lb·°F.

[j]See Adams (1971), MacLean (1941), and Wilkes (1979). Conductivity values listed are for heat transfer across the grain. Thermal conductivity of wood varies linearly with density, and density ranges listed are those normally found for wood species given. If density of wood species is not known, use mean conductivity value. For extrapolation to other moisture contents, the following empirical equation developed by Wilkes (1979) may be used:

$$k = 0.1791 + \frac{(1.874 \times 10^{-2} + 5.753 \times 10^{-4} M)\rho}{1 + 0.01M}$$

where ρ is density of moist wood in lb/ft^3, and M is moisture content in percent.

[k]From Wilkes (1979), an empirical equation for specific heat of moist wood at 75°F is as follows:

$$c_p = \frac{(0.299 + 0.01M)}{(1 + 0.01M)} + \Delta c_p$$

where Δc_p accounts for heat of sorption and is denoted by

$$\Delta c_p = M(1.921 \times 10^{-3} - 3.168 \times 10^{-5} M)$$

where M is moisture content in percent by mass.

Table 12.9 CLTDs for Flat Roofs—24°N Latitude, July

Roof No	Solar time, h											
	2	4	6	8	10	12	14	16	18	20	22	24
1	–2	–5	–6	9	44	76	92	86	58	23	8	2
2	0	–4	–6	1	30	64	86	89	70	36	14	5
3	8	2	–2	3	22	47	68	77	68	47	29	16
4	11	3	–2	–4	5	27	55	75	80	67	43	23
5	16	8	3	1	10	30	52	68	70	59	41	27
8	24	17	11	9	14	27	43	54	58	52	42	32
9	25	16	9	4	5	17	36	54	65	63	51	37
10	31	22	15	9	8	16	30	45	56	59	52	41
13	31	25	20	16	16	23	33	43	49	49	43	37
14	32	27	23	19	19	24	32	40	45	45	42	37

Table 12.10 CLTDs for Flat Roofs—36°N Latitude, July

Roof No.	Solar time, h											
	2	4	6	8	10	12	14	16	18	20	22	24
1	–2	–5	–6	12	45	75	90	84	60	26	9	2
2	0	–4	–6	4	32	63	84	87	70	39	15	5
3	8	2	–2	4	24	47	67	75	68	48	30	17
4	11	3	–1	–3	7	29	55	74	79	67	45	24
5	16	8	3	2	12	31	52	67	70	59	42	27
8	25	17	12	9	15	28	42	54	58	53	43	33
9	26	16	9	4	7	19	37	54	64	63	52	38
10	32	23	15	10	9	17	30	45	56	58	52	42
13	31	25	20	16	17	24	33	43	49	49	44	37
14	32	28	23	20	20	25	32	40	45	46	42	37

Table 12.11 CLTDs for Flat Roofs—48°N Latitude, July

Roof No.	Solar time, h											
	2	4	6	8	10	12	14	16	18	20	22	24
1	–2	–5	–5	15	44	69	83	79	59	29	9	2
2	0	–4	–5	6	32	60	78	81	68	41	16	5
3	8	2	–1	6	24	45	63	71	65	48	30	17
4	12	3	–1	–2	8	29	52	69	74	65	45	25
5	16	8	3	3	13	31	49	63	66	58	42	27
8	24	17	11	10	16	27	40	51	55	51	42	32
9	26	16	9	5	8	19	35	51	60	61	51	38
10	31	22	15	10	10	17	29	43	53	56	51	41
13	30	25	20	16	18	24	32	41	47	47	43	37
14	32	27	23	20	20	24	31	38	43	44	41	36

CAUTION: Approximate data—Use for preliminary computations only. Also, see notes on next page.

Notes for CLTD Data for Flat Roofs

1. Data apply directly to (1) dark surface, (2) indoor temperature is 78°F, (3) outdoor maximum temperature of 95°F with mean temperature of 85°F and daily range of 21°F, (4) solar radiation typical of clear day on 21st day of month, (5) outside surface film resistance of 0.333 $h \cdot ft^2 \cdot °F/Btu$, and (6) inside surface resistance of 0.685 $h \cdot ft^2 \cdot °F/Btu$.
2. Adjustments to design temperatures

$$\text{Corr. CLTD} = \text{CLTD} + (78 - t_r) + (t_m - 85)$$

where t_r = inside temperature and t_m = mean outdoor temperature, or t_m = maximum outdoor temperature – (daily range)/2.

No adjustment recommended for color or for ventilation of air space above a ceiling.

For design purposes, the data suffice for plus or minus 2 weeks from the 21st day of given month.

Table 12.12 Roof Classifications for Use with CLTD Tables for Flat Roofs

Mass Location	Suspended Ceiling	*R*, $h \cdot ft^2 \cdot °F/Btu$	Wood 1 in.	2 in. (Heavyweight) Concrete	Steel Deck	Attic Ceiling Comb.
Mass inside insul.	Without	0 to 10	*	2	*	*
		10 to 20	*	4	*	*
		20 to 25	*	5	*	*
	With	0 to 5	*	5	*	*
		5 to 10	*	8	*	*
		10 to 20	*	13	*	*
		20 to 25	*	14	*	*
Mass evenly placed	Without	0 to 5	1	2	1	1
		5 to 15	2	*	1	2
		15 to 25	4	*	2	2
	With	0 to 5	*	3	1	*
		5 to 10	4	*	1	*
		10 to 15	5	*	2	
		15 to 20	9	*	2	*
		20 to 25	10	*	4	*
Mass outside insul.	Without	0 to 5	*	2	*	*
		5 to 10	*	3	*	*
		10 to 15	*	4	*	*
		15 to 25	*	5	*	*
	With	0 to 10	*	3	*	*
		10 to 15	*	4	*	*
		15 to 20	*	5	*	*

*Denotes roof that is not possible with the chosen parameters

Table 12.13 Approximate CLTDs for Sunlit Walls—24°N Latitude, July

Wall Facing	Solar time, h								Solar time, h								Solar time, h							
	6	8	10	12	14	16	18	20	6	8	10	12	14	16	18	20	6	8	10	12	14	16	18	20
	Low Mass, Low R-Value Wall								Low Mass, Medium R-Value Wall								Low Mass, High R-Value Wall							
N	–2	13	18	22	28	32	34	17	1	0	6	13	18	23	28	30	–2	2	12	18	23	28	32	29
NE	0	39	53	39	30	30	24	13	0	3	20	36	39	35	32	27	–2	9	36	46	38	32	29	22
E	0	44	63	48	32	30	24	13	1	3	22	43	46	40	34	28	–2	10	42	55	44	35	30	23
SE	–2	25	44	42	32	30	24	13	0	1	13	28	35	35	32	27	–2	4	26	40	38	33	29	22
S	–3	3	12	24	31	30	23	13	0	–1	1	7	16	24	27	25	–2	–1	4	13	24	29	28	22
SW	–3	3	13	22	40	58	52	20	1	–1	1	7	15	29	43	47	–2	–1	5	13	24	42	54	44
W	–3	3	13	22	42	73	75	27	2	0	2	7	15	30	52	61	–1	–1	5	13	23	46	69	61
NW	–3	3	13	22	37	62	67	25	1	0	2	7	15	27	45	54	–1	–1	5	13	22	40	60	55
	High Mass, Low R-Value Wall								High Mass, Medium R-Value Wall								High Mass, High R-Value Wall							
N	3	3	7	12	16	21	25	27	10	8	8	10	12	15	18	21	12	9	8	8	10	13	16	19
NE	3	6	20	31	33	32	31	27	11	9	14	21	25	26	27	26	13	10	10	15	21	24	27	27
E	4	6	22	36	39	36	33	29	12	10	15	24	29	30	30	29	14	11	11	17	24	28	30	31
SE	3	4	14	25	30	30	30	26	10	8	11	17	21	24	25	25	13	10	9	12	17	21	24	25
S	3	1	3	7	14	20	23	22	8	6	5	6	10	14	17	18	10	8	6	5	7	10	14	17
SW	5	3	4	8	14	26	38	40	13	10	9	9	11	17	24	30	17	13	10	8	9	12	18	25
W	7	4	4	8	15	28	45	51	17	13	11	11	13	18	28	36	21	16	12	10	11	13	20	30
NW	6	3	4	8	14	25	40	46	15	12	10	10	12	17	25	32	19	14	11	9	10	12	18	26

CAUTION: Approximate data—Use for preliminary computations only.

Table 12.14 Approximate CLTDs for Sunlit Walls—36°N Latitude, July

Wall Facing	Solar time, h								Solar time, h								Solar time, h							
	6	8	10	12	14	16	18	20	6	8	10	12	14	16	18	20	6	8	10	12	14	16	18	20
	Low Mass, Low R-Value Wall								Low Mass, Medium R-Value Wall								Low Mass, High R-Value Wall							
N	–1	12	14	21	28	29	30	17	0	0	5	10	16	22	26	27	–2	3	9	15	21	27	28	27
NE	1	41	46	30	29	29	24	14	0	4	21	33	33	31	30	27	–2	12	36	39	32	30	28	23
E	1	49	64	48	31	30	24	14	1	4	26	45	47	40	34	29	–2	14	46	56	45	34	30	23
SE	–1	31	52	52	36	30	24	14	1	2	16	34	44	41	35	29	–2	7	31	48	47	37	31	23
S	–3	4	18	39	47	40	25	14	0	–1	2	11	25	36	38	32	–2	–1	6	21	37	44	37	25
SW	–2	4	13	23	50	67	59	23	1	0	2	8	17	34	51	54	–1	–1	5	13	28	50	62	51
W	–2	4	13	21	42	73	78	31	2	0	2	8	15	30	52	63	–1	–1	5	13	23	46	69	65
NW	–2	4	13	21	29	53	65	28	1	0	2	8	15	24	39	51	–2	–1	5	13	21	33	53	55
	High Mass, Low R-Value Wall								High Mass, Medium R-Value Wall								High Mass, High R-Value Wall							
N	3	3	6	10	15	20	23	25	9	7	8	9	11	14	17	19	11	9	7	7	9	11	14	17
NE	3	7	20	28	29	29	29	26	10	9	14	20	23	24	25	25	13	10	10	15	19	22	24	25
E	4	8	25	38	40	37	34	29	12	11	17	25	30	31	31	30	15	11	12	18	25	30	31	31
SE	4	5	17	30	37	36	33	29	12	10	13	20	26	29	29	28	14	11	10	14	20	26	29	30
S	3	2	4	11	22	31	33	29	10	8	7	9	14	20	24	25	13	10	7	7	10	15	21	24
SW	6	3	4	8	16	31	44	46	15	12	10	10	13	19	28	34	19	15	11	10	10	14	21	29
W	7	4	5	9	15	28	46	54	17	14	12	11	13	18	28	37	22	17	13	11	11	14	20	30
NW	6	3	4	8	14	22	35	43	14	11	10	10	12	15	22	30	18	14	11	9	10	12	17	24

CAUTION: Approximate data—Use for preliminary computations only.

Table 12.15 Approximate CLTDs for Sunlit Walls—48°N Latitude, July

CAUTION: Approximate data—Use for preliminary computations only.

Wall Facing	Solar time, h								Solar time, h								Solar time, h							
	6	8	10	12	14	16	18	20	6	8	10	12	14	16	18	20	6	8	10	12	14	16	18	20
	Low Mass, Low R-Value Wall								**Low Mass, Medium R-Value Wall**								**Low Mass, High R-Value Wall**							
N	3	10	13	21	27	28	27	21	1	2	6	10	16	21	25	26	–1	5	9	14	21	26	27	27
NE	10	42	38	26	28	29	24	15	1	7	23	31	30	29	28	26	0	18	36	34	28	28	28	23
E	10	54	64	47	31	29	25	15	1	8	30	47	48	40	34	29	0	20	49	57	44	34	29	23
SE	4	36	59	61	45	31	25	15	1	4	20	40	51	49	40	32	–1	11	36	55	56	43	33	24
S	–2	5	28	52	62	51	29	15	1	0	3	16	34	48	50	40	–1	0	9	30	50	57	47	30
SW	–1	5	12	29	59	75	65	29	2	0	3	8	20	40	58	61	–1	0	6	14	33	58	69	57
W	–1	5	13	21	41	72	80	41	2	0	3	8	15	29	51	64	–1	0	6	13	22	45	69	69
NW	–2	5	12	21	27	45	62	37	2	0	2	8	14	22	34	47	–1	0	5	13	20	29	46	54
	High Mass, Low R-Value Wall								**High Mass, Medium R-Value Wall**								**High Mass, High R-Value Wall**							
N	3	4	6	10	14	19	22	24	9	8	8	9	11	14	17	19	12	9	8	8	9	11	14	17
NE	4	10	22	26	26	27	27	25	10	10	15	20	22	23	24	24	13	10	12	16	19	22	23	24
E	4	11	28	40	40	37	34	29	12	12	19	27	32	32	32	30	15	12	14	20	27	31	32	32
SE	4	7	20	35	43	42	38	32	13	12	15	23	30	34	34	32	16	12	12	17	24	30	34	34
S	5	3	6	16	31	41	43	37	13	10	9	12	19	27	32	33	16	12	10	10	14	21	28	32
SW	7	4	5	9	19	36	50	52	18	14	12	12	15	23	32	39	22	17	13	11	12	16	24	33
W	8	5	6	9	15	27	45	55	19	15	12	12	14	19	28	38	23	18	14	12	12	14	20	30
NW	6	4	5	8	14	20	31	41	14	11	10	10	12	15	20	28	18	14	11	9	10	12	16	22

Note 1. Apply data directly to (1) dark surface, (2) indoor temperature of 78°F, (3) outdoor maximum temperature of 95°F with mean temperature of 85°F and daily range of 21°F, (4) outside surface film resistance of 0.333 $(h \cdot ft^2 \cdot °F)/Btu$, and (5) inside surface resistance of 0.685 $(h \cdot ft^2 \cdot °F)/Btu$.

Note 2. Adjustments to design temperatures:

$$\text{Corr. CLTD} = \text{CLTD} + (78 - t_r) + (t_m - 85)$$

where t_r = inside temperature and t_m = mean outdoor temperature, or t_m = maximum outdoor temperature – (daily range)/2

Note 3. Adjustments to months other than July: For design purposes, the data suffice for plus or minus 2 weeks from the 21st day of given month.

Table 12.16 Solar Cooling Load for Sunlit Glass (SCL)

Tables do not consider zone type and are conservative. Use for preliminary computations only.

Glass Facing	Solar time, h																	
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
24°N Latitude, July																		
N	0	19	35	36	36	38	40	42	42	40	38	39	43	32	11	6	3	1
NE	0	54	124	150	144	115	78	58	49	44	38	32	25	14	6	3	1	1
E	0	57	139	177	180	154	107	68	54	46	40	33	25	14	6	3	1	1
SE	0	26	74	104	114	106	83	59	50	44	38	32	25	14	6	3	1	1
S	0	5	15	23	30	35	40	43	43	40	37	32	24	14	6	3	1	1
SW	0	5	15	23	30	35	39	42	61	88	110	118	105	62	24	12	6	3
W	0	5	15	23	30	35	39	41	67	116	160	186	184	118	44	21	11	5
NW	0	5	15	23	30	35	39	41	51	83	122	151	158	106	39	19	9	5
Hor	0	10	55	113	170	218	253	271	273	258	225	176	115	54	24	12	6	3
36°N Latitude, July																		
N	0	25	29	28	32	36	39	40	41	39	36	32	33	36	12	6	3	1
NE	0	79	129	139	120	84	58	50	45	41	37	32	26	17	7	3	2	1
E	0	86	153	184	182	155	107	67	54	45	39	33	26	17	7	3	2	1
SE	0	42	90	125	142	140	119	86	58	48	40	34	27	17	7	3	2	1
S	0	8	17	24	36	53	70	80	79	68	52	38	29	18	7	3	2	1
SW	0	8	17	24	30	35	38	57	90	122	141	144	127	85	32	15	8	4
W	0	8	17	24	30	35	38	40	66	115	159	188	191	149	53	25	12	6
NW	0	8	17	24	30	35	38	40	40	56	93	129	148	127	43	21	10	5
Hor	0	20	66	120	171	215	246	263	265	251	221	178	124	66	28	13	7	3
48°N Latitude, July																		
N	14	28	24	27	31	34	37	38	38	37	35	31	27	34	25	9	4	2
NE	32	101	130	126	95	61	49	44	41	38	35	31	26	19	10	4	2	1
E	31	112	165	188	182	153	104	65	51	43	38	32	27	19	10	4	2	1
SE	11	58	106	143	164	168	152	119	77	54	43	35	28	20	10	4	2	1
S	3	11	18	30	58	90	116	130	130	116	88	56	37	24	12	5	3	1
SW	3	11	18	24	30	34	46	82	122	152	168	166	146	106	50	22	11	5
W	3	11	18	24	30	34	36	38	64	112	156	186	193	167	89	36	17	9
NW	3	11	18	24	30	34	36	38	38	40	67	106	134	134	76	30	14	7
Hor	5	32	73	120	163	200	226	241	242	230	205	170	125	76	35	16	8	4

Tables do not consider zone type and are conservation. Data apply directly to: (1) standard double strength glass with no inside shade, and (2) clear sky, 21st day of month.

Adjustments to table data:

- Latitudes other than 24, 36 and 48°N
  Linear interpolation is acceptable.
- Months other than July
  For design purposes, data will suffice for plus or minus 2 weeks from the 21st day of given month.
- Other types of glass and internal shade
  Use shading coefficients as multiplier.
- Externally shaded glass
  Use north orientation.

Table 12.17 Shading Coefficients* for Single Glass with Indoor Shading by Venetian Blinds or Roller Shades

Type of Glass	Nominal Thickness,[a] in.	Solar Transmittance[b]	Type of Shading: Venetian Blinds		Roller Shade: Opaque		Roller Shade: Translucent
			Medium	Light	Dark	White	Light
Clear	3/32[c]	0.87 to 0.80	0.74[d]	0.67[d]	0.81	0.39	0.44
			(0.63)[e]	(0.58)[e]			
Clear	1/4 to 1/2	0.80 to 0.71					
Clear pattern	1/8 to 1/2	0.87 to 0.79					
Heat-absorbing pattern	1/8	—					
Tinted	3/16, 7/32	0.74, 0.71					
Heat-absorbing[f]	3/16, 1/4	0.46					
Heat-absorbing pattern	3/16, 1/4	—	0.57	0.53	0.45	0.30	0.36
Tinted	1/8, 7/32	0.59, 0.45					
Heat-absorbing or pattern	—	0.44 to 0.30	0.54	0.52	0.40	0.28	0.32
Heat-absorbing[f]	3/8	0.34					
Heat-absorbing or pattern		0.29 to 0.15					
	—	0.24	0.42	0.40	0.36	0.28	0.31
Reflective coated glass	S.C. = 0.30[g]		0.25	0.23			
	= 0.40		0.33	0.29			
	= 0.50		0.42	0.38			
	= 0.60		0.50	0.44			

[a]Refer to manufacturers' literature for values.
[b]For vertical blinds with opaque white and beige louvers in the tightly closed position, SC is 0.25 and 0.29 when used with glass of 0.71 to 0.80 transmittance.
[c]Typical residential glass thickness.
[d]From Van Dyck and Konen (1982), for 45° open venetian blinds, 35° solar incidence, and 35° profile angle.
[e]Values for closed venetian blinds. Use these values only when operation is automated for solar gain reduction (as opposed to daylight use).
[f]Refers to gray, bronze, and green tinted heat-absorbing glass.
[g]SC for glass with no shading device.

* Note: Shading Coefficient (SC) has been superseded by solar heat gain coefficient (SHGC) including the effect of incident angle of solar radiation on the glass, and the effect of type of framing. This shading coefficient table is sufficiently accurate for the approximate cooling load calculations of this publication. For the glazing portion of single-pane clear and tinted fenestration, SC = SHGC/0.87. This does not include frame effects.

Table 12.18 Representative Rates at Which Heat and Moisture are Given Off by Human Beings in Different States of Activity [2013F, Ch 18, Tbl 1]

Degree of Activity	Location	Total Heat, Btu/h		Sensible Heat, Btu/h	Latent Heat, Btu/h	% Sensible Heat that is Radiant[b]	
		Adult Male	Adjusted, M/F[a]			Low V	High V
Seated at theater	Theater, matinee	390	330	225	105		
Seated at theater, night	Theater, night	390	350	245	105	60	27
Seated, very light work	Offices, hotels, apartments	450	400	245	155		
Moderately active office work	Offices, hotels, apartments	475	450	250	200		
Standing, light work; walking	Department store; retail store	550	450	250	200	58	38
Walking, standing	Drug store, bank	550	500	250	250		
Sedentary work	Restaurant[c]	490	550	275	275		
Light bench work	Factory	800	750	275	475		
Moderate dancing	Dance hall	900	850	305	545	49	35
Walking 3 mph; light machine work	Factory	1000	1000	375	625		
Bowling[d]	Bowling alley	1500	1450	580	870		
Heavy work	Factory	1500	1450	580	870	54	19
Heavy machine work; lifting	Factory	1600	1600	635	965		
Athletics	Gymnasium	2000	1800	710	1090		

Notes:

1. Tabulated values are based on 75°F room dry-bulb temperature. For 80°F room dry bulb, total heat remains the same, but sensible heat values should be decreased by approximately 20%, and latent heat values increased accordingly.
2. Also see Table 4, Chapter 9, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 Btu/h.

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

[b] Values approximated from data in Table 6, Chapter 9, where V is air velocity with limits shown in that table.

[c] Adjusted heat gain includes 60 Btu/h for food per individual (30 Btu/h sensible and 30 Btu/h latent).

[d] Figure one person per alley actually bowling, and all others as sitting (400 Btu/h) or standing or walking slowly (550 Btu/h).

Heat Gain from Lighting

The energy absorbed by the structure and contents contributes to space cooling load only after a time lag, some still reradiating after the heat sources have been switched off. This may make load lower than instantaneous heat gain, thus affecting the peak load.

Instantaneous rate of heat gain from lights, q_{el} Btu/h:

$$q_{el} = 3.41\ WF_{ul}F_{sa}$$

where

W	=	total lights wattage installed
F_{ul}	=	lighting use factor (proportion in use)
F_{sa}	=	lighting special allowance factor
3.41	=	conversion factor

The **total light wattage** is obtained from the ratings of all lamps installed, both for general illumination and for display use. Ballasts are not included, but are addressed by a separate factor. Wattages of magnetic ballasts are significant; the energy consumption of high-efficiency electronic ballasts might be insignificant compared to that of the lamps.

The **lighting use factor** is the ratio of wattage in use, for the conditions under which the load estimate is being made, to total installed wattage. For commercial applications such as stores, the use factor is generally 1.0.

The **special allowance factor** is the ratio of the lighting fixtures' power consumption, including lamps and ballast, to the nominal power consumption of the lamps. For incandescent lights, this factor is 1. For fluorescent lights, it accounts for power consumed by the ballast as well as the ballast's effect on lamp power consumption. The special allowance factor can be less than 1 for electronic ballasts that lower electricity consumption below the lamp's rated power consumption. Use manufacturers' values for system (lamps + ballast) power, when available.

For high-intensity-discharge lamps (e.g. metal halide, mercury vapor, high- and low-pressure sodium vapor lamps), the actual lighting system power consumption should be available from the manufacturer of the fixture or ballast. Ballasts available for metal halide and high pressure sodium vapor lamps may have special allowance factors from about 1.3 (for low-wattage lamps) down to 1.1 (for high-wattage lamps).

An alternative procedure is to estimate the lighting heat gain on a per square foot basis. Such an approach may be required when final lighting plans are not available. Table 12.19 shows the maximum lighting power density (LPD) (lighting heat gain per square foot) allowed by ASHRAE Standard 90.1-2010 for a range of space types.

Table 12.19 Lighting Power Densities Using Space-by-Space Method
[Std 90.1-2010, Tbl 9.6.1]

Common Space Types*	LPD, W/ft^2	Building-Specific Space Types	LPD, W/ft^2
Office—enclosed	1.1	Gymnasium/exercise center	
Office—open plan	1.1	Playing Area	1.4
Conference/meeting/ multipurpose	1.3	Exercise Area	0.9
Classroom/lecture/training	1.4	Courthouse/police station/penitentiary	
For penitentiary	1.3	Courtroom	1.9
Lobby	1.3	Confinement cells	0.9
For hotel	1.1	Judges' chambers	1.3
For performing arts theater	3.3	Fire Stations	
For motion picture theater	1.1	Engine room	0.8
Audience/seating area	0.9	Sleeping quarters	0.3
For gymnasium	0.4	Post office—sorting area	1.2
For exercise center	0.3	Convention center—exhibit space	1.3
For convention center	0.7	Library	
For penitentiary	0.7	Card file and cataloging	1.1
For religious buildings	1.7	Stacks	1.7
For sports arena	0.4	Reading area	1.2
For performing arts theater	2.6	Hospital	
For motion picture theater	1.2	Emergency	2.7
For transportation	0.5	Recovery	0.8
Atrium—first three floors	0.6	Nurses' station	1.0
Atrium—each additional floor	0.2	Exam/treatment	1.5
Lounge/recreation	1.2	Pharmacy	1.2
For hospital	0.8	Patient room	0.7
Dining Area	0.9	Operating room	2.2
For penitentiary	1.3	Nursery	0.6
For hotel	1.3	Medical supply	1.4
For motel	1.2	Physical therapy	0.9
For bar lounge/leisure dining	1.4	Radiology	0.4
For family dining	2.1	Laundry—washing	0.6
Food preparation	1.2	Automotive—service/repair	0.7
Laboratory	1.4	Manufacturing	
Restrooms	0.9	Low bay (<25 ft floor to ceiling height)	1.2
Dressing/locker/fitting room	0.6	High bay (≥25 ft floor to ceiling height)	1.7
Corridor/transition	0.5	Detailed manufacturing	2.1
For hospital	1.0	Equipment room	1.2
For manufacturing facility	0.5	Control room	0.5
Stairs—active	0.6	Hotel/motel guest rooms	1.1
Active storage	0.8	Dormitory—living quarters	1.1
For hospital	0.9	Museum	
Inactive storage	0.3	General exhibition	1.0
For museum	0.8	Restoration	1.7
Electrical/mechanical	1.5	Bank/office—banking activity area	1.5
Workshop	1.9	Religious buildings	
Sales area [for accent lighting, see Section 9.6.2(B) of ASHRAE Standard 90.1]	1.7	Worship pulpit, choir	2.4
		Fellowship hall	0.9
		Retail	

Table 12.19 Lighting Power Densities Using Space-by-Space Method
[Std 90.1-2010, Tbl 9.6.1] ***(Continued)***

Common Space Types*	LPD, W/ft²	Building-Specific Space Types	LPD, W/ft²
		Sales area [for accent lighting, see Section 9.6.3(C) of ASHRAE Standard 90.1]	1.7
		Mall concourse	1.7
		Sports arena	
		Ring sports area	2.7
		Court sports area	2.3
		Indoor playing field area	1.4
		Warehouse	
		Fine material storage	1.4
		Medium/bulky material storage	0.9
		Parking garage—garage area	0.2
		Transportation	
		Airport—concourse	0.6
		Air/train/bus—baggage area	1.0
		Terminal—ticket counter	1.5

*In cases where both a common space type and a building-specific type are listed, the building-specific space type applies.

Table 12.20 provides a range of design data under typical operating conditions: airflow 1 cfm/ft^2, supply air between 59°F and 62°F, room temperature between 72°F and 75°F, and lighting heat input in a range from 0.9 to 2.6 W/ft^2. For a fluorescent luminaire without lens, Figure 12.1 gives more precise data. The data should be used with judgment.

Table 12.20 Lighting Heat Gain Parameters for Typical Operating Conditions
[2013F, Ch 18, Tbl 3]

Luminaire Category	Space Fraction	Radiative Fraction	Notes
Recessed fluorescent luminaire without lens	0.64 to 0.74	0.48 to 0.68	• Use middle values in most situations • May use higher space fraction, and lower radiative fraction for luminaire with side-slot returns • May use lower values of both fractions for direct/indirect luminaire • May use higher values of both fractions for ducted returns
Recessed fluorescent luminaire with lens	0.40 to 0.50	0.61 to 0.73	• May adjust values in the same way as for recessed fluorescent luminaire without lens
Downlight compact fluorescent luminaire	0.12 to 0.24	0.95 to 1.0	• Use middle or high values if detailed features are unknown • Use low value for space fraction and high value for radiative fraction if there are large holes in luminaire's reflector
Downlight incandescent luminaire	0.70 to 0.80	0.95 to 1.0	• Use middle values if lamp type is unknown • Use low value for space fraction if standard lamp (i.e. A-lamp) is used • Use high value for space fraction if reflector lamp (i.e. BR-lamp) is used
Non-in-ceiling fluorescent luminaire	1.0	0.5 to 0.57	• Use lower value for radiative fraction for surface-mounted luminaire • Use higher value for radiative fraction for pendant luminaire

Source: Fisher and Chantrasrisalai (2006).

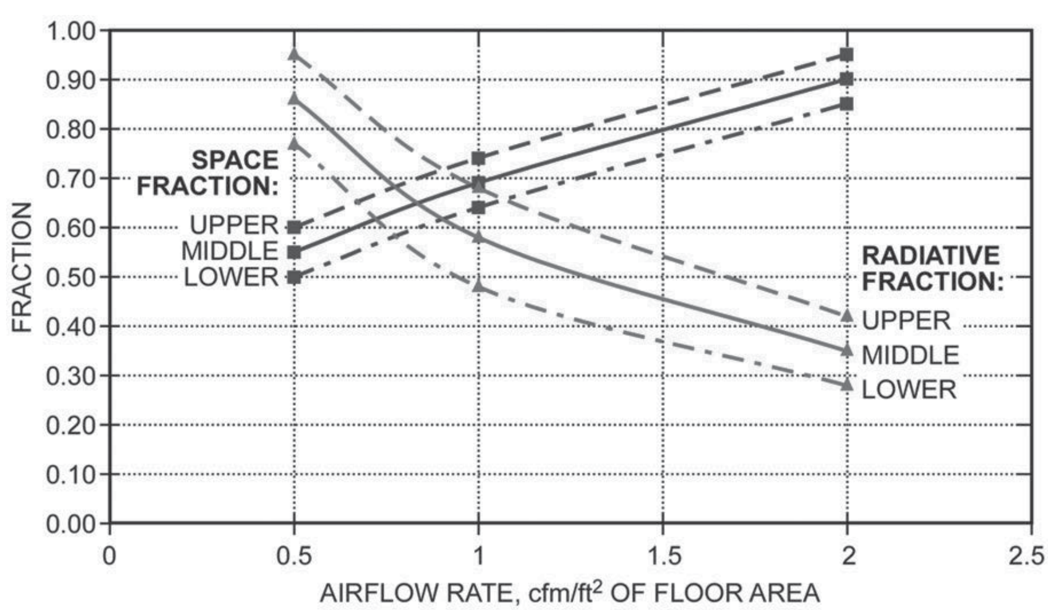

Figure 12.1 Lighting Heat Gain Parameters for Recessed Fluorescent Luminaire Without Lens
[2013F, Ch 18, Fig 3]

Heat Gain from Motors and their Loads

Instantaneous rate of heat gain from equipment operated by electric motors within a conditioned space.

$$q_{em} = 2545\ (\mathrm{P}/E_M)\ F_{UM}\ F_{LM}$$

where

q_{em}	=	heat equivalent of equipment operation, Btu/h
P	=	motor power rating, hp
E_M	=	motor efficiency, decimal fraction < 1.0
F_{UM}	=	motor use factor 1.0 or <1.0 (proportion operating)
F_{LM}	=	motor load factor 1.0 or <1.0

When motor is outside the conditioned space, but load is inside,

$$q_{em} = 2545\ P\ F_{UM}\ F_{LM}$$

When motor is inside the conditioned space, but load is outside,

$$q_{em} = 2545\ P \left(\frac{1.0 - E_M}{E_M}\right) F_{UM}\ F_{LM}$$

Heat output of a motor is generally proportional to motor load, within rated overload limits. Because of typically high no-load motor current, fixed losses, and other reasons, F_{LM} is generally assumed to be unity, and no adjustment should be made for underloading or overloading unless the situation is fixed and can be accurately established, and reduced-load efficiency data can be obtained from the motor manufacturer.

Unless the manufacturer’s technical literature indicates otherwise, motor heat gain normally should be equally divided between radiant and convective components for the subsequent cooling load calculations.

Table 12.21 Minimum Nominal Full-Load Efficiency for 60 HZ NEMA General Purpose Electric Motors (Subtype I) Rated 600 Volts or Less (Random Wound)*
[2013F, Ch 18, Tbl 4]

Minimum Nominal Full Load Efficiency (%) for Motors Manufactured on or after December 19, 2010						
	Open Drip-Proof Motors			Totally Enclosed Fan-Cooled Motors		
Number of Poles ⇒	2	4	6	2	4	6
Synchronous Speed (RPM) ⇒	3600	1800	1200	3600	1800	1200
Motor Horsepower						
1	77.0	85.5	82.5	77.0	85.5	82.5
1.5	84.0	86.5	86.5	84.0	86.5	87.5
2	85.5	86.5	87.5	85.5	86.5	88.5
3	85.5	89.5	88.5	86.5	89.5	89.5
5	86.5	89.5	89.5	88.5	89.5	89.5
7.5	88.5	91.0	90.2	89.5	91.7	91.0
10	89.5	91.7	91.7	90.2	91.7	91.0
15	90.2	93.0	91.7	91.0	92.4	91.7
20	91.0	93.0	92.4	91.0	93.0	91.7
25	91.7	93.6	93.0	91.7	93.6	93.0
30	91.7	94.1	93.6	91.7	93.6	93.0
40	92.4	94.1	94.1	92.4	94.1	94.1
50	93.0	94.5	94.1	93.0	94.5	94.1
60	93.6	95.0	94.5	93.6	95.0	94.5
75	93.6	95.0	94.5	93.6	95.4	94.5
100	93.6	95.4	95.0	94.1	95.4	95.0
125	94.1	95.4	95.0	95.0	95.4	95.0
150	94.1	95.8	95.4	95.0	95.8	95.8
200	95.0	95.8	95.4	95.4	96.2	95.8
250	95.0	95.8	95.4	95.8	96.2	95.8
300	95.4	95.8	95.4	95.8	96.2	95.8
350	95.4	95.8	95.4	95.8	96.2	95.8
400	95.8	95.8	95.8	95.8	96.2	95.8
450	95.8	96.2	96.2	95.8	96.2	95.8
500	95.8	96.2	96.2	95.8	96.2	95.8

Source: ASHRAE Standard 90.1-2010

*Nominal efficiencies established in accordance with NEMA Standard MG1. Design A and Design B are National Electric Manufacturers Association (NEMA) design class designations for fixed-frequency small and medium AC squirrel-cage induction motors.

Cooking Appliances

Heat gain: $q_s = q_{input} F_U F_R$, where F_U is the usage factor and F_R is the radiation factor.

Table 12.22 Recommended Rates of Radiant and Convective Heat Gain from Unhooded Electric Appliances during Idle (Ready-to-Cook) Conditions [2013F, Ch 18, Tbl 5A]

Appliance	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h				Usage Factor F_U	Radiation Factor F_R
	Rated	Standby	Sensible Radiant	Sensible Convective	Latent	Total		
Cabinet: hot serving (large), insulated*	6,800	1,200	400	800	0	1,200	0.18	0.33
hot serving (large), uninsulated	6,800	3,500	700	2,800	0	3,500	0.51	0.20
proofing (large)*	17,400	1,400	1,200	0	200	1,400	0.08	0.86
proofing (small 15-shelf)	14,300	3,900	0	900	3,000	3,900	0.27	0.00
Coffee brewing urn	13,000	1,200	200	300	700	1,200	0.09	0.17
Drawer warmers, 2-drawer (moist holding)*	4,100	500	0	0	200	200	0.12	0.00
Egg cooker	10,900	700	300	400	0	700	0.06	0.43
Espresso machine*	8,200	1,200	400	800	0	1,200	0.15	0.33
Food warmer: steam table (2-well-type)	5,100	3,500	300	600	2,600	3,500	0.69	0.09
Freezer (small)	2,700	1,100	500	600	0	1,100	0.41	0.45
Hot dog roller*	3,400	2,400	900	1,500	0	2,400	0.71	0.38
Hot plate: single burner, high speed	3,800	3,000	900	2,100	0	3,000	0.79	0.30
Hot-food case (dry holding)*	31,100	2,500	900	1,600	0	2,500	0.08	0.36
Hot-food case (moist holding)*	31,100	3,300	900	1,800	600	3,300	0.11	0.27
Microwave oven: commercial (heavy duty)	10,900	0	0	0	0	0	0.00	0.00
Oven: countertop conveyorized bake/finishing*	20,500	12,600	2,200	10,400	0	12,600	0.61	0.17
Panini*	5,800	3,200	1,200	2,000	0	3,200	0.55	0.38
Popcorn popper*	2,000	200	100	100	0	200	0.10	0.50

Table 12.22 Recommended Rates of Radiant and Convective Heat Gain from Unhooded Electric Appliances during Idle (Ready-to-Cook) Conditions [2013F, Ch 18, Tbl 5A] ***(Continued)***

Appliance	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h				Usage Factor	Radiation Factor
	Rated	Standby	Sensible Radiant	Sensible Convective	Latent	Total	F_U	F_R
Rapid-cook oven (quartz-halogen)*	41,000	0	0	0	0	0	0.00	0.00
Rapid-cook oven (microwave/convection)*	24,900	4,100	1,000	3,100	0	1,000	0.16	0.24
Reach-in refrigerator*	4,800	1,200	300	900	0	1,200	0.25	0.25
Refrigerated prep table*	2,000	900	600	300	0	900	0.45	0.67
Steamer (bun)	5,100	700	600	100	0	700	0.14	0.86
Toaster: 4-slice pop up (large): cooking	6,100	3,000	200	1,400	1,000	2,600	0.49	0.07
contact (vertical)	11,300	5,300	2,700	2,600	0	5,300	0.47	0.51
conveyor (large)	32,800	10,300	3,000	7,300	0	10,300	0.31	0.29
small conveyor	5,800	3,700	400	3,300	0	3,700	0.64	0.11
Waffle iron	3,100	1,200	800	400	0	1,200	0.39	0.67

*Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).

Table 12.23 Recommended Rates of Radiant Heat Gain from Hooded Electric Appliances during Idle (Ready-to-Cook) Conditions [2013F, Ch 18, Tbl 5B]

Appliance	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h	Usage Factor F_U	Radiation Factor F_R
	Rated	Standby	Sensible Radiant		
Broiler: underfired 3 ft	36,900	30,900	10,800	0.84	0.35
Cheesemelter*	12,300	11,900	4,600	0.97	0.39
Fryer: kettle	99,000	1,800	500	0.02	0.28
Fryer: open deep-fat, 1-vat	47,800	2,800	1,000	0.06	0.36
Fryer: pressure	46,100	2,700	500	0.06	0.19
Griddle: double sided 3 ft (clamshell down)*	72,400	6,900	1,400	0.10	0.20
Griddle: double sided 3 ft (clamshell up)*	72,400	11,500	3,600	0.16	0.31
Griddle: flat 3 ft	58,400	11,500	4,500	0.20	0.39
Griddle-small 3 ft*	30,700	6,100	2,700	0.20	0.44
Induction cooktop*	71,700	0	0	0.00	0.00
Induction wok*	11,900	0	0	0.00	0.00
Oven: combi: combi-mode*	56,000	5,500	800	0.10	0.15
Oven: combi: convection mode	56,000	5,500	1,400	0.10	0.25
Oven: convection full-size	41,300	6,700	1,500	0.16	0.22
Oven: convection half-size*	18,800	3,700	500	0.20	0.14
Pasta cooker*	75,100	8,500	0	0.11	0.00
Range top: top off/oven on*	16,600	4,000	1,000	0.24	0.25
Range top: 3 elements on/ oven off	51,200	15,400	6,300	0.30	0.41
Range top: 6 elements on/ oven off	51,200	33,200	13,900	0.65	0.42
Range top: 6 elements on/ oven on	67,800	36,400	14,500	0.54	0.40
Range: hot-top	54,000	51,300	11,800	0.95	0.23
Rotisserie*	37,900	13,800	4,500	0.36	0.33
Salamander*	23,900	23,300	7,000	0.97	0.30
Steam kettle: large (60 gal) simmer lid down*	110,600	2,600	100	0.02	0.04
Steam kettle: small (40 gal) simmer lid down*	73,700	1,800	300	0.02	0.17
Steamer: compartment: atmospheric*	33,400	15,300	200	0.46	0.01
Tilting skillet/braising pan	32,900	5,300	0	0.16	0.00

*Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).

Table 12.24 Recommended Rates of Radiant Heat Gain from Hooded Solid Fuel Appliances during Idle (Ready-to-Cook) Conditions [2013F, Ch 18, Tbl 5D]

Appliance	Energy Rate, Btu/h	Rate of Heat Gain, Btu/h		Usage Factor F_U	Radiation Factor F_R
	Rated	Standby	Sensible		
Broiler: solid fuel: charcoal	40 lb	42,000	6200	N/A	0.15
Broiler: solid fuel: wood (mesquite)*	40 lb	49,600	7000	N/A	0.14

*Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).

Table 12.25 Recommended Rates of Radiant and Convective Heat Gain from Warewashing Equipment during Idle (Standby) or Washing Conditions [2013F, Ch 18, Tbl 5E]

Appliance	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h					Usage Factor F_U	Radiation Factor F_R
			Unhooded				Hooded		
	Rated	Standby/ Washing	Sensible Radiant	Sensible Convective	Latent	Total	Sensible Radiant		
Dishwasher (conveyor type, chemical sanitizing)	46,800	5700/ 43,600	0	4450	13490	17940	0	0.36	0
Dishwasher (conveyor type, hot-water sanitizing) standby	46,800	5700/ N/A	0	4750	16970	21720	0	N/A	0
Dishwasher (door-type, chemical sanitizing) washing	18,400	1200/ 13,300	0	1980	2790	4770	0	0.26	0
Dishwasher (door-type, hot-water sanitizing) washing	18,400	1200/ 13,300	0	1980	2790	4770	0	0.26	0
Dishwasher* (under-counter type, chemical sanitizing) standby	26,600	1200/ 18,700	0	2280	4170	6450	0	0.35	0.00
Dishwasher* (under-counter type, hot-water sanitizing) standby	26,600	1700/ 19,700	800	1040	3010	4850	800	0.27	0.34
Booster heater*	130,000	0	500	0	0	0	500	0	N/A

*Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).
Note: Heat load values are prorated for 30% washing and 70% standby.

Table 12.26 Recommended Rates of Radiant Heat Gain from Hooded Gas Appliances during Idle (Ready-to-Cook) Conditions [2013F, Ch 18, Tbl 5C]

Appliance	Energy Rate, Btu/h		Rate of Heat Gain, Btu/h	Usage Factor F_U	Radiation Factor F_R
	Rated	Standby	Sensible Radiant		
Broiler: batch*	95,000	69,200	8,100	0.73	0.12
Broiler: chain (conveyor)	132,000	96,700	13,200	0.73	0.14
Broiler: overfired (upright)*	100,000	87,900	2,500	0.88	0.03
Broiler: underfired 3 ft	96,000	73,900	9,000	0.77	0.12
Fryer: doughnut	44,000	12,400	2,900	0.28	0.23
Fryer: open deep-fat, 1 vat	80,000	4,700	1,100	0.06	0.23
Fryer: pressure	80,000	9,000	800	0.11	0.09
Griddle: double sided 3 ft (clamshell down)*	108,200	8,000	1,800	0.07	0.23
Griddle: double sided 3 ft (clamshell up)*	108,200	14,700	4,900	0.14	0.33
Griddle: flat 3 ft	90,000	20,400	3,700	0.23	0.18
Oven: combi: combi-mode*	75,700	6,000	400	0.08	0.07
Oven: combi: convection mode	75,700	5,800	1,000	0.08	0.17
Oven: convection full-size	44,000	11,900	1,000	0.27	0.08
Oven: conveyor (pizza)	170,000	68,300	7,800	0.40	0.11
Oven: deck	105,000	20,500	3,500	0.20	0.17
Oven: rack mini-rotating*	56,300	4,500	1,100	0.08	0.24
Pasta cooker*	80,000	23,700	0	0.30	0.00
Range top: top off/oven on*	25,000	7,400	2,000	0.30	0.27
Range top: 3 burners on/oven off	120,000	60,100	7,100	0.50	0.12
Range top: 6 burners on/oven off	120,000	120,800	11,500	1.01	0.10
Range top: 6 burners on/oven on	145,000	122,900	13,600	0.85	0.11
Range: wok*	99,000	87,400	5,200	0.88	0.06
Rethermalizer*	90,000	23,300	11,500	0.26	0.49
Rice cooker*	35,000	500	300	0.01	0.60
Salamander*	35,000	33,300	5,300	0.95	0.16
Steam kettle: large (60 gal) simmer lid down*	145,000	5,400	0	0.04	0.00
Steam kettle: small (10 gal) simmer lid down*	52,000	3,300	300	0.06	0.09
Steam kettle: small (40 gal) simmer lid down	100,000	4,300	0	0.04	0.00
Steamer: compartment: atmospheric*	26,000	8,300	0	0.32	0.00
Tilting skillet/braising pan	104,000	10,400	400	0.10	0.04

*Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).

Hospital and Laboratory Equipment

Heat gain varies significantly. In a laboratory, heat gain ranges from 15 to 70 Btuh/ft^2. Medical equipment is highly varied in type and application. Table 12.21 is relevant for portable and bench-type equipment. For large equipment, such as MRI, obtain heat gain from the manufacturer.

Table 12.27 Recommended Heat Gain from Typical Medical Equipment
[2013F, Ch 18, Tbl 6]

Equipment	Nameplate, W	Peak, W	Average, W
Anesthesia system	250	177	166
Blanket warmer	500	504	221
Blood pressure meter	180	33	29
Blood warmer	360	204	114
ECG/RESP	1440	54	50
Electrosurgery	1000	147	109
Endoscope	1688	605	596
Harmonical scalpel	230	60	59
Hysteroscopic pump	180	35	34
Laser sonics	1200	256	229
Optical microscope	330	65	63
Pulse oximeter	72	21	20
Stress treadmill	N/A	198	173
Ultrasound system	1800	1063	1050
Vacuum suction	621	337	302
X-ray system	968		82
	1725	534	480
	2070		18

Source: Hosni et al. (1999)

Table 12.28 Recommended Heat Gain from Typical Laboratory Equipment
[2013F, Ch 18, Tbl 7]

Equipment	Nameplate, W	Peak, W	Average, W
Analytical balance	7	7	7
Centrifuge	138	89	87
	288	136	132
	5500	1176	730
Electrochemical analyzer	50	45	44
	100	85	84
Flame photometer	180	107	105
Fluorescent microscope	150	144	143
	200	205	178
Function generator	58	29	29
Incubator	515	461	451
	600	479	264
	3125	1335	1222
Orbital shaker	100	16	16
Oscilloscope	72	38	38
	345	99	97
Rotary evaporator	75	74	73
	94	29	28
Spectronics	36	31	31
Spectrophotometer	575	106	104
	200	122	121
	N/A	127	125
Spectro fluorometer	340	405	395
Thermocycler	1840	965	641
	N/A	233	198
Tissue culture	475	132	46
	2346	1178	1146

Source: Hosni et al. (1999).

Table 12.29 Recommended Heat Gain from Typical Computer Equipment [2013F, Ch 18, Tbl 8]

Equipment	Description	Nameplate Power, W	Average Power, W	Radiant Fraction
Desktop computer[a]	Manufacturer A (model A); 2.8 GHz processor, 1 GB RAM	480	73	0.10[a]
	Manufacturer A (model B); 2.6 GHz processor, 2 GB RAM	480	49	0.10[a]
	Manufacturer B (model A); 3.0 GHz processor, 2 GB RAM	690	77	0.10[a]
	Manufacturer B (model B); 3.0 GHz processor, 2 GB RAM	690	48	0.10[a]
	Manufacturer A (model C); 2.3 GHz processor, 3 GB RAM	1200	97	0.10[a]
Laptop computer[b]	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 17 in. screen	130	36	0.25[b]
	Manufacturer 1; 1.8 GHz processor, 1 GB RAM, 17 in. screen	90	23	0.25[b]
	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 14 in. screen	90	31	0.25[b]
	Manufacturer 2; 2.13 GHz processor, 1 GB RAM, 14 in. screen, tablet PC	90	29	0.25[b]
	Manufacturer 2; 366 MHz processor, 130 MB RAM (4 in. screen)	70	22	0.25[b]
	Manufacturer 3; 900 MHz processor, 256 MB RAM (10.5 in. screen)	50	12	0.25[b]
Flat-panel monitor[c]	Manufacturer X (model A); 30 in. screen	383	90	0.40[c]
	Manufacturer X (model B); 22 in. screen	360	36	0.40[c]
	Manufacturer Y (model A); 19 in. screen	288	28	0.40[c]
	Manufacturer Y (model B); 17 in. screen	240	27	0.40[c]
	Manufacturer Z (model A); 17 in. screen	240	29	0.40[c]
	Manufacturer Z (model C); 15 in. screen	240	19	0.40[c]

Source: Hosni and Beck (2008).

[a]Power consumption for newer desktop computers in operational mode varies from 50 to 100 W, but a conservative value of about 65 W may be used. Power consumption in sleep mode is negligible. Because of cooling fan, approximately 90% of load is by convection and 10% is by radiation. Actual power consumption is about 10 to 15% of nameplate value.

[b]Power consumption of laptop computers is relatively small: depending on processor speed and screen size, it varies from about 15 to 40 W. Thus, differentiating between radiative and convective parts of the cooling load is unnecessary and the entire load may be classified as convective. Otherwise, a 75/25% split between convective and radiative components may be used. Actual power consumption for laptops is about 25% of nameplate values.

[c]Flat-panel monitors have replaced cathode ray tube (CRT) monitors in many workplaces, providing better resolution and being much lighter. Power consumption depends on size and resolution, and ranges from about 20 W (for 15 in. size) to 90 W (for 30 in.). The most common sizes in workplaces are 19 and 22 in., for which an average 30 W power consumption value may be used. Use 60/40% split between convective and radiative components. In idle mode, monitors have negligible power consumption. Nameplate values should not be used.

Table 12.30 Recommended Heat Gain from Typical Laser Printers and Copiers
[2013F, Ch 18, Tbl 9]

Equipment	Description	Nameplate Power, W	Average Power, W	Radiant Fraction
Laser printer, typical desktop, small-office type[a]	Printing speed up to 10 pages per minute	430	137	0.30[a]
	Printing speed up to 35 pages per minute	890	74	0.30[a]
	Printing speed up to 19 pages per minute	508	88	0.30[a]
	Printing speed up to 17 pages per minute	508	98	0.30[a]
	Printing speed up to 19 pages per minute	635	110	0.30[a]
	Printing speed up to 24 page per minute	1344	130	0.30[a]
Multifunction (copy, print, scan)[b]	Small, desktop type	600	30	d
		40	15	d
	Medium, desktop type	700	135	d
Scanner[b]	Small, desktop type	19	16	d
Copy machine[c]	Large, multiuser, office type	1750	800 (idle 260 W)	d (idle 0.00[c])
		1440	550 (idle 135 W)	d (idle 0.00[c])
		1850	1060 (idle 305 W)	d (idle 0.00[c])
Fax machine	Medium	936	90	d
	Small	40	20	d
Plotter	Manufacturer A	400	250	d
	Manufacturer B	456	140	d

Source: Hosni and Beck (2008).

[a]Various laser printers commercially available and commonly used in personal offices were tested for power consumption in print mode, which varied from 75 to 140 W, depending on model, print capacity, and speed. Average power consumption of 110 W may be used. Split between convection and radiation is approximately 70/30%.

[b]Small multifunction (copy, scan, print) systems use about 15 to 30 W; medium-sized ones use about 135 W. Power consumption in idle mode is negligible. Nameplate values do not represent actual power consumption and should not be used. Small, single-sheet scanners consume less than 20 W and do not contribute significantly to building cooling load.

[c]Power consumption for large copy machines in large offices and copy centers ranges from about 550 to 1100 W in copy mode. Consumption in idle mode varies from about 130 to 300 W. Count idle-mode power consumption as mostly convective in cooling load calculations.

[d]Split between convective and radiant heat gain was not determined for these types of equipment.

Table 12.31 Recommended Heat Gain from Miscellaneous Office Equipment
[2013F, Ch 18, Tbl 10]

Equipment	Maximum Input Rating, W	Recommended Rate of Heat Gain, W
Mail-processing equipment		
Folding machine	125	80
Inserting machine, 3600 to 6800 pieces/h	600 to 3300	390 to 2150
Labeling machine, 1500 to 30,000 pieces/h	600 to 6600	390 to 4300
Postage meter	230	150
Vending machines		
Cigarette	72	72
Cold food/beverage	1150 to 1920	575 to 960
Hot beverage	1725	862
Snack	240 to 275	240 to 275
Other		
Bar code printer	440	370
Cash registers	60	48
Check processing workstation,12 pockets	4800	2470
Coffee maker, 10 cups	1500	1050 W sensible, 1540 Btu/h latent
Microfiche reader	85	85
Microfilm reader	520	520
Microfilm reader/printer	1150	1150
Microwave oven, 1 ft^3	600	400
Paper shredder	250 to 3000	200 to 2420
Water cooler, 32 qt/h	700	350

Table 12.32 Recommended Load Factors for Various Types of Offices
[2013F, Ch 18, Tbl 11]

Type of Use	Load Factor, W/ft^2	Description
100% Laptop, light	0.25	167 ft^2/workstation, all laptop use, 1 printer per 10, speakers, misc.
medium	0.33	125 ft^2/workstation, all laptop use, 1 printer per 10, speakers, misc.
50% Laptop, light	0.40	167 ft^2/workstation, 50% laptop / 50% desktop, 1 printer per 10, speakers, misc.
medium	0.50	125 ft^2/workstation, 50% laptop / 50% desktop, 1 printer per 10, speakers, misc.
100% Desktop, light	0.60	167 ft^2/workstation, all desktop use, 1 printer per 10, speakers, misc.
medium	0.80	125 ft^2/workstation, all desktop use, 1 printer per 10, speakers, misc.
100% Desktop, two monitors	1.00	125 ft^2/workstation, all desktop use, 2 monitors, 1 printer per 10, speakers, misc.
100% Desktop, heavy	1.50	85 ft^2/workstation, all desktop use, 2 monitors, 1 printer per 8, speakers, misc.
100% Desktop, full on	2.00	85 ft^2/workstation, all desktop use, 2 monitors, 1 printer per 8, speakers, misc., no diversity.

Source: Wilkins and Hosni (2011).

Table 12.33 Recommended Diversity Factors for Office Equipment
[2013F, Ch 18, Tbl 12]

Device	Recommended Diversity Factor
Desktop computer	75%
LCD monitor	60%
Notebook computer	75%

Table 12.34 Refrigerating Effect Produced by Open Refrigerated Display Fixtures

Type of Display Fixture	Btu/h·ft of Fixture*		
	Latent Heat	Sensible Heat	Total Refrigerating Effect
Low temperature			
Frozen Food			
Single Deck	38	207	245
Single Deck, Double Island	70	400	470
2 Deck	144	576	720
3 Deck	322	1288	1610
4 or 5 Deck	400	1600	2000
Ice Cream			
Single Deck	64	366	430
Single Deck, Double Island	70	400	470
Standard Temperature			
Meats			
Single Deck	52	298	350
Multideck	219	876	1095
Dairy			
Multideck	196	784	980
Produce			
Single Deck	36	204	240
Multideck	192	768	960

* These figures are general magnitudes for fixtures adjusted for average desired product temperatures and apply to store ambients in front of the display cases of 72°F to 74°F with 50% to 55% rh. Raising the dry bulb only 3°F to 5°F and the humidity 5% to 10% can increase heat removal 25% or more. Equally lower temperatures and humidities as in winter, have an equally marked effect on lowering heat removal from the space.