RADIANT TIME SERIES (RTS) METHOD

Cooling load calculations methods were identified in Chapter 5. Considering the need to use computer software to efficiently and accurately apply these methods, *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition, does not cover any of the methods in detail. Instead the variables of building heat gain are discussed in this material to allow better understanding of the contributing and influencing factors of heat gain. This knowledge can then be applied when using and analyzing the output of different load calculation software. For the users of this text that have interest in manually conducting a building cooling load, the RTS Method is the most appropriate to employ. This online material outlines the methodology as well as provides an example building load calculation. Much of this content, as well as additional detail, can be found in Chapter 18 of the 2017 *ASHRAE Handbook—Fundamentals*.

The radiant time series (RTS) method is a simplified method for performing design cooling load calculations that is derived from the heat balance (HB) method described in Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition. It effectively replaces all other simplified (non-heat-balance) methods, such as the transfer function method (TFM), the cooling load temperature difference/cooling load factor (CLTD/CLF) method, and the total equivalent temperature difference/time averaging (TETD/TA) method.

The RTS method was developed in response to the desire to offer a method that is rigorous, yet does not require iterative calculations, and that quantifies each component contribution to the total cooling load. In addition, it is desirable for the user to be able to inspect and compare the coefficients for different construction and zone types in a form illustrating their relative impact on the result. These characteristics of the RTS method make it easier to apply engineering judgment during the cooling load calculation process.

The method is suitable for peak design load calculations, but it should not be used for annual energy simulations due to its inherent limiting assumptions. The RTS method, while simple in concept, involves too many calculations to be used practically using a simple computerized spreadsheet.

Figure 1 gives an overview of the RTS method. In the calculation of solar radiation, transmitted solar heat gain through windows, sol-air temperature, and infiltration. Important areas that are different from other methods include the computation of conductive heat gain, the splitting of all heat gains into radiant and convective portions, and the conversion of radiant heat gains into cooling loads.

Design cooling loads are based on the assumption of steady-periodic conditions (i.e., the design day's weather, occupancy, and heat gain conditions are identical to those for preceding days such that the loads repeat on an identical 24-hour cyclical basis). Thus, the heat gain for a particular component at a particular hour is the same as 24 hours prior, which is the same as 48 hours prior, etc. This assumption is the basis for the RTS derivation from the HB method.

Cooling load calculations must address two time-delay effects inherent in building heat transfer processes: (1) delay of conductive heat gain through opaque massive exterior surfaces (walls, roofs, or floors) and (2) delay of radiative heat gain conversion to cooling loads.

Exterior walls and roofs conduct heat due to temperature differences between outdoor and indoor air. In addition, solar energy on exterior surfaces is absorbed, then transferred by conduction to the building interior. Due to the mass and thermal capacity of the wall or roof construction materials, there is a substantial time delay in heat input at the exterior surface becoming heat gain at the interior surface.

Most heat sources transfer energy to a room by a combination of convection and radiation. See Table 1. The convection part of heat gain immediately becomes cooling load. The radiation part must first be absorbed by the finishes and mass of the interior room surfaces and becomes cooling load only when it is later transferred by convection from those surfaces to the room air. Thus, radiant heat gains become cooling loads over a delayed period of time.

The RTS method accounts for both conduction time delay and radiant time delay effects by multiplying hourly heat gains by 24-hour time series. The time series multiplication, in effect, distributes heat gains over

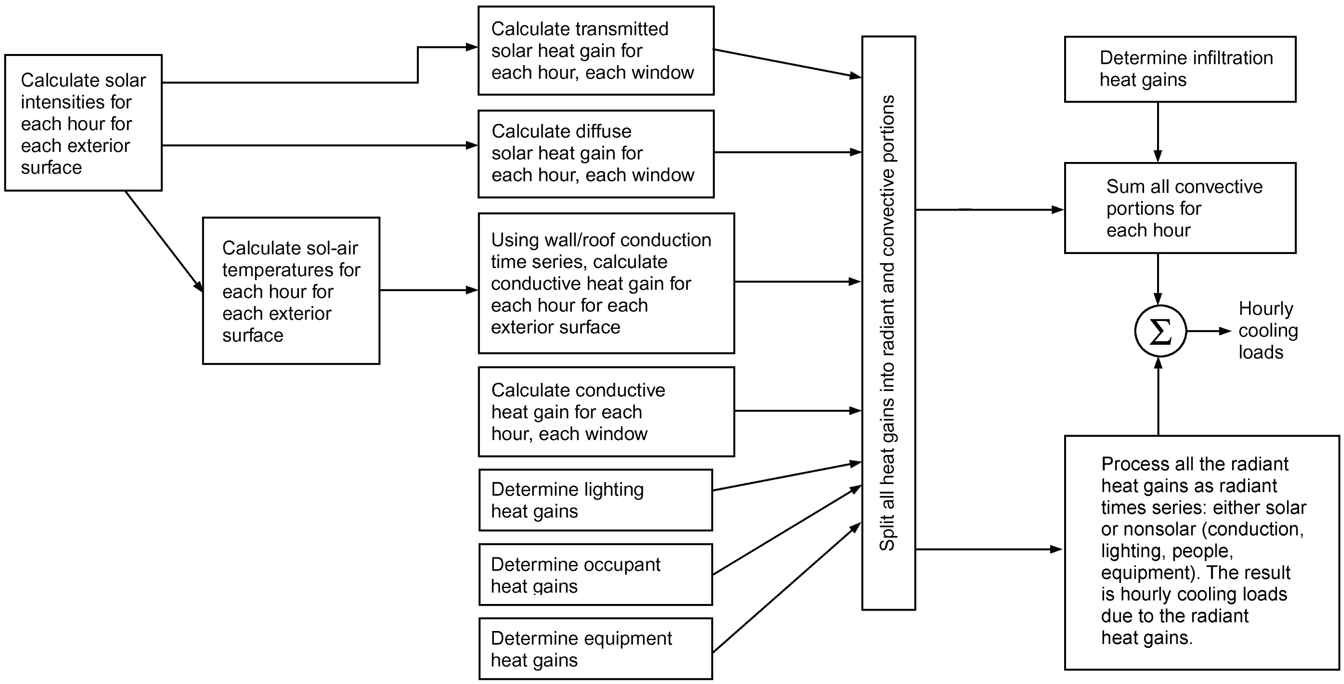

Fig. 1 Overview of Radiant Time Series Method

Table 1 Convective and Radiant Percentages of Total Sensible Heat Gain

Heat Gain Source	Radiant Heat, %	Convective Heat, %
Transmitted solar, no inside shade	100	0
Window solar, with inside shade	63	37
Absorbed (by fenestration) solar	63	37
Fluorescent lights, suspended, unvented	67	33
Fluorescent lights, recessed, vented to return air	59	41
Fluorescent lights, recessed, vented to return air and supply air	19	81
Incandescent lights	80	20
People	70	30
Conduction, exterior walls	63	37
Conduction, exterior roofs	84	16
Infiltration and ventilation	0	100
Machinery and appliances	20 to 80	80 to 20

Sources: Pedersen et al. (1998), Hosni et al. (1999).

time. Series coefficients, which are called radiant time factors and conduction time factors, are derived using the heat balance method. Radiant time factors reflect the percentage of an earlier radiant heat gain that becomes cooling load during the current hour. Likewise, conduction time factors reflect the percentage of an earlier heat gain at the exterior of a wall or roof that becomes heat gain at the inside during the current hour. By definition, each radiant or conduction time series must total 100%.

These series can be used to easily compare the time-delay impact of one construction versus another. This ability to compare choices is of particular benefit in the design process, when all construction details may not have been decided. Comparison can illustrate the magnitude of difference between the choices, allowing the engineer to apply judgment and make more informed assumptions in estimating the load.

As part of the presentation of this method, RTS Method Load Calculation Spreadsheets are available with the online supplemental materials accompanying this book at www.ashrae.org/PHVAC9th. These spreadsheets are intended as an educational tool for students or experienced engineers wishing to explore the RTS method. These spreadsheets allow the user to perform RTS cooling load calculations for lights, people, equipment, walls/roofs, and fenestration components using design day weather profiles for any month. Cooling and heating loads can be calculated for individual rooms or block load zones. Twelve-month cooling calculations can be done to determine the month and time of peak cooling load for each room or block load zone. In addition, room/zone worksheets can be copied and modified within the spreadsheet to analyze as many rooms or zones as desired; the number of rooms/zones is limited only by the available computer memory.

1 RTS Procedure

The general procedure for calculating cooling load for each load component (lights, people, walls, roofs, windows, appliances, etc.) with RTS is as follows:

1. Calculate 24-hour profile of component heat gain for design day (for conduction, first account for conduction time delay by applying conduction time series).
2. Split heat gains into radiant and convective parts (see Table 1 for radiant and convective fractions).
3. Apply appropriate radiant time series to radiant part of heat gains to account for time delay in conversion to cooling load.
4. Sum convective part of heat gain and delayed radiant part of heat gain to determine cooling load for each hour for each cooling load component.

After calculating cooling loads for each component for each hour, sum those to determine the total cooling load for each hour and select the hour with the peak load for design of the air-conditioning system. This process should be repeated for multiple design months to determine the month when the peak load occurs, especially with windows on southern exposures (northern exposure in southern latitudes), which can result in higher peak room cooling loads in winter months than in summer.

1.1 Conduction Heat Gain

In the RTS method, conduction through exterior walls and roofs is calculated using conduction time series (CTS). Wall and roof conductive heat input at the exterior is defined by the conduction Equation (1) as

$$q_{i,\theta-n} = UA(t_{e,\theta-n} - t_{rc}) \tag{1}$$

where

$q_{i,\theta-n}$ = conductive heat input for the surface n hours ago, Btu/h
U = overall heat transfer coefficient for the surface, Btu/h·ft²·°F
A = surface area, ft²
$t_{e,\theta-n}$ = sol-air temperature, °F, n hours ago
t_{rc} = presumed constant room air temperature, °F

Sol-Air Temperature. This is the temperature of the outdoor air that, in the absence of all radiation changes, gives the same rate of heat entry into the surface as would the combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with outdoor air.

Heat Gain Through Exterior Surfaces. The heat balance at a sunlit surface gives the heat flux into the surface q/A in Btu/h·ft², as

$$\frac{q}{A} = \alpha E_t + h_o(t_o - t_s) - \varepsilon\Delta R \tag{2}$$

where

α = absorptance of surface for solar radiation
E_t = total solar radiation incident on surface, Btu/h·ft²
h_o = coefficient of heat transfer by longwave radiation and convection at outer surface, Btu/h·ft²·°F
t_o = outdoor air temperature, °F
t_s = surface temperature, °F

ε = hemispherical emittance of surface

ΔR = difference between longwave radiation incident on surface from sky and surroundings and radiation emitted by black-body at outdoor air temperature, Btu/h·ft^2

Assuming the rate of heat transfer can be expressed in terms of the sol-air temperature t_e:

$$q/A = h_o(t_e - t_s) \tag{3}$$

From Equations (2) and (3):

$$t_e = t_o + \alpha I_t/h_o - \varepsilon \Delta R/h_o \tag{4}$$

For horizontal surfaces that receive longwave radiation from the sky only, an appropriate value of ΔR is about 20 Btu/h·ft^2, so if $\varepsilon = 1$ and $h_o = 3.0$ Btu/h·ft^2·°F, the longwave correction term is about 7°F.

Because vertical surfaces receive longwave radiation from the ground and surrounding buildings, as well as from the sky, accurate ΔR values are difficult to determine. When solar radiation intensity is high, surfaces of terrestrial objects usually have a higher temperature than the outdoor air; thus, their longwave radiation compensates to some extent for the sky's low emittance. Therefore, it is assumed that $\Delta R = 0$ for vertical surfaces.

The sol-air temperatures in Table 2 are calculated based on $\varepsilon\Delta R/h_o$ = 7°F for horizontal surfaces and 0°F for vertical surfaces; total solar intensity values for the calculation were the same as those used to evaluate the solar heat gain factors (SHGF) for July 21 at 40° N latitude. These values of I_t incorporate diffuse radiation from a clear sky and ground reflection but make no allowance for reflection from adjacent walls.

Surface Colors. Sol-air temperature values are given for two values of the parameter α/h_o (Table 2); 0.15 is appropriate for a light-colored surface, while 0.30 is the usual maximum value for this parameter (i.e., for a dark-colored surface or any surface for which the permanent lightness cannot be reliably anticipated).

Air Temperature Cycle. The air temperature cycle used to calculate sol-air temperatures is given in Column 2, Table 2. These values are obtained by using the daily temperature range and the percent (%) difference from Table 3. Sol-air temperatures can be adjusted to any other air temperature cycle by adding or subtracting the difference between the desired air temperature and the air temperature value given in Column 2.

Hourly Air Temperatures. The hourly air temperatures in Column 2, Table 2 are for a location with a design temperature of 95°F and a range of 21°F. To compute corresponding temperatures for other locations, select a suitable design temperature and note the outdoor daily range.

For each hour, take the percentage of the daily range indicated in Table 3 and subtract from the design temperature.

Conductive heat gain through walls or roofs can be calculated using conductive heat inputs for the current and past 23 hours and conduction time series, as illustrated in Equation (5):

$$q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta-1} + c_2 q_{i,\theta-2} + c_3 q_{i,\theta-3} + \ldots + c_{23} q_{i,\theta-23} \tag{5}$$

where

q_θ = hourly conductive heat gain, Btu/h, for the surface

$q_{i,\theta}$ = heat input for the current hour, Btu/h

$q_{i,\theta-n}$ = heat input n hours ago, Btu/h

c_0, c_1, etc. = conduction time factors, %

Conduction time factors for representative wall and roof types are provided in Tables 4 and 5, which are included in the Resources section at the end of this online material. Those values were derived by first calculating conduction transfer functions for each example wall and roof construction. The assumption of steady-periodic heat input conditions for design load calculations allowed the conduction transfer functions to be reformulated into periodic response factors as demonstrated by Spitler and Fisher (1999a). The periodic response factors were further simplified by dividing the 24 periodic response factors by the respective overall wall or roof U-factor to form the conduction time series (CTS). The CTS factors can then be used in Equation (2) and provide a means for comparison of time delay characteristics between different wall and roof constructions. Construction material data used in the calculations for walls and roofs included in Tables 4 and 5 are listed in Table 6 (also available in the Resources section at the end of this online material).

Table 2 Sol-Air Temperature (t_e) for July 21, 40° N Latitude

$$t_e = t_o + \alpha I_t/h_o - \varepsilon\Delta R/h_o$$

Time	Air Temp. t_o, °F	Light Colored Surface, α/h_o = 0.15									Time	Air Temp. t_o, °F	Dark Colored Surface, α/h_o = 0.30								
		N	NE	E	SE	S	SW	W	NW	HOR			N	NE	E	SE	S	SW	W	NW	HOR
1	76	76	76	76	76	76	76	76	76	69	1	76	76	76	76	76	76	76	76	76	69
2	76	76	76	76	76	76	76	76	76	69	2	76	76	76	76	76	76	76	76	76	69
3	75	75	75	75	75	75	75	75	75	68	3	75	75	75	75	75	75	75	75	75	68
4	74	74	74	74	74	74	74	74	74	67	4	74	74	74	74	74	74	74	74	74	67
5	74	74	74	74	74	74	74	74	74	67	5	74	74	75	75	74	74	74	74	74	67
6	74	80	93	95	84	76	76	76	76	72	6	74	85	112	115	94	77	77	77	77	77
7	75	80	99	106	94	78	78	78	78	81	7	75	84	124	136	113	81	81	81	81	94
8	77	81	99	109	101	82	81	81	81	92	8	77	85	121	142	125	86	85	85	85	114
9	80	85	96	109	106	88	85	85	85	102	9	80	90	112	138	131	96	89	89	89	131
10	83	88	91	105	107	95	88	88	88	111	10	83	94	100	127	131	107	94	94	94	145
11	87	93	93	99	106	102	93	93	93	118	11	87	98	99	111	125	118	100	98	98	156
12	90	96	96	96	102	106	102	96	96	122	12	90	101	101	102	114	123	114	102	101	162
13	93	99	99	99	99	108	112	105	99	124	13	93	104	104	104	106	124	131	117	105	162
14	94	99	99	99	99	106	118	116	102	122	14	94	105	105	105	105	118	142	138	111	156
15	95	100	100	100	100	103	121	124	111	117	15	95	105	104	104	104	111	146	153	127	146
16	94	98	98	98	98	99	118	126	116	109	16	94	102	102	102	102	103	142	159	138	131
17	93	98	96	96	96	96	112	124	117	99	17	93	102	99	99	99	99	131	154	142	112
18	91	97	93	93	93	93	101	112	110	89	18	91	102	94	94	94	94	111	132	129	94
19	87	87	87	87	87	87	87	87	87	80	19	87	87	87	87	87	87	87	88	88	80
20	85	85	85	85	85	85	85	85	85	78	20	85	85	85	85	85	85	85	85	85	78
21	83	83	83	83	83	83	83	83	83	76	21	83	83	83	83	83	83	83	83	83	76
22	81	81	81	81	81	81	81	81	81	74	22	81	81	81	81	81	81	81	81	81	74
23	79	79	79	79	79	79	79	79	79	72	23	79	79	79	79	79	79	79	79	79	72
24	77	77	77	77	77	77	77	77	77	70	24	77	77	77	77	77	77	77	77	77	70
Avg.	**83**	**86**	**88**	**90**	**90**	**87**	**90**	**90**	**88**	**90**	**Avg.**	**83**	**89**	**94**	**99**	**97**	**93**	**97**	**99**	**94**	**104**

Note: Sol-air temperatures are calculated based on $\varepsilon\Delta R/h_o$ = 7°F for horizontal surfaces and 0°F for vertical surfaces.

Table 3 Percentage of Daily Range

Time, h	%	Time, h	%	Time, h	%
1	87	9	71	17	10
2	92	10	56	18	21
3	96	11	39	19	34
4	99	12	23	20	47
5	100	13	11	21	58
6	98	14	3	22	68
7	93	15	0	23	76
8	84	16	3	24	82

Whether or not sunlight is present, heat flows through fenestration by thermal conduction, as expressed by

Conductive heat flow	=	Overall coefficient of heat transfer	×	Outdoor-indoor temperature difference

or

$$q/A = U(t_o - t_i) \tag{6}$$

where

q/A = instantaneous rate of heat transfer through fenestration
U = overall coefficient of heat transfer for the glazing
t_o = outdoor air temperature
ti = inside air temperature

Values of the overall coefficient of heat transfer for a number of widely used fenestrations are in Chapter 15 of the 2017 *ASHRAE Handbook—Fundamentals* (also see Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition). Table 7 includes some useful solar equations.

For fenestration heat gain, the following equations apply:

Direct beam solar heat gain q_b:

$$q_b = AE_D \text{SHGC}(\Theta)\text{IAC} \tag{7}$$

Diffuse solar heat gain q_d:

$$q_d = A(E_d + E_r)(\text{SHGC})_D\text{IAC} \tag{8}$$

Conductive heat gain q_c:

$$q_c = UA(T_{\text{out}} - T_{\text{in}}) \tag{9}$$

Total fenestration heat gain q:

$$q = q_b + q_d + q_c \tag{10}$$

where

A = window area, ft^2
E_D, E_d, E_r = direct, diffuse, and ground-reflected irradiance, calculated using the equations in Table 7
SHGC(Θ) = direct solar heat gain coefficient as a function of incident angle q; may be interpolated between values in Table 8 (included in the Resources section at the end of this online material)
$(\text{SHGC})_D$ = diffuse solar heat gain coefficient (also referred to as hemispherical SHGC); from Table 8 (included in the Resources section at the end of this online material)
T_{in} = inside temperature, °F
T_{out} = outside temperature, °F
U = overall U-factor, including frame and mounting orientation, Btu/h·ft^2·°F, from Table 5-16 of Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition
IAC = inside shading attenuation coefficient, = 1.0 if no inside shading device

If specific window manufacturer's SHGC and U-factor data are available, those should be used. For fenestration equipped with inside shading (blinds, drapes, or shades), IAC is listed in Table 9, which is included in the Resources section at the end of this online material. The inside shading attenuation coefficients given are used to calculate both direct and diffuse solar heat gains.

Fenestration ratings (U-factor and SHGC) are based on the entire product area, including frames. Thus, for load calculations, fenestration area is the area of the entire opening in the wall or roof.

Nonuniform exterior shading, caused by roof overhangs, side fins, or building projections, requires separate hourly calculations for the externally shaded and unshaded areas of the window in question, with the

Table 7 Solar Heat Gain
(Table 14, Chapter 30, 2005 *ASHRAE Handbook—Fundamentals*)

Solar Angles

All angles are in degrees. The solar azimuth ϕ and the surface azimuth ψ are measured in degrees from south; angles to the east of south are negative, and angles to the west of south are positive. Calculate solar altitude, azimuth, and surface incident angles as follows:

Apparent solar time AST, in decimal hours:

$$AST = LST + ET/60 + (LSM - LON)/15$$

Hour angle H, degrees:

$$H = 15(\text{hours of time from local solar noon}) = 15(AST - 12)$$

Solar altitude β:

$$\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\delta$$

Solar azimuth ϕ:

$$\cos\phi = (\sin\beta \sin L - \sin\delta)/(\cos\beta \cos L)$$

Surface-solar azimuth γ:

$$\gamma = \phi - \psi$$

Incident angle θ:

$$\cos\theta = \cos\beta \cos\gamma \sin\Sigma + \sin\beta \cos\Sigma$$

where
- ET = equation of time, decimal minutes
- L = latitude
- LON = local longitude, decimal degrees of arc
- LSM = local standard time meridian, decimal degrees of arc
  - = 60° for Atlantic Standard Time
  - = 75° for Eastern Standard Time
  - = 90° for Central Standard Time
  - = 105° for Mountain Standard Time
  - = 120° for Pacific Standard Time
  - = 135° for Alaska Standard Time
  - = 150° for Hawaii-Aleutian Standard Time
- LST = local standard time, decimal hours
- δ = solar declination, °
- ψ = surface azimuth, °
- Σ = surface tilt from horizontal, horizontal = 0°

Values of ET and δ are given in Table 2 of Chapter 14 of the 2019 *ASHRAE Handbook—HVAC Applications* for the 21st day of each month.

Direct, Diffuse, and Total Solar Irradiance

Direct normal irradiance E_{DN}

$$\text{If } \beta > 0 \qquad E_{DN} = \left[\frac{A}{\exp(B/\sin\beta)}\right]CN$$

$$\text{Otherwise, } E_{DN} = 0$$

Surface direct irradiance E_D

$$\text{If } \cos\theta > 0 \qquad E_D = E_{DN}\cos\theta$$

$$\text{Otherwise, } E_D = 0$$

Ratio Y of sky diffuse on vertical surface to sky diffuse on horizontal surface

$$\text{If } \cos\theta > -0.2 \qquad Y = 0.55 + 0.437\cos\theta + 0.313\cos^2\theta$$

$$\text{Otherwise, } Y = 0.45$$

Diffuse irradiance E_d

Vertical surfaces

$$E_d = CYE_{DN}$$

Surfaces other than vertical

$$E_d = CE_{DN}(1 + \cos\Sigma)/2$$

Ground-reflected irradiance

$$E_r = E_{DN}(C + \sin\beta)\rho_g(1 - \cos\Sigma)/2$$

Total surface irradiance

$$E_t = E_D + E_d + E_r$$

where
- A = apparent solar constant
- B = atmospheric extinction coefficient
- C = sky diffuse factor
- CN = clearness number multiplier for clear/dry or hazy/humid locations. See Figure 5 in Chapter 33 of the 2019 *ASHRAE Handbook—HVAC Applications* for CN values.
- E_d = diffuse sky irradiance
- E_r = diffuse ground-reflected irradiance
- ρ_g = ground reflectivity

Values of *A, B,* and *C* are given in Table 1of Chapter 35, 2011 *ASHRAE Handbook—HVAC Applications* for the 21st day of each month. Values of ground reflectivity ρ_g are given in Table 10 of Chapter 31 of the 2005 *ASHRAE Handbook—Fundamentals*.

inside shading SHGC still used to account for any internal shading devices. The areas, shaded and unshaded, depend on the location of the shadow line on a surface in the plane of the glass.

To account for the different types of fenestration and shading devices, used the inside shading attenuation coefficient IAC, which relates the solar heat gain through a glazing system under a specific set of conditions to the solar heat gain through the reference glazing material under the same conditions.

Most fenestration has some type of internal shading to provide privacy and aesthetic effects, as well as to give varying degrees of sun control. The IAC values and other glazing are given in Tables 8 though 12 for various fenestrations and shading device combinations.

Table 9, which is included in the Resources section at the end of this online material, gives values of IAC (derived from measurements) for a variety of glazing and shading combinations.

The IAC bears a certain similarity to the shading coefficient. There is, however, an important difference: we must calculate the solar heat flux through the unshaded glazing at the appropriate angle before applying the IAC. With the shading coefficient, only the angular dependence of single glazing was included (through the now-discarded SHGF). The effectiveness of any internal shading device depends on its ability to reflect incoming solar radiation back through the fenestration before it can be absorbed and converted into heat within the building.

Table 10, included in the Resources section at the end of this online material, gives between-glass solar attenuation coefficients (BAC) for double glazing with between-glass shading. Table 11, also included in the Resources section at the end of this online material, lists approximate values of solar-optical properties for the typical indoor shading devices described in Tables 9 and 10.

Skylights. Skylight solar heat gain strongly depends on the configuration of the space below or adjacent to (i.e., in sloped applications) the skylight formed by the skylight curb and any associated light well.

Five aspects must be considered: (1) transmittance and absorptance of the skylight unit, (2) transmitted solar flux that reaches the aperture of the light well, (3) whether that aperture is covered by a diffuser, (4) transmitted solar flux that strikes the walls of the light well, and (5) reflectance of the walls of the light well. Data for flat skylights, which may be considered as sloped glazings, are found in Table 5-16 of Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition, and Table 12, which is included in the Resources section at the end of this online material.

1.2 Cooling Load Calculations Using RTS

The instantaneous cooling load is defined as the rate at which heat energy is convected to the zone air at a given point in time. The computation of cooling load is complicated by the radiant exchange between surfaces, furniture, partitions, and other mass in the zone. Most heat gain sources transfer energy by both convection and radiation. Radiative heat transfer introduces to the process a time dependency that is not easily quantified. Radiation is absorbed by the thermal masses in the zone and then later transferred by convection into the space. This process creates a time lag and dampening effect. The convection portion of heat gains, on the other hand, is assumed to immediately become cooling load in the hour in which that heat gain occurs.

Heat balance procedures calculate the radiant exchange between surfaces based on their surface temperatures and emissivities, but they typically rely on estimated "radiative-convective splits" to determine the contribution of internal loads, including people, lighting, appliances, and equipment, to the radiant exchange. The radiant time series procedure further simplifies the heat balance procedure by also relying on an estimated radiative-convective split of wall and roof conductive heat gain instead of simultaneously solving for the instantaneous convective and radiative heat transfer from each surface, as is done in the heat balance procedure.

Thus, the cooling load for each load component (lights, people, walls, roofs, windows, appliances, etc.) for a particular hour is the sum of the convective portion of the heat gain for that hour plus the time-delayed portion of radiant heat gains for that hour and the previous 23 hours. Table 1 contains recommendations for splitting each of the heat gain components into convective and radiant portions.

The radiant time series method converts the radiant portion of hourly heat gains to hourly cooling loads using radiant time factors, the coefficients of the radiant time series. Radiant time factors are used to calculate the cooling load for the current hour on the basis of current and past heat gains. The radiant time series for a particular zone gives the time-dependent response of the zone to a single pulse of radiant energy. The series shows the portion of the radiant pulse that is convected to the zone air for each hour. Thus, r_0 represents the fraction of the radiant pulse convected to the zone air in the current hour r_1 in the previous hour, and so on. The radiant time series thus generated is used to convert the radiant portion of hourly heat gains to hourly cooling loads.

Two different radiant time series are used: solar, for directly transmitted solar heat gain (radiant energy assumed to be distributed to the floor and furnishings only), and nonsolar for all other types of heat gains (radiant energy assumed to be uniformly distributed on all internal surfaces). Nonsolar RTS apply to radiant heat gains from people, lights, appliances, walls, roofs, and floors. Also, for diffuse solar heat gain and direct solar heat gain from fenestration with inside shading (blinds, drapes, etc.), the nonsolar RTS should be used. Radiation from those sources is assumed to be more uniformly distributed onto all room surfaces.

Representative solar and nonsolar RTS data for light, medium, and heavyweight constructions are provided in Tables 13 and 14, which are included in the Resources section at the end of this online material. Those were calculated using the zone characteristics listed in Table 15 (also included in the Resources section at the end of this online material).

2 Design Loads Calculation Example

To illustrate the cooling and heating load calculation procedures discussed in this material, an example problem has been developed based on a building located at latitude 33.6° and longitude 84.4° and an elevation of 1027 ft above sea level with 99.6% heating design DB = 21.9°F and 1% cooling design of 91.6°F DB and 73.8°F WB. This example is a two-story office building of approximately 35,000 ft^2, including a variety of common office functions and occupancies. In addition to demonstrating calculation procedures, a hypothetical design/construction process is discussed to illustrate (1) application of load calculations and (2) the need to develop reasonable assumptions when specific data are not yet available, as often occurs in everyday design processes.

Table 16 summarizes RTS load calculation procedures.

Table 16 Summary of RTS Load Calculation Procedures

(Adapted from Table 26, Chapter 18, 2021 *ASHRAE Handbook—Fundamentals*)

Equation	Equation No. in Chapter
External Heat Gain	
Sol-Air Temperature $t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o}$ where t_e = sol-air temperature, °F t_o = outdoor air temperature, °F a = absorptance of surface for solar radiation E_t = total solar radiation incident on surface, Btu/h·ft^2 h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface, Btu/h·ft^2·°F e = hemispherical emittance of surface ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature, Btu/h·ft^2; 20 for horizontal surfaces; 0 for vertical surfaces	(1) of this online material
Wall and Roof Transmission $q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta\text{-}1} + c_2 q_{i,\theta\text{-}2} + \dots + c_{23} q_{i,\theta\text{-}23}$ $q_{i,\theta\text{-}n} = UA(t_{e,\theta\text{-}n} - t_{rc})$ where q_θ = hourly conductive heat gain for surface, Btu/h $q_{i,\theta}$ = heat input for current hour $q_{i,\theta\text{-}n}$ = conductive heat input for surface n hours ago, Btu/h c_0, c_1, etc. = conduction time factors U = overall heat transfer coefficient for surface, Btu/h·ft^2·°F A = surface area, ft^2	(2) of this online material
Fenestration Transmission $q_c = UA(T_{out} - T_{in})$ where q = fenestration transmission heat gain, Btu/h U = overall U-factor, including frame and mounting orientation from Table 5-6 of ASHRAE (2021b) A = window area, ft^2 T_{in} = indoor temperature, °F T_{out} = outdoor temperature, °F	
Partitions, Ceilings, Floors Transmission $q = UA(t_b - t_i)$ where q = heat transfer rate, Btu/h U = coefficient of overall heat transfer between adjacent and conditioned space, Btu/h·ft^2·°F A = area of separating section concerned, ft^2 t_b = average air temperature in adjacent space, °F t_i = air temperature in conditioned space, °F	(5-11) of Chapter 5 of ASHRAE (2021b)
Internal Heat Gain	
Occupants $q_s = q_{s,per} N$ $q_l = q_{l,per} N$ where q_s = occupant sensible heat gain, Btu/h q_l = occupant latent heat gain, Btu/h $q_{l,per}$ = latent heat gain per person, Btu/h·person; see Table 5-15 of ASHRAE (2021b) N = number of occupants	
Lighting $q_{el} = 3.41 W F_{ul} F_{sa}$ where q_{el} = heat gain, Btu/h W = total light wattage, W F_{ul} = lighting use factor F_{sa} = lighting special allowance factor 3.41 = conversion factor	(5-18) of Chapter 5 of ASHRAE (2021b)
Electric Motors $q_{em} = 2545(P/E_M) F_{MU} F_{LM}$ E_M = motor efficiency, decimal fraction <1.0 F_{MU} = motor use factor, 1.0 or decimal fraction <1.0 F_{LM} = motor load factor, 1.0 or decimal fraction <1.0 2545 = conversion factor, Btu/h·hp	(5-19) of Chapter 5 of ASHRAE (2021b)
Cooking Appliances $q_s = q_{input} F_U F_R$ where q_s = sensible heat gain, Btu/h q_{input} = nameplate or rated energy input, Btu/h F_U = usage factor F_R = radiation factor	
For other appliances and equipment, find q_s and q_L.	

Table 16 Summary of RTS Load Calculation Procedures *(Continued)*

(Adapted from Table 26, Chapter 18, 2021 *ASHRAE Handbook—Fundamentals*)

Equation	Equation No. in Chapter	Equation	Equation No. in Chapter
Fenestration Solar $q_b = AE_{t,b}\,\mathrm{SHGC}(\theta)\mathrm{IAC}(\theta,\Omega)$ $q_d = A(E_{t,d} + E_{t,r})\langle\mathrm{SHGC}\rangle_D\,\mathrm{IAC}_D$ where q_b = beam direct solar heat gain, Btu/h q_d = diffuse solar heat gain, Btu/h A = window area, ft^2 E_D, E_d, E_r = beam, direct diffuse, and ground-reflected diffuse irradiance, calculated using equations in Table 7 SHGC(θ) = beam solar heat gain coefficient as a function of incident angle θ; may be interpolated between values in Table 8 IAC(θ.Ω) = indoor solar attenuation coefficient for beam solar heat gain coefficient; = 1.0 if no indoor shading device. IAC(θ.Ω) is a function of shade type and, depending on type, may also be a function of beam solar angle of incidence θ and shade geometry IAC_D = indoor solar attenuation coefficient for diffuse solar heat gain coefficient; = 1.0 if not indoor shading device. IAC_D is a function of shade type and, depending on type, may also be a function of shade geometry *Instantaneous Room Cooling Load* $Q_s = \Sigma Q_{i,r} + \Sigma Q_{i,c}$ $Q_l = \Sigma q_{i,l}$ where Q_s = room sensible cooling load, Btu/h $Q_{i,r}$ = radiant portion of sensible cooling load for current hour, resulting from heat gain element i, Btu/h $Q_{i,c}$ = convective portion of sensible cooling load, resulting from heat gain element i, Btu/h Q_l = room latent cooling load, Btu/h $q_{i,l}$ = latent heat gain for heat gain element i, Btu/h		*Convective Portion of Sensible Cooling Load* $Q_{i,c} = q_{i,c}$ where $q_{i,c}$ is convective portion of heat gain from heat gain element *i*, Btu/h. $q_{i,c} = q_{i,s}(1 - F_r)$ where $q_{i,s}$ = sensible heat gain from heat gain element i, Btu/h F_r = fraction of heat gain that is radiant; see row for radiant portion for sources of radiant fraction data for individual heat gain elements *Radiant Portion of Sensible Cooling Load* $Q_{i,r} = Q_{r,\theta}$ $Q_{r,\theta} = r_0 q_{r,\theta} + r_1 q_{r,\theta-1} + r_2 q_{r,\theta-2} + r_3 q_{r,\theta-3} + \cdots + r_{23} q_{r,\theta-23}$ where $Q_{r,\theta}$ = radiant cooling load Q_r for current hour θ, Btu/h $q_{r,\theta}$ = radiant heat gain for current hour, Btu/h $q_{r,\theta-n}$= radiant heat gain n hours ago, Btu/h r_0, r_1, etc.=radiant time factors; see Table 13 for radiant time factors for nonsolar heat gains: wall, roof, partition, ceiling, floor, fenestration transmission heat gains, and occupant, lighting, motor, appliance heat gain. Also used for fenestration diffuse solar heat gain; see Table 14 for radiant time factors for fenestration beam solar heat gain. $q_{r,\theta} = q_{i,s}F_r$ where $q_{i,s}$ = sensible heat gain from heat gain element i, Btu/h F_r = fraction of heat gain that is radiant.	

Single-Room Example. Calculate the peak heating and cooling loads for the office room shown in Figure 2, for the defined location. The room is on the second floor of a two-story building and has two vertical exterior exposures, with a flat roof above.

Room Characteristics

Area: 130 ft^2

Floor: Carpeted 5 in. concrete slab on metal deck above a conditioned space.

Roof: Flat metal deck topped with rigid closed-cell polyisocyanurate foam core insulation (R = 30), and light-colored membrane roofing. Space above 9 ft (suspended acoustical tile ceiling is used as a return air plenum). Assume 30% of cooling load from the roof is directly absorbed in the return airstream without becoming room load. Use roof U = 0.032 Btu/h·ft^2·°F.

Spandrel wall: Spandrel bronze-tinted glass, opaque, backed with air space, rigid mineral fiber insulation (R = 5.0), mineral fiber batt insulation (R = 13), and 5/8 in. gypsum wall board. Use spandrel wall U = 0.077 Btu/h·ft^2·°F.

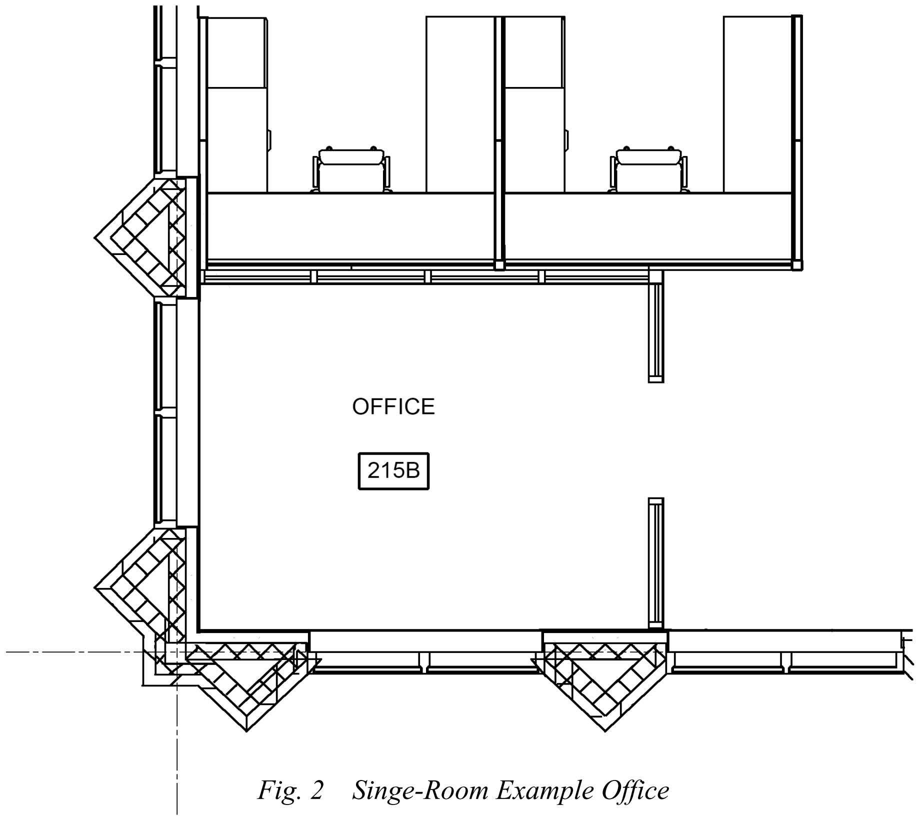

Fig. 2 Singe-Room Example Office

Brick wall: Light-brown-colored face brick (4 in.), lightweight (concrete block (6 in.), rigid continuous insulation (R = 5), mineral fiber batt insulation (R = 13), and gypsum wall board (5/8 in.). Use brick wall U = 0.08 Btu/h·ft^2·°F.

Windows: Double glazed, 1/4 in. (bronze-tinted outdoor pane, 1/2 in.) air space and 1/4 in. (clear indoor pane with light-colored interior miniblinds. Window normal solar heat gain coefficient (SHGC) = 0.49. Windows are nonoperable and mounted in aluminum frames with thermal breaks having overall combined U = 0.56 Btu/h·ft^2·°F (based on IO Type 5 from Table 5-6 of Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition). Indoor attenuation coefficients (IACs) for indoor miniblinds are based on light venetian blinds (assumed louver reflectance = 0.8 and louvers positioned at 45° angle) with heat-absorbing double glazing (Type 5 from Table 5-6), IAC(0) = 0.74, IAC(60) = 0.65, IAD(diff) = 0.79, and radiant fraction = 0.54. Each window is 6.25 ft (wide by 6.4 ft (tall for an area per window = 40 ft^2).

South exposure:	Orientation	=	30° east of true south
	Window area	=	40 ft^2
	Spandrel wall area	=	60 ft^2
	Brick wall area	=	60 ft^2
West exposure:	Orientation	=	60° west of south
	Window area	=	40 ft^2
	Spandrel wall area	=	60 ft^2
	Brick wall area	=	40 ft^2

Occupancy: 1 person from 8:00 AM to 5:00 PM.

Lighting: One 4-lamp pendant fluorescent 8 ft type. The fixture has four 32 W T-8 lamps plus electronic ballasts (special allowance factor 0.85 per manufacturer’s data), for a total of 110 W for the room. Operation is from 7:00 AM to 7:00 PM. Assume 0% of cooling load from lighting is directly absorbed in the return airstream without becoming room load.

Table 17 Monthly/Hourly 5% Design Temperatures, °F

	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
hr	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db	wb
1	45.8	45.2	47.5	45.2	53.7	49.4	59.8	55.0	66.9	62.2	72.1	66.7	73.8	68.9	73.7	68.9	69.6	64.7	60.2	56.9	51.9	50.3	47.4	47.4
2	45.1	44.7	46.7	44.7	52.8	49.0	59.0	54.7	66.1	61.9	71.3	66.4	73.0	68.7	73.0	68.7	68.8	64.4	59.4	56.5	51.1	49.8	46.7	46.7
3	44.5	44.3	46.0	44.3	52.1	48.7	58.3	54.4	65.5	61.7	70.7	66.2	72.4	68.5	72.4	68.5	68.3	64.2	58.8	56.2	50.4	49.5	46.1	46.1
4	43.9	43.9	45.4	43.9	51.5	48.3	57.6	54.1	64.9	61.5	70.1	66.0	71.8	68.3	71.8	68.3	67.7	64.0	58.2	56.0	49.8	49.1	45.5	45.5
5	43.5	43.5	45.0	43.6	51.0	48.1	57.2	53.9	64.5	61.3	69.7	65.9	71.4	68.2	71.4	68.2	67.3	63.9	57.8	55.8	49.4	48.9	45.1	45.1
6	43.9	43.9	45.4	43.9	51.5	48.3	57.6	54.1	64.9	61.5	70.1	66.0	71.8	68.3	71.8	68.3	67.7	64.0	58.2	56.0	49.8	49.1	45.5	45.5
7	45.3	44.8	46.9	44.8	53.0	49.1	59.2	54.8	66.3	62.0	71.5	66.5	73.2	68.7	73.2	68.7	69.0	64.5	59.6	56.6	51.3	50.0	46.9	46.9
8	48.6	47.1	50.4	47.1	56.9	51.0	62.9	56.4	69.7	63.3	74.9	67.6	76.7	69.8	76.5	69.8	72.3	65.7	63.1	58.1	54.8	51.9	50.2	49.2
9	52.3	49.7	54.4	49.6	61.1	53.1	67.1	58.2	73.5	64.7	78.7	68.9	80.5	70.9	80.2	70.9	75.9	67.0	67.0	59.8	58.8	54.2	53.9	51.7
10	55.6	52.0	58.0	51.8	65.0	54.9	70.8	59.8	77.0	66.0	82.2	70.0	83.9	72.0	83.5	71.9	79.1	68.1	70.4	61.3	62.4	56.2	57.2	54.0
11	58.5	54.1	61.1	53.8	68.3	56.6	74.1	61.2	80.0	67.1	85.2	71.0	87.0	72.9	86.4	72.8	82.0	69.1	73.5	62.7	65.5	57.9	60.1	56.0
12	60.5	55.4	63.2	55.2	70.6	57.7	76.3	62.2	82.0	67.8	87.2	71.6	89.0	73.5	88.4	73.4	83.9	69.8	75.5	63.5	67.6	59.1	62.1	57.3
13	62.0	56.5	64.9	56.2	72.4	58.6	78.1	62.9	83.6	68.4	88.8	72.2	90.6	74.0	89.9	73.9	85.4	70.4	77.2	64.3	69.3	60.0	63.6	58.3
14	63.0	57.2	65.9	56.9	73.5	59.1	79.2	63.4	84.6	68.8	89.8	72.5	91.6	74.3	90.9	74.2	86.4	70.7	78.2	64.7	70.3	60.6	64.6	59.0
15	63.0	57.2	65.9	56.9	73.5	59.1	79.2	63.4	84.6	68.8	89.8	72.5	91.6	74.3	90.9	74.2	86.4	70.7	78.2	64.7	70.3	60.6	64.6	59.0
16	61.8	56.4	64.6	56.1	72.2	58.4	77.9	62.8	83.4	68.4	88.6	72.1	90.4	73.9	89.7	73.8	85.3	70.3	77.0	64.2	69.0	59.9	63.4	58.2
17	60.3	55.3	63.0	55.0	70.4	57.6	76.1	62.1	81.8	67.8	87.0	71.6	88.8	73.4	88.2	73.4	83.7	69.7	75.3	63.5	67.4	59.0	61.9	57.2
18	58.3	53.9	60.9	53.7	68.1	56.5	73.9	61.1	79.8	67.0	85.0	70.9	86.8	72.8	86.2	72.8	81.8	69.1	73.3	62.6	65.3	57.8	59.9	55.8
19	55.4	51.9	57.7	51.7	64.7	54.8	70.6	59.7	76.8	65.9	82.0	69.9	83.7	71.9	83.3	71.9	79.0	68.0	70.2	61.2	62.1	56.0	57.0	53.9
20	53.3	50.4	55.5	50.3	62.3	53.6	68.2	58.7	74.6	65.1	79.8	69.2	81.5	71.3	81.2	71.2	76.9	67.3	68.0	60.3	59.9	54.8	54.9	52.4
21	51.5	49.2	53.6	49.1	60.2	52.6	66.2	57.8	72.7	64.4	77.9	68.6	79.7	70.7	79.4	70.7	75.1	66.7	66.2	59.4	58.0	53.7	53.1	51.2
22	49.7	48.0	51.7	47.9	58.2	51.6	64.2	56.9	70.9	63.7	76.1	68.0	77.9	70.2	77.6	70.1	73.4	66.1	64.3	58.6	56.1	52.6	51.3	50.0
23	48.4	47.0	50.2	46.9	56.6	50.9	62.7	56.3	69.5	63.2	74.7	67.6	76.5	69.7	76.3	69.7	72.1	65.6	62.9	58.0	54.6	51.8	50.0	49.1
24	47.0	46.0	48.8	46.0	55.1	50.1	61.2	55.6	68.1	62.7	73.3	67.1	75.0	69.3	74.9	69.3	70.7	65.1	61.5	57.4	53.2	51.0	48.6	48.2

Equipment: One computer and a personal printer are used, for which an allowance of 1 W/ft^2 is to be accommodated by the cooling system, for a total of 130 W for the room. Operation is from 8:00 AM to 5:00 PM.

Infiltration: For purposes of this example, assume the building is maintained under positive pressure during peak cooling conditions and therefore has no infiltration. Assume that infiltration during peak heating conditions is equivalent to one air change per hour.

Weather data: Latitude = 33.64, longitude = 84.43, elevation = 1027 ft above sea level, 99.6% heating design dry-bulb temperature = 21.9°F. For cooling load calculations, use 5% dry-bulb/coincident wet-bulb monthly design day profile. See Table 17 for temperature profiles used in these examples.

Indoor design conditions: 72°F DB for heating; 75°F DB with 50% rh for cooling.

Cooling Loads Using RTS Method. Traditionally, simplified cooling load calculation methods have estimated the total cooling load at a particular design condition by independently calculating and then summing the load from each component (walls, windows, people, lights, etc). Although the actual heat transfer processes for each component do affect each other, this simplification is appropriate for design load calculations and useful to the designer in understanding the relative contribution of each component to the total cooling load.

Cooling loads are calculated with the RTS method on a component basis similar to previous methods. The following example parts illustrate cooling load calculations for individual components of this single room for a particular hour and month. Equations used are summarized in Table 16.

Part 1. Internal cooling load using radiant time series. Calculate the cooling load from lighting at 3:00 PM for the previously described office.

Solution: First calculate the 24-hour heat gain profile for lighting, then split those heat gains into radiant and convective portions, apply the appropriate RTS to the radiant portion, and sum the convective and radiant cooling load components to determine total cooling load at the designated time. Using Equation (5-18) of Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition, the lighting heat gain profile, based on the occupancy schedule indicated is

q_1 = (110 W)3.41(0%) = 0	q_{13} = (110 W)3.41(100%) = 375
q_2 = (110 W)3.41(0%) = 0	q_{14} = (110 W)3.41(100%) = 375
q_3 = (110 W)3.41(0%) = 0	q_{15} = (110 W)3.41(100%) = 375
q_4 = (110 W)3.41(0%) = 0	q_{16} = (110 W)3.41(100%) = 375
q_5 = (110 W)3.41(0%) = 0	q_{17} = (110 W)3.41(100%) = 375
q_6 = (110 W)3.41(0%) = 0	q_{18} = (110 W)3.41(100%) = 375
q_7 = (110 W)3.41(100%) = 375	q_{19} = (110 W)3.41(0%) = 0
q_8 = (110 W)3.41(100%) = 375	q_{20} = (110 W)3.41(0%) = 0
q_9 = (110 W)3.41(100%) = 375	q_{21} = (110 W)3.41(0%) = 0
q_{10} = (110 W)3.41(100%) = 375	q_{22} = (110 W)3.41(0%) = 0
q_{11} = (110 W)3.41(100%) = 375	q_{23} = (110 W)3.41(0%) = 0
q_{12} = (110 W)3.41(100%) = 375	q_{24} = (110 W)3.41(0%) = 0

The convective portion is simply the lighting heat gain for the hour being calculated times the convective fraction for non-in-ceiling fluorescent luminaire (pendant), from Table 3 of Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*:

$$Q_{c,15} = (375)(43\%) = 161.3 \text{ Btu/h}$$

The radiant portion of the cooling load is calculated using lighting heat gains for the current hour and past 23 h, the radiant fraction from Table 3 of Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals* (57%), and radiant time series from Table 16. From that table, select the RTS for medium-weight construction, assuming 50% glass and carpeted floors as representative of the described construction. Thus, the radiant cooling load for lighting is

$$Q_{r,15} = r_0(0.48)q_{15} + r_1(0.48)q_{14} + r_2(0.48)q_{13} + r_3(0.48)q_{12} + \cdots + r_{23}(0.48)q_{16}$$

$$\begin{aligned}
&= (0.49)(0.57)(375) + (0.17)(0.57)(375) + (0.09)(0.57)(375) + (0.05)(0.57)(375) \\
&+ (0.03)(0.57)(375) + (0.02)(0.57)(375) + (0.02)(0.57)(375) + (0.01)(0.57)(375) \\
&+ (0.01)(0.57)(375) + (0.01)(0.57)(0) + (0.01)(0.57)(0) + (0.01)(0.57)(0) + (0.01)(0.57)(0) \\
&+ (0.01)(0.57)(0) + (0.01)(0.5748)(0) + (0.01)(0.57)(0) + (0.01)(0.57)(0) + (0.01)(0.57)(0) \\
&+ (0.01)(0.57)(0) + (0.01)(0.57)(0) + (0.00)(0.57)(0) + (0.00)(0.57)(375) \\
&+ (0.00)(0.57)(375) + (0.00)(0.57)(375) = 190.3 \text{ Btu/h}
\end{aligned}$$

The total lighting cooling load at the designated hour is thus

$$Q_{light} = Q_{c,15} + Q_{r,15} = 161.3 + 190.3 = 351.6 \text{ Btu/h}$$

See Table 18 for the office's lighting usage, heat gain, and cooling load profiles.

Part 2. Wall cooling load using sol-air temperature, conduction time series and radiant time series. Calculate the cooling load contribution from the spandrel wall section facing 60° west of south at 3:00 PM local standard time in July for the previously described office.

Solution: Determine the wall cooling load by calculating (1) sol-air temperatures at the exterior surface, (2) heat input based on sol-air temperature, (3) delayed heat gain through the mass of the wall to the interior surface using conduction time series, and (4) delayed space cooling load from heat gain using radiant time series.

First, calculate the sol-air temperature at 3:00 PM local standard time (LST) (4:00 PM daylight saving time) on July 21 for a vertical, dark-colored wall surface, facing 60° west of south, given a solar clear sky optical depth for beam irradiance τ_b ("taub") = 0.515 and τ_d ("taud") for diffuse irradiance = 2.066 from monthly

Table 18 Cooling Load Component: Lighting, Btu/h

Hour	Usage Profile, %	Heat Gain	Heat Gain Convective 43%	Heat Gain Radiant 57%	Nonsolar RTS Zone Type 8, %	Radiant Cooling Load	Total Sensible Cooling Load	% Lighting to Return 0%	Room Sensible Cooling Load
1	0	—	—	—	49	26	26	—	26
2	0	—	—	—	17	26	26	—	26
3	0	—	—	—	9	24	24	—	24
4	0	—	—	—	5	21	21	—	21
5	0	—	—	—	3	19	19	—	19
6	0	—	—	—	2	17	17	—	17
7	100	375	161	214	2	120	281	—	281
8	100	375	161	214	1	154	315	—	315
9	100	375	161	214	1	171	332	—	332
10	100	375	161	214	1	180	341	—	341
11	100	375	161	214	1	184	345	—	345
12	100	375	161	214	1	186	347	—	347
13	100	375	161	214	1	188	349	—	349
14	100	375	161	214	1	188	349	—	349
15	100	375	161	214	1	190	352	—	352
16	100	375	161	214	1	192	354	—	354
17	100	375	161	214	1	195	356	—	356
18	100	375	161	214	1	197	358	—	358
19	0	—	—	—	1	94	94	—	94
20	0	—	—	—	1	60	60	—	60
21	0	—	—	—	0	43	43	—	43
22	0	—	—	—	0	34	34	—	34
23	0	—	—	—	0	30	30	—	30
24	0	—	—	—	0	28	28	—	28
		4,501	1,936	2,566	100	2,566	4,501	—	4,501

weather data for July with the ground reflectivity assumed at $\rho_g = 0.2$. Sol-air temperature is calculated for the dark-colored wall as $\alpha/h_o = 0.30$, and for vertical surfaces, $\varepsilon\Delta R/h_o = 0$. (Note: when the city of the building is provided, this information can be collected from weather data charts [see Chapter 4 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition].)

The solar irradiance E_t on the wall must be determined.

Solar Angles:

ψ = southwest orientation = +60°

Σ = surface tilt from horizontal (where horizontal = 0°) = 90° for vertical wall surface

3:00 PM LST = hour 15

Calculate solar altitude, solar azimuth, surface solar azimuth, and incident angle as follows:
From Table 7, solar position data and constants for July 21 are

$$ET = -6.4 \text{ min}$$

$$\delta = 20.4°$$

$$E_o = 419.8 \text{ Btu/h}\cdot\text{ft}^2$$

Local standard meridian (LSM) for Eastern Time Zone = 75°

Apparent solar time AST

$$\begin{aligned} AST &= LST + ET/60 + (LSM - LON)/15 \\ &= 15 + (-6.4/60) + [(75 - 84.43)/15] \\ &= 14.2647 \end{aligned}$$

Hour angle H, degrees

$$\begin{aligned} H &= 15(AST - 12) \\ &= 15(14.2647 - 12) \\ &= 33.97° \end{aligned}$$

Solar altitude β

$$\begin{aligned} \sin\beta &= \cos L \cos\delta \cos H + \sin L \sin\delta \\ &= \cos(33.64)\cos(20.4)\cos(33.97) + \sin(33.64)\sin(20.4) \\ &= 0.841 \\ \beta &= \sin^{-1}(0.841) = 57.2° \end{aligned}$$

Solar azimuth ϕ

$$\begin{aligned} \cos\phi &= (\sin\beta \sin L - \sin\delta)/(\cos\beta \cos L) \\ &= [(\sin(57.2)\sin(33.64) - \sin(20.4)]/[\cos(57.2)\cos(33.64)] \\ &= 0.258 \\ \phi &= \cos^{-1}(0.253) = 75.05° \end{aligned}$$

Surface-solar azimuth γ

$$\begin{aligned} \gamma &= \phi - \psi \\ &= 75.05 - 60 \\ &= 15.05° \end{aligned}$$

Incident angle θ

$$\begin{aligned} \cos\theta &= \cos\beta \cos g \sin\Sigma + \sin\beta \cos\Sigma \\ &= \cos(57.2)\cos(15.05)\sin(90) + \sin(57.2)\cos(90) \\ &= 0.523 \\ \theta &= \cos^{-1}(0.523) = 58.45° \end{aligned}$$

Beam normal irradiance E_b

$$\begin{aligned} E_b &= E_o \exp(-\tau_b m^{ab}) \\ m &= \text{relative air mass} \\ &= 1/[\sin\beta + 0.50572(6.07995 + \beta)^{-1.6364}],\ \beta \text{ expressed in degrees} \\ &= 1.18905 \\ ab &= \text{beam air mass exponent} \\ &= 1.454 - 0.406\tau_b - 0.268\tau_d + 0.021\tau_b\tau_d \\ &= 0.713566 \\ E_b &= 419.8 \exp[-0.440(1.18905^{0.713566})] = 234.4 \text{ Btu/h·ft}^2 \end{aligned}$$

Surface beam irradiance $E_{t,b}$

$$\begin{aligned} E_{t,b} &= E_b \cos\theta \\ &= (234.4)\cos(58.5) = 122.7 \text{ Btu/h·ft}^2 \end{aligned}$$

Ratio Y of sky diffuse radiation on vertical surface to sky diffuse radiation on horizontal surface

$$\begin{aligned} Y &= 0.55 + 0.437\cos\theta + 0.313\cos^2\theta \\ &= 0.55 + 0.437\cos(58.45) + 0.313\cos^2(58.45) \\ &= 0.8644 \end{aligned}$$

Diffuse irradiance E_d – Horizontal surfaces

$$E_d = E_o \exp(-\tau_d m^{ad})$$

ad = diffuse air mass exponent

$= 0.507 + 0.205\tau_b - 0.080\,\tau_d - 0.190\,\tau_b\tau_d$

$= 0.245137$

$$E_d = E_o \exp(-\tau_d m^{ad})$$

$= 419.8 \exp[-2.066(1.8905^{0.245137})] = 48.6$ Btu/h·ft²

Diffuse irradiance E_d – Vertical surfaces

$E_{t,d} = E_d Y$

$= (48.6)(0.864) = 42.0$ Btu/h·ft

Ground reflected irradiance $E_{t,r}$

$E_{t,r} = (E_b \sin\beta + E_d)\rho_g(1 - \cos\Sigma)/2$

$= [234.4 \sin(57.2) + 48.6](0.2)[1 - \cos(90)]/2 = 24.6$ Btu/h·ft²

Total surface irradiance E_t

$E_t = E_D + E_d + E_r$

$= 122.7 + 42.0 + 24.6 = 189.3$ Btu/h·ft²

Sol-air temperature from Equation (1) (Table 16):

$T_e = t_o + \alpha E_t/h_o - \varepsilon\Delta R/h_o$

$= 91.6 + (0.30)(189.3) - 0 = 148.39$°F

This procedure is used to calculate the sol-air temperatures for each hour on each surface. Because of the tedious solar angle and intensity calculations, using a simple computer spreadsheet or other computer software can reduce the effort involved. A spreadsheet was used to calculate a 24-hour sol-air temperature profile for the data of this example. See Table 19 for the solar angle and intensity calculations and Table 20 for the sol-air temperatures for this wall surface and orientation.

Conductive heat gain is calculated using Equation (5-11) from Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition. First, calculate the 24-hour heat input profile using Equation (5-11) and the sol-air temperatures for a southwest-facing wall with dark exterior color:

$q_{i,1}$ = (0.077)(60)(73.9 – 75) = –5 Btu/h
$q_{i,2}$ = (0.077)(60)(73 – 75) = –9
$q_{i,3}$ = (0.077)(60)(72.4 – 75) = –12
$q_{i,4}$ = (0.077)(60)(71.8 – 75) = –15
$q_{i,5}$ = (0.077)(60)(71.4 – 75) = –17
$q_{i,6}$ = (0.077)(60)(72.8 – 75) = –10
$q_{i,7}$ = (0.077)(60)(77.4 – 75) = 11
$q_{i,8}$ = (0.077)(60)(84.1 – 75) = 42
$q_{i,9}$ = (0.077)(60)(90.8 – 75) = 73
$q_{i,10}$ = (0.077)(60)(96.7 – 75) = 100
$q_{i,11}$ = (0.077)(60)(101.5 – 75) = 122
$q_{i,12}$ = (0.077)(60)(105.5 – 75) = 141
$q_{i,13}$ = (0.077)(60)(122.4 – 75) = 219
$q_{i,14}$ = (0.077)(60)(139.6 – 75) = 298
$q_{i,15}$ = (0.077)(60)(150.7 – 75) = 350
$q_{i,16}$ = (0.077)(60)(153.7 – 75) = 363
$q_{i,17}$ = (0.077)(60)(147.7 – 75) = 336
$q_{i,18}$ = (0.077)(60)(131.7 – 75) = 262
$q_{i,19}$ = (0.077)(60)(103.1 – 75) = 130
$q_{i,20}$ = (0.077)(60)(81.7 – 75) = 31
$q_{i,21}$ = (0.077)(60)(79.8 – 75) = 22
$q_{i,22}$ = (0.077)(60)(78.0 – 75) = 14
$q_{i,23}$ = (0.077)(60)(76.5 – 75) = 7
$q_{i,24}$ = (0.077)(60)(75.1 – 75) = 0

Table 19 Conduction: Wall Component of Solar Irradiance (Month 7)

						Direct Beam Solar			Diffuse Solar Heat Gain					
Local Std. Hour	Apparent Solar Time	Hour Angle H	Solar Altitude β	Solar Azimuth ϕ	Solar Air Mass m	Beam Normal E_b, Btu/h·ft²	Surface Incident Angle θ	Surface Direct, Btu/h·ft²	Diffuse Horizontal E_d, Btu/h·ft²	Ground Diffuse, Btu/h·ft²	Y Ratio	Sky Diffuse, Btu/h·ft²	Subtotal Diffuse, Btu/h·ft²	Total Surface Irradiance, Btu/h·ft²
1	0.26	–176	–36	–175	—	0.0	117.4	0.0	0.0	0.0	0.4500	0.0	0.0	0.0
2	1.26	–161	–33	–159	—	0.0	130.9	0.0	0.0	0.0	0.4500	0.0	0.0	0.0
3	2.26	–146	–27	–144	—	0.0	144.5	0.0	0.0	0.0	0.4500	0.0	0.0	0.0
4	3.26	–131	–19	–132	—	0.0	158.1	0.0	0.0	0.0	0.4500	0.0	0.0	0.0
5	4.26	–116	–9	–122	—	0.0	171.3	0.0	0.0	0.0	0.4500	0.0	0.0	0.0
6	5.26	–101	3	–113	16.91455	8.7	172.5	0.0	6.7	0.7	0.4500	3.0	3.7	3.7
7	6.26	–86	14	–105	3.98235	105.6	159.5	0.0	23.1	4.9	0.4500	10.4	15.3	15.3
8	7.26	–71	27	–98	2.22845	168.6	145.9	0.0	34.0	10.9	0.4500	15.3	26.2	26.2
9	8.26	–56	39	–90	1.58641	205.2	132.3	0.0	41.5	17.1	0.4500	18.7	35.8	35.8
10	9.26	–41	51	–81	1.27776	227.3	118.8	0.0	46.8	22.5	0.4500	21.1	43.5	43.5
11	10.26	–26	63	–67	1.11740	240.4	105.6	0.0	50.2	26.5	0.4553	22.9	49.4	49.4
12	11.26	–11	74	–39	1.04214	247.0	92.6	0.0	52.1	28.9	0.5306	27.6	56.5	56.5
13	12.26	4	76	16	1.02872	248.2	80.2	42.1	52.4	29.4	0.6332	33.2	62.6	104.7
14	13.26	19	69	57	1.07337	244.2	68.7	88.9	51.3	27.9	0.7505	38.5	66.4	155.2
15	14.2647	33.97	57.2	75.05	1.18905	234.4	58.45	122.7	48.6	24.6	0.8644	42.0	66.6	189.3
16	15.26	49	45	86	1.41566	217.0	50.4	138.3	44.3	19.7	0.9555	42.3	62.0	200.3
17	16.26	64	32	94	1.86186	188.2	45.8	131.3	37.9	13.9	1.0073	38.1	52.0	183.3
18	17.26	79	20	102	2.89735	139.7	45.5	97.9	28.7	7.7	1.0100	29.0	36.7	134.6
19	18.26	94	8	109	6.84406	55.0	49.7	35.6	15.3	2.3	0.9631	14.8	17.1	52.6
20	19.26	109	–3	117	—	0.0	57.5	0.0	0.0	0.0	0.8755	0.0	0.0	0.0
21	20.26	124	–14	127	—	0.0	67.5	0.0	0.0	0.0	0.7630	0.0	0.0	0.0
22	21.26	139	–23	138	—	0.0	79.0	0.0	0.0	0.0	0.6452	0.0	0.0	0.0
23	22.26	154	–30	151	—	0.0	91.3	0.0	0.0	0.0	0.5403	0.0	0.0	0.0
24	23.26	169	–35	167	—	0.0	104.2	0.0	0.0	0.0	0.4618	0.0	0.0	0.0

Next, calculate wall heat gain using conduction time series. The preceding heat input profile is used with conduction time series to calculate the wall heat gain. From Table 4, the most similar wall construction is wall number 1. This is a spandrel glass wall that has similar mass and thermal capacity. Using Equation (2), which was introduced in Table 16, the conduction time factors for wall 1 can be used in conjunction with the 24-hour heat input profile to determine the wall heat gain at 3:00 PM LST:

$$q_{15} = c_0 q_{i,15} + c_1 q_{i,14} + c_2 q_{i,13} + c_3 q_{i,12} + \cdots + c_{23} q_{i,16}$$

$$= (0.18)(350) + (0.58)(298) + (0.20)(219) + (0.04)(141) + (0.00)(122) + (0.00)(100)$$
$$+ (0.00)(73) + (0.00)(42) + (0.00)(11) + (0.00)(-10) + (0.00)(-17) + (0.00)(-15)$$
$$+ (0.00)(-12) + (0.00)(-9) + (0.00)(-5) + (0.00)(0) + (0.00)(7) + (0.00)(14) + (0.00)(22)$$
$$+ (0.00)(31) + (0.00)(130) + (0.00)(262) + (0.00)(336) + (0.00)(363) = 285 \text{ Btu/h}$$

Because of the tedious calculations involved, a spreadsheet is used to calculate the remainder of a 24-hour heat gain profile indicated in Table 20 for the data of this example.

Finally, calculate wall cooling load using radiant time series. Total cooling load for the wall is calculated by summing the convective and radiant portions. The convective portion is simply the wall heat gain for the

Table 20 Conduction: Wall Component of Sol-Air Temperatures, Heat Input, Heat Gain, Cooling Load (Month 7)

Local Std. Hour	Total Surface Irradiance, Btu/h·ft²	Outdoor Temp., °F	Sol-Air Temp., °F	Indoor Temp., °F	Heat Input, Btu/h	CTS Type 1, %	Heat Gain, Btu/h Total	Heat Gain, Btu/h Convective 54%	Heat Gain, Btu/h Radiant 46%	Nonsolar RTS Zone Type 8, %	Radiant Cooling Load, Btu/h	Total Cooling Load, Btu/h
1	0.0	73.8	73.8	75	–6	18	1	1	1	49	15	16
2	0.0	73.0	73.0	75	–9	57	–4	–2	–2	17	12	10
3	0.0	72.4	72.4	75	–12	20	–8	–5	–4	9	10	5
4	0.0	71.8	71.8	75	–15	4	–12	–6	–5	5	8	2
5	0.0	71.4	71.4	75	–17	1	–14	–8	–7	3	7	–1
6	3.7	71.8	72.9	75	–10	0	–15	–8	–7	2	6	–2
7	15.3	73.2	77.8	75	13	0	–7	–4	–3	2	6	3
8	26.2	76.7	84.6	75	44	0	13	7	6	1	11	18
9	35.8	80.5	91.2	75	75	0	41	22	19	1	18	40
10	43.5	83.9	97.0	75	101	0	70	38	32	1	27	65
11	49.4	87.0	101.8	75	124	0	97	52	45	1	36	88
12	56.5	89.0	106.0	75	143	0	120	65	55	1	43	108
13	104.7	90.6	122.0	75	217	0	150	81	69	1	53	134
14	155.2	91.6	138.2	75	292	0	211	114	97	1	70	184
15	189.3	91.6	148.4	75	339	0	278	150	128	1	91	241
16	200.3	90.4	150.5	75	349	0	325	175	149	1	111	286
17	183.3	88.8	143.8	75	318	0	337	182	155	1	122	305
18	134.6	86.8	127.2	75	241	0	311	168	143	1	122	290
19	52.6	83.7	99.5	75	113	0	238	129	110	1	108	237
20	0.0	81.5	81.5	75	30	0	134	72	62	1	80	153
21	0.0	79.7	79.7	75	22	0	56	30	26	0	53	84
22	0.0	77.9	77.9	75	13	0	28	15	13	0	36	51
23	0.0	76.5	76.5	75	7	0	16	9	7	0	26	35
24	0.0	75.0	75.0	75	0	0	8	4	4	0	20	24

hour being calculated times the convective fraction for walls from Table 14 of Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals* (54%):

$$Q_c = (285)(0.54) = 154 \text{ Btu/h}$$

The radiant portion of the cooling load is calculated using conductive heat gains for the current and past 23 h, the radiant fraction for walls from Table 14 of Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals* (46%), and radiant time series from Table 14 of this online material. Select the RTS for medium-weight construction, assuming 50% glass and carpeted floors as representative for the described construction. Use the wall heat gains from Table 14 for 24-hour design conditions in July. Thus, the radiant cooling load for the wall at 3:00 PM is

$$Q_{r,15} = r_0(0.46)q_{i,15} + r_1(0.46)\, q_{i,14} + r_2(0.46)\, q_{i,13} + r_3(0.46)\, q_{i,12} + \cdots + r_{23}(0.46)\, q_{i,16}$$

$$\begin{aligned} &= (0.49)(0.46)(285) + (0.17)(0.46)(214) + (0.09)(0.46)(150) + (0.05)(0.46)(119) \\ &+ (0.03)(0.46)(96) + (0.02)(0.46)(69) + (0.02)(0.46)(39) + (0.01)(0.46)(11) \\ &+ (0.01)(0.46)(-8) + (0.01)(0.46)(-15) + (0.01)(0.46)(-14) + (0.01)(0.46)(-12) \\ &+ (0.01)(0.46)(-9) + (0.01)(0.46)(-4) + (0.01)(0.46)(1) + (0.01)(0.46)(8) \\ &+ (0.01)(0.46)(15) + (0.01)(0.46)(27) + (0.01)(0.46)(58) + (0.01)(0.46)(147) \\ &+ (0.00)(0.46)(257) + (0.00)(0.46)(329) + (0.00)(0.46)(353) + (0.00)(0.46)(337) = 93 \text{ Btu/h} \end{aligned}$$

The total wall cooling load at the designated hour is thus

$$Q_{wall} = Q_c + Q_{r15} = 154 + 93 = 247 \text{ Btu/h}$$

Again, a simple computer spreadsheet or other software is necessary to reduce the effort involved. A spreadsheet was used with the heat gain profile to split the heat gain into convective and radiant portions, apply RTS to the radiant portion, and total the convective and radiant loads to determine a 24-hour cooling load profile for this example, with results in Table 20.

Part 3. Window cooling load using radiant time series. Calculate the cooling load contribution, with and without indoor shading (venetian blinds) for the window area facing 60° west of south at 3:00 PM in July for the conference room example.

Solution: First, calculate the 24-hour heat gain profile for the window, then split those heat gains into radiant and convective portions, apply the appropriate RTS to the radiant portion, then sum the convective and radiant cooling load components to determine total window cooling load for the time. The window heat gain components are calculated. From Part 2, at hour 15 LST (3:00 PM):

E_B = 133.6 Btu/h·ft^2
E_D = 36.6 Btu/h·ft^2
E_r = 25.7 Btu/h·ft^2
θ = 58.45°

From Table 5-6 of Chapter 5 of *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition, for glass type 5d,

$$\text{SHGC}(\theta) = \text{SHGC}(58.45) = 0.3978 \text{ (interpolated)}$$

$$\langle \text{SHGC} \rangle_D = 0.41$$

From Table 14B of Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals* for light-colored blinds (assumed louver reflectance = 0.8 and louvers positioned at 45° angle) on double-glazed, heat-absorbing windows, IAC(0) = 0.74, IAC(60) = 0.65, IAC(diff) = 0.79, and radiant fraction = 0.54. Without blinds, IAC = 1.0. Therefore, window heat gain components for hour 15, without blinds, are

$$q_{b15} = AE_{t,b}\,\text{SHGC}(\theta)(\text{IAC}) = (40)(133.6)(0.3978)(1.00) = 2126 \text{ Btu/h}$$

$$q_{d15} = A(E_{t,d} + E_r)\langle \text{SHGC} \rangle_D(\text{IAC}) = (40)(36.6 + 25.7)(0.41)(1.00) = 1021 \text{ Btu/h}$$

$$q_{c15} = UA(t_{out} - t_{in}) = (0.56)(40)(91.9 - 75) = 379 \text{ Btu/h}$$

This procedure is repeated to determine these values for a 24-hour heat gain profile, shown in Table 13 (included in the Resources section at the end of this online material).

Total cooling load for the window is calculated by summing the convective and radiant portions. For windows with indoor shading (blinds, drapes, etc.), the direct beam, diffuse, and conductive heat gains may be summed and treated together in calculating cooling loads. However, in this example, the window does not have indoor shading, and the direct beam solar heat gain should be treated separately from the diffuse and conductive heat gains. The direct beam heat gain, without indoor shading, is treated as 100% radiant, and solar RTS factors from Table 13 are used to convert the beam heat gains to cooling loads. The diffuse and conductive heat gains can be totaled and split into radiant and convective portions according to Table 14 of Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*, and nonsolar RTS factors from Table 14 of this online material (included in the Resources section at the end of this online material) are used to convert the radiant portion to cooling load.

The solar beam cooling load is calculated using heat gains for the current hour and past 23 hours and radiant time series from Table 13. From Table 13, select the solar RTS for medium-weight construction, assuming 50% glass and carpeted floors for this example. Using Table 21 values for direct solar heat gain, the radiant cooling load for the window direct beam solar component is

$$Q_{b,15} = r_0 q_{b,15} + r_1 q_{b,14} + r_2 q_{b,13} + r_3 q_{b,12} + \cdots + r_{23} q_{b,16}$$

$$\begin{aligned}
&= (0.54)(2126) + (0.16)(1234) + (0.08)(302) + (0.04)(0) + (0.03)(0) + (0.02)(0) + (0.01)(0) \\
&+ (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.01)(0) \\
&+ (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.01)(0) + (0.00)(0) + (0.00)(865) \\
&+ (0.00)(2080) + (0.00)(2656) + (0.00)(2670) = 1370 \text{ Btu/h}
\end{aligned}$$

This process is repeated for other hours; results are listed in Table 22.

Table 21 Window Component of Heat Gain (No Blinds or Overhang) (Month 7)

	Beam Solar Heat Gain						Diffuse Solar Heat Gain							Conduction		
Local Std. Hour	Beam Normal, Btu/h·ft²	Surface Incident Angle	Surface Beam, Btu/h·ft²	Beam SHGC	Adjusted Beam IAC	Beam Solar Heat Gain, Btu/h	Diffuse Horiz. E_d, Btu/h·ft²	Ground Diffuse, Btu/h·ft²	Y Ratio	Sky Diffuse, Btu/h·ft²	Subtotal Diffuse, Btu/h·ft²	Hemis. SHGC	Diff. Solar Heat Gain, Btu/h	Outside Temp., °F	Conduction Heat Gain, Btu/h	Total Window Heat Gain, Btu/h
1	0.0	117.4	0.0	0.000	1.000	0	0.0	0.0	0.4500	0.0	0.0	0.410	0	73.9	–25	–25
2	0.0	130.9	0.0	0.000	1.000	0	0.0	0.0	0.4500	0.0	0.0	0.410	0	73.0	–45	–45
3	0.0	144.5	0.0	0.000	1.000	0	0.0	0.0	0.4500	0.0	0.0	0.410	0	72.4	–58	–58
4	0.0	158.1	0.0	0.000	1.000	0	0.0	0.0	0.4500	0.0	0.0	0.410	0	71.8	–72	–72
5	0.0	171.3	0.0	0.000	1.000	0	0.0	0.0	0.4500	0.0	0.0	0.410	0	71.4	–81	–81
6	16.5	172.5	0.0	0.000	0.000	0	5.7	0.6	0.4500	2.6	3.2	0.410	52	71.8	–72	–19
7	130.7	159.5	0.0	0.000	0.000	0	19.8	5.2	0.4500	8.9	14.1	0.410	231	73.2	–40	191
8	193.5	145.9	0.0	0.000	0.000	0	29.3	11.6	0.4500	13.2	24.8	0.410	406	76.7	38	444
9	228.3	132.3	0.0	0.000	0.000	0	36.0	18.0	0.4500	16.2	34.2	0.410	560	80.6	125	686
10	248.8	118.8	0.0	0.000	0.000	0	40.7	23.5	0.4500	18.3	41.8	0.410	686	84.1	204	890
11	260.9	105.6	0.0	0.000	0.000	0	43.8	27.7	0.4553	19.9	47.6	0.410	781	87.2	273	1055
12	266.9	92.6	0.0	0.000	0.000	0	45.4	30.1	0.5306	24.1	54.2	0.410	890	89.2	318	1208
13	268.0	80.2	45.5	0.166	1.000	302	45.7	30.6	0.6332	29.0	59.6	0.410	977	90.9	356	1635
14	264.3	68.7	96.2	0.321	1.000	1234	44.7	29.1	0.7505	33.6	62.7	0.410	1028	91.9	379	2640
15	255.3	58.4	133.6	0.398	1.000	2126	42.3	25.7	0.8644	36.6	62.3	0.410	1021	91.9	379	3526
16	239.2	50.4	152.4	0.438	1.000	2670	38.4	20.7	0.9555	36.7	57.4	0.410	942	90.7	352	3964
17	212.2	45.8	148.1	0.448	1.000	2656	32.7	14.6	1.0073	33.0	47.6	0.410	781	89.0	314	3751
18	165.3	45.5	115.8	0.449	1.000	2080	24.7	8.1	1.0100	24.9	33.1	0.410	542	87.0	269	2892
19	76.0	49.7	49.1	0.441	1.000	865	13.0	2.4	0.9631	12.5	14.9	0.410	244	83.9	199	1309
20	0.0	57.5	0.0	0.403	0.000	0	0.0	0.0	0.8755	0.0	0.0	0.410	0	81.7	150	150
21	0.0	67.5	0.0	0.330	0.000	0	0.0	0.0	0.7630	0.0	0.0	0.410	0	79.8	108	108
22	0.0	79.0	0.0	0.185	0.000	0	0.0	0.0	0.6452	0.0	0.0	0.410	0	78.0	67	67
23	0.0	91.3	0.0	0.000	1.000	0	0.0	0.0	0.5403	0.0	0.0	0.410	0	76.5	34	34
24	0.0	104.2	0.0	0.000	1.000	0	0.0	0.0	0.4618	0.0	0.0	0.410	0	75.1	2	2

For diffuse and conductive heat gains, the radiant fraction according to Table 14 of Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals* is 46%. The radiant portion is processed using nonsolar RTS coefficients from Table 14 of this online material. The results are listed in Tables 20 and 21. For 3:00 PM, the diffuse and conductive cooling load is 1297 Btu/h.

The total window cooling load at the designated hour is thus

$$Q_{window} = Q_b + Q_{diff + cond} = 1370 + 1297 = 2667 \text{ Btu/h}$$

Again, a computer spreadsheet or other software is commonly used to reduce the effort involved in calculations. The spreadsheet shown in Table 21 is expanded in Table 22 to include splitting the heat gain into convective and radiant portions, applying RTS to the radiant portion, and totaling the convective and radiant loads to determine a 24-hour cooling load profile for a window without indoor shading.

If the window has an indoor shading device, it is accounted for with the indoor attenuation coefficients (IAC), the radiant fraction, and the RTS type used. If a window has no indoor shading, 100% of the direct beam energy is assumed to be radiant and solar RTS factors are used. However, if an indoor shading device is present, the direct beam is assumed to be interrupted by the shading device, and a portion immediately

Table 22 Window Component of Cooling Load (No Blinds or Overhang)

	Unshaded Direct Beam Solar (if AC = 1)						Shaded Direct Beam (AC < 1.0) + Diffuse + Conduction									
Local Std. Hour	Beam Heat Gain, Btu/h	Con-vective 0%, Btu/h	Radiant 100%, Btu/h	Solar RTS, Zone Type 8, %	Radiant Btu/h	Cooling Load, Btu/h	Beam Heat Gain, Btu/h	Diffuse Heat Gain, Btu/h	Con-duction Heat Gain, Btu/h	Total Heat Gain, Btu/h	Con-vective 54%, Btu/h	Radiant 46%, Btu/h	Nonsolar RTS, Zone Type 8	Radiant Btu/h	Cooling Load, Btu/h	Window Cooling Load, Btu/h
1	0	0	0	54	119	119	0	0	–25	–25	–13	–11	49%	59	45	165
2	0	0	0	16	119	119	0	0	–45	–45	–24	–21	17%	49	24	144
3	0	0	0	8	119	119	0	0	–58	–58	–31	–27	9%	41	9	129
4	0	0	0	4	119	119	0	0	–72	–72	–39	–33	5%	32	–6	113
5	0	0	0	3	119	119	0	0	–81	–81	–44	–37	3%	25	–19	100
6	0	0	0	2	119	119	0	52	–72	–19	–10	–9	2%	32	22	141
7	0	0	0	1	119	119	0	231	–40	191	103	88	2%	78	181	301
8	0	0	0	1	116	116	0	406	38	444	240	204	1%	148	388	504
9	0	0	0	1	104	104	0	560	125	686	370	315	1%	225	596	700
10	0	0	0	1	83	83	0	686	204	890	481	409	1%	300	780	863
11	0	0	0	1	56	56	0	781	273	1055	569	485	1%	365	935	991
12	0	0	0	1	29	29	0	890	318	1208	652	556	1%	426	1078	1108
13	302	0	302	1	172	172	0	977	356	1333	720	613	1%	480	1200	1372
14	1234	0	1234	1	715	715	0	1028	379	1406	759	647	1%	521	1281	1995
15	2126	0	2126	1	1370	1370	0	1021	379	1400	756	644	1%	541	1297	2666
16	2670	0	2670	1	1893	1893	0	942	352	1294	699	595	1%	530	1229	3122
17	2656	0	2656	1	2090	2090	0	781	314	1094	591	503	1%	487	1078	3168
18	2080	0	2080	1	1890	1890	0	542	269	811	438	373	1%	411	849	2739
19	865	0	865	1	1211	1211	0	244	199	444	240	204	1%	302	542	1753
20	0	0	0	0	549	549	0	0	150	150	81	69	1%	196	277	826
21	0	0	0	0	322	322	0	0	108	108	58	49	0%	145	203	525
22	0	0	0	0	213	213	0	0	67	67	36	31	0%	112	148	361
23	0	0	0	0	157	157	0	0	34	34	18	15	0%	89	107	265
24	0	0	0	0	128	128	0	0	2	2	1	1	0%	72	73	201

becomes cooling load by convection. Also, the energy is assumed to be radiated to all surfaces of the room, therefore nonsolar RTS values are used to convert the radiant load into cooling load.

IAC values depend on several factors: (1) type of shading device, (2) position of shading device relative to window, (3) reflectivity of shading device, (4) angular adjustment of shading device, as well as (5) solar position relative to the shading device. These factors are discussed in detail in Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals*. For this example with venetian blinds, the IAC for beam radiation is treated separately from the diffuse solar gain. The direct beam IAC must be adjusted based on the profile angle of the sun. At 3:00 PM in July, the profile angle of the sun relative to the window surface is 58°. Calculated using Equation (39) from Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals*, the beam IAC = 0.653. The diffuse IAC is 0.79. Thus, the window heat gains, with light-colored blinds, at 3:00 PM are

$$q_{b15} = AE_D\,\mathrm{SHGC}(\theta)(\mathrm{IAC}) = (40)(133.6)(0.3978)(0.653) = 1388 \text{ Btu/h}$$

$$q_{d15} = A(E_d + E_r)\langle\mathrm{SHGC}\rangle_D(\mathrm{IAC})_D = (40)(36.6 + 25.7)(0.41)(0.79) = 807 \text{ Btu/h}$$

$$q_{c15} = UA(t_{out} - t_{in}) = (0.56)(40)(91.9 - 75) = 379 \text{ Btu/h}$$

Because the same radiant fraction and nonsolar RTS are applied to all parts of the window heat gain when indoor shading is present, those loads can be totaled and the cooling load calculated after splitting the radiant

Table 23 Window Component of Cooling Load (With Blinds, No Overhang)

	Unshaded Direct Beam Solar (if AC = 1)						Shaded Direct Beam (AC < 1.0) + Diffuse + Conduction									
Local Std. Hour	Beam Heat Gain, Btu/h	Convective 0%, Btu/h	Radiant 100%, Btu/h	Solar RTS, Zone Type 8, %	Radiant Btu/h	Cooling Load, Btu/h	Beam Heat Gain, Btu/h	Diffuse Heat Gain, Btu/h	Conduction Heat Gain, Btu/h	Total Heat Gain, Btu/h	Convective 54%, Btu/h	Radiant 46%, Btu/h	Nonsolar RTS, Zone Type 8	Radiant, Btu/h	Cooling Load, Btu/h	Window Cooling Load, Btu/h
1	0	0	0	1	0	0	0	0	–25	–25	–11	–13	49%	105	94	94
2	0	0	0	0	0	0	0	0	–45	–45	–21	–24	17%	90	70	70
3	0	0	0	0	0	0	0	0	–58	–58	–27	–31	9%	81	54	54
4	0	0	0	0	0	0	0	0	–72	–72	–33	–39	5%	72	39	39
5	0	0	0	0	0	0	0	0	–81	–81	–37	–44	3%	63	26	26
6	0	0	0	0	0	0	0	41	–72	–30	–14	–16	2%	70	56	56
7	0	0	0	0	0	0	0	183	–40	143	66	77	2%	114	180	180
8	0	0	0	0	0	0	0	321	38	359	165	194	1%	183	348	348
9	0	0	0	0	0	0	0	443	125	568	261	307	1%	260	522	522
10	0	0	0	0	0	0	0	542	204	746	343	403	1%	331	674	674
11	0	0	0	0	0	0	0	617	273	891	410	481	1%	391	801	801
12	0	0	0	0	0	0	0	703	318	1021	470	551	1%	443	913	913
13	0	0	0	0	0	0	196	772	356	1325	609	715	1%	540	1149	1149
14	0	0	0	0	0	0	802	812	379	1992	916	1076	1%	751	1668	1668
15	0	0	0	0	0	0	1388	807	379	2574	1184	1390	1%	987	2171	2171
16	0	0	0	0	0	0	1784	744	352	2880	1325	1555	1%	1170	2495	2495
17	0	0	0	0	0	0	1816	617	314	2747	1263	1483	1%	1221	2484	2484
18	0	0	0	0	0	0	1458	428	269	2156	992	1164	1%	1103	2094	2094
19	0	0	0	0	0	0	624	193	199	1017	468	549	1%	774	1242	1242
20	0	0	0	0	0	0	0	0	150	150	69	81	1%	434	503	503
21	0	0	0	0	0	0	0	0	108	108	49	58	0%	290	339	339
22	0	0	0	0	0	0	0	0	67	67	31	36	0%	209	240	240
23	0	0	0	0	0	0	0	0	34	34	15	18	0%	160	176	176
24	0	0	0	0	0	0	0	0	2	2	1	1	0%	128	129	129

portion for processing with nonsolar RTS. This is shown by the spreadsheet results in Table 23. The total window cooling load with venetian blinds at 3:00 PM = 2171 Btu/h.

Part 4. Window cooling load using radiant time series for window with overhang shading. Calculate the cooling load contribution for the previous example with the addition of a 10 ft overhang shading the window.

Solution: In Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals*, methods are described and examples provided for calculating the area of a window shaded by attached vertical or horizontal projections. For 3:00 PM LST IN July, the solar position calculated in previous examples is

Solar altitude $\beta = 57.2°$

Solar azimuth $\phi = 75.1°$

Surface-solar azimuth $\gamma = 15.1°$

From Equation (32) of Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals*, profile angle Ω is calculated by

$$\tan\Omega = \tan\beta/\cos\gamma = \tan(57.2)/\cos(15.1) = 1.6087$$

$$\Omega = 58.1°$$

Table 24 Window Component of Cooling Load (With Blinds and Overhang)

	Overhang and Fins Shading					Shaded Direct Beam (AC < 1.0) + Diffuse + Conduction									
Local Std. Hour	Surface Solar Azimuth	Profile Angle	Shadow Width, ft	Shadow Height, ft	Direct Sunlit Area, ft^2	Beam Heat Gain, Btu/h	Diffuse Heat Gain, Btu/h	Con-duction Heat Gain, Btu/h	Total Heat Gain, Btu/h	Con-vective 54%, Btu/h	Radiant 46%, Btu/h	Nonsolar RTS, Zone Type 8	Radiant, Btu/h	Cooling Load, Btu/h	Window Cooling Load, Btu/h
1	–235	52	0.0	0.0	0.0	0	0	–25	–25	–13	–11	49%	55	42	42
2	–219	40	0.0	0.0	0.0	0	0	–45	–45	–24	–21	17%	43	19	19
3	–204	29	0.0	0.0	0.0	0	0	–58	–58	–31	–27	9%	36	4	4
4	–192	19	0.0	0.0	0.0	0	0	–72	–72	–39	–33	5%	28	–11	–11
5	–182	9	0.0	0.0	0.0	0	0	–81	–81	–44	–37	3%	20	–23	–23
6	–173	–3	0.0	0.0	0.0	0	41	–72	–30	–16	–14	2%	26	10	10
7	–165	–15	0.0	0.0	0.0	0	183	–40	143	77	66	2%	64	141	141
8	–158	–28	0.0	0.0	0.0	0	321	38	359	194	165	1%	122	316	316
9	–150	–43	0.0	0.0	0.0	0	443	125	568	307	261	1%	189	496	496
10	–141	–58	0.0	0.0	0.0	0	542	204	746	403	343	1%	253	656	656
11	–127	–73	0.0	0.0	0.0	0	617	273	891	481	410	1%	310	791	791
12	–99	–87	0.0	0.0	0.0	0	703	318	1021	551	470	1%	363	914	914
13	–44	80	0.0	6.4	0.0	0	772	356	1128	609	519	1%	409	1018	1018
14	–3	69	0.0	6.4	0.0	0	812	379	1190	643	548	1%	443	1085	1085
15	15	58	0.0	6.4	0.0	0	807	379	1186	640	545	1%	457	1098	1098
16	26	48	0.0	6.4	0.0	0	744	352	1096	592	504	1%	449	1040	1040
17	34	38	0.0	6.4	0.0	0	617	314	930	502	428	1%	412	915	915
18	42	26	0.0	4.9	18.9	344	428	269	1041	562	479	1%	427	990	990
19	49	12	0.0	2.2	53.0	414	193	199	806	435	371	1%	380	816	816
20	57	–6	0.0	0.0	0.0	0	0	150	150	81	69	1%	219	300	300
21	67	–32	0.0	0.0	0.0	0	0	108	108	58	49	0%	154	212	212
22	78	–64	0.0	0.0	0.0	0	0	67	67	36	31	0%	113	150	150
23	91	87	0.0	0.0	0.0	0	0	34	34	18	15	0%	87	106	106
24	107	67	0.0	0.0	0.0	0	0	2	2	1	1	0%	70	71	71

From Equation (34) of Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals*, shadow height S_H is

$$S_H = P_H \tan\Omega = 10(1.6087) = 16.1 \text{ ft}$$

Because the window is 6.4 ft tall, at 3:00 PM the window is completely shaded by the 10 ft (deep overhang. Thus, the shaded window heat gain includes only diffuse solar and conduction gains. This is converted to cooling load by separating the radiant portion, applying RTS, and adding the resulting radiant cooling load to the convective portion to determine total cooling load. Those results are in Table 24. The total window cooling load = 1098 Btu/h.

Part 5. Room cooling load total. Calculate the sensible cooling loads for the previously described office at 3:00 PM in July.

Solution: The steps in the previous example parts are repeated for each of the internal and external loads components, including the southeast-facing window, spandrel and brick walls, the southwest-facing brick wall, the roof, people, and equipment loads. The results are tabulated in Table 25. The total room sensible cooling load for the office is 3674 Btu/h (at 3:00 PM in July. When this calculation process is repeated for a 24-hour design day for each month, it is found that the peak room sensible cooling load actually occurs in July at hour 14 (2:00 PM solar time) at 3675 Btu/h as indicated in Table 26.

Table 25 Single-Room Example Cooling Load (July 3:00 PM) for Example Office Building

2017 ASHRAE FUNDAMENTALS EXAMPLE-IP UNITS						rev 2016-07-31		02-Aug-16
	Burdell Engineering Associates						George P. Burdell, P.E.	
09N021	ASHRAE Example Office Building							Atlanta, Georgia
ROOM NO./NAME:		215B	Office Example - July 3 pm - not peak - Table 34					
	Length:	13	feet				Infiltration cfm	
	Width:	10	feet	Area	130	sq. feet	Cooling:	Heating:
	Ceiling Height:	9	feet	Volume	1170	cubic feet	0	19.5
INTERNAL LOADS:			Btuh/person:	Lighting,	Equipment,	Inside Design Conditions:		
		# People:	Sensible:	watts:	watts:	Cooling:	DB, F	75
	Over-ride Room Input:	1	250	110	130		RH	50%
	Default:	1	Latent:	143	130	Heating:	DB, F	72
	Use:	1	200	110	130	Outside Cooling Weather:		
EXPOSURES:		North	South	East	West	A - GA - ATLANTA HARTSFIELD-JACKSON - 5%		
	Nominal Azimuth:	-180	0	-90	90	Heating 99.6%, F:		21.9
	Actual Azimuth:	-210	-30	-120	60	Supply	Cooling, F	57
	Tilt:	90	90	90	90	Air:	Heating, F	100
	Type 1 Wall Area, sf:	0	60	0	40	Brick pilasters		
	Type 2 Wall Area, sf:	0	60	0	60	Spandrel panels		
	No. Type 1 Windows:	0	0	0	0	Dbl glazed, low-E, bronze		
	No. Type 2 Windows:	0	1	0	1	Dbl glz, low-E, brnz 10' ohng		
	Roof Area, sf:	130	30%	= Roof % to RA		26%	= Lights % to RA	
ROOM LOADS:		Peak Rm.Sens. Occurs:			Room	Ret. Air	Room	Room
		Month:	7	Per Unit	Sensible	Sensible	Latent	Sensible
		Hour:	15	Cooling	Cooling:	Cooling:	Cooling	Heating:
INTERNAL LOADS:			No. People:	Btuh/pers	Btuh	Btuh	Btuh	Btuh
		People:	1	234	234		200	
			watts:	Btuh/room sf				
		Lighting:	110	2.0	263			
	Lighting % to RA:		26%	0.7		92		
		Equipment:	130	3.3	429			
ENVELOPE LOADS:								
			Roof Area,sf	Btuh/roof sf				
ROOF:	0.032	U factor	130	1.0	132			208
		Roof % to RA:	30%			57		
WALLS:			Wall Area,sf	Btuh/wall sf				
	Wall Type 1:	Brick pilasters						
0.08	U factor	North	0	0.0	-			-
		South	60	1.7	103			240
		East	0	0.0	-			-
		West	40	1.2	47			160
	Wall Type 2	Spandrel panels						
0.077	U factor	North	0	0.0	-			-
		South	60	2.9	173			231
		East	0	0.0	-			-
		West	60	4.0	241			231
WINDOWS:			Window Area,sf:	Btuh/win sf				
	Window Type 1:	Dbl glazed, low-E, bronze						
40	sf/window	North	0	0.0	-			-
49%	SHGF(0)	South	0	0.0	-			-
0.56	U factor	East	0	0.0	-			-
74%	IAC	West	0	0.0	-			-
	Window Type 2:	Dbl glz, low-E, brnz 10' ohng						
40	sf/window	North	0	0.0	-			-
49%	SHGF(0)	South	40	24.1	962			1,122
0.56	U factor	East	0	0.0	-			-
74%	IAC	West	40	28.5	1,141			1,122
INFILTRATION LOADS:			cfm	Btuh/cfm				
		Cooling, Sensible:	0	0.0	-			
		Cooling, Latent:	0	0.0			-	
		Heating:	19.5	55.1				1,075
					-----	-----	-----	-----
			ROOM LOAD TOTALS =		3,724	149	200	4,391
			COOLING CFM =		188	HEATING CFM =		143
				CFM/SF =	1.4			
BLOCK LOADS:		TOTAL ROOM SENS+RA+LATENT =			4,073		ROOM HTG:	4,391
Peak Block Load Occurs:		OUTSIDE AIR:		OA Sensible:	-		OA Heating:	-
Month:	7	OA cfm =	0	OA Latent:	-			-----
Hour:	15	FAN HEAT:	0	HP to S. Air:	-	TOT HEATING,btuh=		4,391
		PUMP HEAT:	0	HP to CHW:	-	Heating btuh/sf =		33.8
					-----	tons	sf/ton	
		TOTAL BLOCK COOLING LOAD, btuh =			4,073	0.3	383	

Table 26 RTS Representative Zone Construction for Tables 5 and 6

Construction Class	Exterior Wall	Roof/Ceiling	Partitions	Floor	Furnishings
Light	steel siding, 2 in. insulation, air space, 3/4 in. gyp	4 in. LW concrete, ceiling air space, acoustic tile	3/4 in. gyp, air space, 3/4 in. gyp	acoustic tile, ceiling air space, 4 in. LW concrete	1 in. wood at 50% of floor area
Medium	4 in. face brick, 2 in. insulation, air space, 3/4 in. gyp	4 in. HW concrete, ceiling air space, acoustic tile	3/4 in. gyp, air space, 3/4 in. gyp	acoustic tile, ceiling air space, 4 in. HW concrete	1 in. wood at 50% of floor area
Heavy	4 in. face brick, 8 in. HW concrete air space, 2 in. insulation, 3/4 in. gyp	8 in. HW concrete, ceiling air space, acoustic tile	3/4 in. gyp, 8 in. HW concrete block, 3/4 in. gyp	acoustic tile, ceiling air space, 8 in. HW concrete	1 in. wood at 50% of floor area

Although simple in concept, these steps involved in calculating cooling loads are tedious and repetitive, even using the "simplified" RTS method; practically, they should be performed using a computer spreadsheet or other program. The calculations should be repeated for multiple design conditions (i.e., times of day, other months) to determine the maximum cooling load for mechanical equipment sizing. Example spreadsheets for computing each cooling load component using conduction and radiant time series are available from ASHRAE. To illustrate the full building example discussed previously, those individual component spreadsheets have been compiled to allow calculation of cooling and heating loads on a room by room basis as well as for a "block" calculation for analysis of overall areas or buildings where detailed room-by-room data are not available.

2.1 Single-Room Example Peak Heating Load

Although the physics of heat transfer that creates a heating load is identical to that for cooling loads, a number of traditionally used simplifying assumptions facilitate a much simpler calculation procedure. As described in the Heating Load Calculations section, design heating load calculations typically assume a single outdoor temperature, with no heat gain from solar or internal sources, under steady-state conditions. Thus, space heating load is determined by computing the heat transfer rate through building envelope elements ($UA\Delta T$) plus heat required because of outdoor air infiltration.

Part 6. Room heating load. Calculate the room heating load for the previous described office, including infiltration airflow at one air change per hour.

Solution: Because solar heat gain is not considered in calculating design heating loads, orientation of similar envelope elements may be ignored and total areas of each wall or window type combined. Thus, the total spandrel wall area = 60 + 60 = 120 ft^2, total brick wall area = 60 + 40 = 100 ft^2, and total window area = 40 + 40 = 80 ft^2. For this example, use the U-factors that were used for cooling load conditions. The 99.6% heating design dry-bulb temperature is 21.9°F and the indoor design temperature is 72°F. The room volume with a 9 ft ceiling = 9 × 130 = 1170 ft^3. At one air change per hour, the infiltration airflow = 1 × 1170/60 = 19.5 cfm. Thus, the heating load is

Windows:	0.56 × 80 × (72 – 21.9)	=	2244 Btu/h
Spandrel wall:	0.077 × 120 × (72 – 21.9)	=	463
Brick wall:	0.08 × 100 × (72 – 21.9)	=	401
Roof:	0.032 × 130 × (72 – 21.9)	=	208
Infiltration:	19.5 × 1.1 × (72 – 21.9)	=	1075
	Total room heating load:		4391 Btu/h

Additional examples of cooling and heating load calculations are given in Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*.

3 References

Amende, K.L., J.A. Keen, L.E. Catlin, M. Tosh, A.M. Sneed, and R.H. Howell. 2021b. *Principles of Heating, Ventilating, and Air Conditioning*, Ninth Edition.

ASHRAE. 2005. *ASHRAE Handbook—Fundamentals*.

ASHRAE. 2011. *ASHRAE Handbook—HVAC Applications*.

ASHRAE. 2013. *ASHRAE Handbook—Fundamentals*.

ASHRAE. 2017. *ASHRAE Handbook—Fundamentals*.

ASHRAE. 2019. *ASHRAE Handbook—HVAC Applications.*

ASHRAE. 2021a. *ASHRAE Handbook—Fundamentals*.

Resources

Table 4 Wall Conduction Time Series (CTS)

(Table 16, Chapter 18, 2013 *ASHRAE Handbook—Fundamentals*)

	CURTAIN WALLS			STUD WALLS				EIFS			BRICK WALLS									
Wall Number =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
U-Factor, $Btu/h \cdot ft^2 \cdot °F$	0.075	0.076	0.075	0.074	0.074	0.071	0.073	0.118	0.054	0.092	0.101	0.066	0.050	0.102	0.061	0.111	0.124	0.091	0.102	0.068
Total *R*	13.3	13.2	13.3	13.6	13.6	14.0	13.8	8.5	18.6	10.8	9.9	15.1	20.1	9.8	16.3	9.0	8.1	11.0	9.8	14.6
Mass, lb/ft^2	6.3	4.3	16.4	5.2	17.3	5.2	13.7	7.5	7.8	26.8	42.9	44.0	44.2	59.6	62.3	76.2	80.2	96.2	182.8	136.3
Thermal Capacity, $Btu/ft^2 \cdot °F$	1.5	1.0	3.3	1.2	3.6	1.6	3.0	1.8	1.9	5.9	8.7	8.7	8.7	11.7	12.4	15.7	15.3	19.0	38.4	28.4
Hour	Conduction Time Factors, %																			
0	18	25	8	19	6	7	5	11	2	1	0	0	0	1	2	2	1	3	4	3
1	58	57	45	59	42	44	41	50	25	2	5	4	1	1	2	2	1	3	4	3
2	20	15	32	18	33	32	34	26	31	6	14	13	7	2	2	2	3	3	4	3
3	4	3	11	3	13	12	13	9	20	9	17	17	12	5	3	4	6	3	4	4
4	0	0	3	1	4	4	4	3	11	9	15	15	13	8	5	5	7	3	4	4
5	0	0	1	0	1	1	2	1	5	9	12	12	13	9	6	6	8	4	4	4
6	0	0	0	0	1	0	1	0	3	8	9	9	11	9	7	6	8	4	4	5
7	0	0	0	0	0	0	0	0	2	7	7	7	9	9	7	7	8	5	4	5
8	0	0	0	0	0	0	0	0	1	6	5	5	7	8	7	7	8	5	4	5
9	0	0	0	0	0	0	0	0	0	6	4	4	6	7	7	6	7	5	4	5
10	0	0	0	0	0	0	0	0	0	5	3	3	5	7	6	6	6	5	4	5
11	0	0	0	0	0	0	0	0	0	5	2	2	4	6	6	6	6	5	5	5
12	0	0	0	0	0	0	0	0	0	4	2	2	3	5	5	5	5	5	5	5
13	0	0	0	0	0	0	0	0	0	4	1	2	2	4	5	5	4	5	5	5
14	0	0	0	0	0	0	0	0	0	3	1	2	2	4	5	5	4	5	5	5
15	0	0	0	0	0	0	0	0	0	3	1	1	1	3	4	4	3	5	4	4
16	0	0	0	0	0	0	0	0	0	3	1	1	1	3	4	4	3	5	4	4
17	0	0	0	0	0	0	0	0	0	2	1	1	1	2	3	4	3	4	4	4
18	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	3	2	4	4	4
19	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	3	2	4	4	4
20	0	0	0	0	0	0	0	0	0	2	0	0	0	1	3	3	2	4	4	4
21	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2	1	4	4	4
22	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2	1	4	4	3
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	4	3
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 4 of Chapter 18 of 2013 *ASHRAE Handbook—Fundamentals*)	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01
	F09	F08	F10	F08	F10	F11	F07	F06	F06	F06	M01	M01	M01	M01	M01	M01	M01	M01	M01	M01
	F04	F04	F04	G03	G03	G02	G03	I01	I01	I01	F04	F04	F04	F04	F04	F04	F04	F04	F04	F04
	I02	I02	I02	I04	I04	I04	I04	G03	G03	G03	I01	G03	I01	I01	M03	I01	I01	I01	I01	M15
	F04	F04	F04	G01	G01	G04	G01	F04	I04	M03	G03	I04	G03	M03	I04	M05	M01	M13	M16	I04
	G01	G01	G01	F02	F02	F02	F02	G01	G01	F04	F04	G01	I04	F02	G01	G01	F02	F04	F04	G01
	F02	F02	F02	—	—	—	—	F02	F02	G01	G01	F02	G01	—	F02	F02	—	G01	G01	F02
	—	—	—	—	—	—	—	—	—	F02	F02	—	F02	—	—	—	—	F02	F02	—

Wall Number Descriptions

1. Spandrel glass, R-10 insulation board, gyp board
2. Metal wall panel, R-10 insulation board, gyp board
3. 1 in. stone, R-10 insulation board, gyp board
4. Metal wall panel, sheathing, R-11 batt insulation, gyp board
5. 1 in. stone, sheathing, R-11 batt insulation, gyp board
6. Wood siding, sheathing, R-11 batt insulation, 1/2 in. wood
7. 1 in. stucco, sheathing, R-11 batt insulation, gyp board
8. EIFS finish, R-5 insulation board, sheathing, gyp board
9. EIFS finish, R-5 insulation board, sheathing, R-11 batt insulation, gyp board
10. EIFS finish, R-5 insulation board, sheathing, 8 in. LW CMU, gyp board
11. Brick, R-5 insulation board, sheathing, gyp board
12. Brick, sheathing, R-11 batt insulation, gyp board
13. Brick, R-5 insulation board, sheathing, R-11 batt insulation, gyp board
14. Brick, R-5 insulation board, 8 in. LW CMU
15. Brick, 8 in. LW CMU, R-11 batt insulation, gyp board
16. Brick, R-5 insulation board, 8 in. HW CMU, gyp board
17. Brick, R-5 insulation board, brick
18. Brick, R-5 insulation board, 8 in. LW concrete, gyp board
19. Brick, R-5 insulation board, 12 in. HW concrete, gyp board
20. Brick, 8 in. HW concrete, R-11 batt insulation, gyp board

Table 4 Wall Conduction Time Series (CTS) (*Continued*)
(Table 16, Chapter 18, 2013 *ASHRAE Handbook—Fundamentals*)

	CONCRETE BLOCK WALL						PRECAST AND CAST-IN-PLACE CONCRETE WALLS								
Wall Number =	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
U-Factor, Btu/h·ft^2·°F	0.067	0.059	0.073	0.186	0.147	0.121	0.118	0.074	0.076	0.115	0.068	0.082	0.076	0.047	0.550
Total *R*	14.8	16.9	13.7	5.4	6.8	8.2	8.4	13.6	13.1	8.7	14.7	12.2	13.1	21.4	1.8
Mass, lb/ft^2	22.3	22.3	46.0	19.3	21.9	34.6	29.5	29.6	53.8	59.8	56.3	100.0	96.3	143.2	140.0
Thermal Capacity, Btu/ft^2·°F	4.8	4.8	10.0	4.1	4.7	7.4	6.1	6.1	10.8	12.1	11.4	21.6	20.8	30.9	30.1
Hour	Conduction Time Factors, %														
0	0	1	0	1	0	1	1	0	1	2	1	3	1	2	1
1	4	1	2	11	3	1	10	8	1	2	2	3	2	2	2
2	13	5	8	21	12	2	20	18	3	3	3	4	5	3	4
3	16	9	12	20	16	5	18	18	6	5	6	5	8	3	7
4	14	11	12	15	15	7	14	14	8	6	7	6	9	5	8
5	11	10	11	10	12	9	10	11	9	6	8	6	9	5	8
6	9	9	9	7	10	9	7	8	9	6	8	6	8	6	8
7	7	8	8	5	8	8	5	6	9	6	7	5	7	6	8
8	6	7	7	3	6	8	4	4	8	6	7	5	6	6	7
9	4	6	6	2	4	7	3	3	7	6	6	5	6	6	6
10	3	5	5	2	3	6	2	2	7	5	6	5	5	6	6
11	3	4	4	1	3	6	2	2	6	5	5	5	5	5	5
12	2	4	3	1	2	5	1	2	5	5	5	4	4	5	4
13	2	3	2	1	2	4	1	1	4	5	4	4	4	5	4
14	2	3	2	0	1	4	1	1	4	4	4	4	3	4	4
15	1	3	2	0	1	3	1	1	3	4	3	4	3	4	3
16	1	2	1	0	1	3	0	1	2	4	3	4	3	4	3
17	1	2	1	0	1	2	0	0	2	3	3	4	2	4	3
18	1	2	1	0	0	2	0	0	1	3	2	4	2	4	2
19	0	1	1	0	0	2	0	0	1	3	2	3	2	3	2
20	0	1	1	0	0	2	0	0	1	3	2	3	2	3	2
21	0	1	1	0	0	2	0	0	1	3	2	3	2	3	1
22	0	1	1	0	0	1	0	0	1	3	2	3	1	3	1
23	0	1	0	0	0	1	0	0	1	2	2	2	1	3	1
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 4 of Chapter 18 of 2013 *ASHRAE Handbook—Fundamentals*)	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01
	M03	M08	F07	M08	M08	M09	M11	M11	M11	F06	M13	F06	M15	M16	M16
	I04	I04	M05	F02	F04	F04	I01	I04	I02	I01	I04	I02	I04	I05	F02
	G01	G01	I04	—	G01	G01	F04	G01	M11	M13	G01	M15	G01	G01	—
	F02	F02	G01	—	F02	F02	G01	F02	F02	G01	F02	G01	F02	F02	—
	—	—	F02	—	—	—	F02	—	—	F02	—	F02	—	—	—

Wall Number Descriptions

21. 8 in. LW CMU, R-11 batt insulation, gyp board
22. 8 in. LW CMU with fill insulation, R-11 batt insulation, gyp board
23. 1 in. stucco, 8 in. HW CMU, R-11 batt insulation, gyp board
24. 8 in. LW CMU with fill insulation
25. 8 in. LW CMU with fill insulation, gyp board
26. 12 in. LW CMU with fill insulation, gyp board
27. 4 in. LW concrete, R-5 board insulation, gyp board
28. 4 in. LW concrete, R-11 batt insulation, gyp board
29. 4 in. LW concrete, R-10 board insulation, 4 in. LW concrete
30. EIFS finish, R-5 insulation board, 8 in. LW concrete, gyp board
31. 8 in. LW concrete, R-11 batt insulation, gyp board
32. EIFS finish, R-10 insulation board, 8 in. HW concrete, gyp board
33. 8 in. HW concrete, R-11 batt insulation, gyp board
34. 12 in. HW concrete, R-19 batt insulation, gyp board
35. 12 in. HW concrete

Table 5 Roof Conduction Time Series (CTS), Layers, U-Factors, Mass and Thermal Capacity

(Table 17, Chapter 18, 2013 *ASHRAE Handbook—Fundamentals*)

	SLOPED FRAME ROOFS						WOOD DECK		METAL DECK ROOFS					CONCRETE ROOFS					
Roof Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
U-factor, Btu/h·ft^2·°F	0.044	0.040	0.045	0.041	0.042	0.041	0.69	0.058	0.080	0.065	0.057	0.036	0.052	0.054	0.052	0.051	0.056	0.055	0.042
Total *R*	22.8	25.0	22.2	24.1	23.7	24.6	14.5	17.2	12.6	15.4	17.6	27.6	19.1	18.6	19.2	19.7	18.0	18.2	23.7
Mass, lb/ft^2	5.5	4.3	2.9	7.1	11.4	7.1	10.0	11.5	4.9	6.3	5.1	5.6	11.8	30.6	43.9	57.2	73.9	97.2	74.2
Thermal Capacity, Btu/ft·°F	1.3	0.8	0.6	2.3	3.6	2.3	3.7	3.9	1.4	1.6	1.4	1.6	2.8	6.6	9.3	12.0	16.3	21.4	16.2
Hour	Conduction Time Factors, %																		
0	6	10	27	1	1	1	0	1	18	4	8	1	0	1	2	2	2	3	1
1	45	57	62	17	17	12	7	3	61	41	53	23	10	2	2	2	2	3	2
2	33	27	10	31	34	25	18	8	18	35	30	38	22	8	3	3	5	3	6
3	11	5	1	24	25	22	18	10	3	14	7	22	20	11	6	4	6	5	8
4	3	1	0	14	13	15	15	10	0	4	2	10	14	11	7	5	7	6	8
5	1	0	0	7	6	10	11	9	0	1	0	4	10	10	8	6	7	6	8
6	1	0	0	4	3	6	8	8	0	1	0	2	7	9	8	6	6	6	7
7	0	0	0	2	1	4	6	7	0	0	0	0	5	7	7	6	6	6	7
8	0	0	0	0	0	2	5	6	0	0	0	0	4	6	7	6	6	6	6
9	0	0	0	0	0	1	3	5	0	0	0	0	3	5	6	6	5	5	5
10	0	0	0	0	0	1	3	5	0	0	0	0	2	5	5	6	5	5	5
11	0	0	0	0	0	1	2	4	0	0	0	0	1	4	5	5	5	5	5
12	0	0	0	0	0	0	1	4	0	0	0	0	1	3	5	5	4	5	4
13	0	0	0	0	0	0	1	3	0	0	0	0	1	3	4	5	4	4	4
14	0	0	0	0	0	0	1	3	0	0	0	0	0	3	4	4	4	4	3
15	0	0	0	0	0	0	1	3	0	0	0	0	0	2	3	4	4	4	3
16	0	0	0	0	0	0	0	2	0	0	0	0	0	2	3	4	3	4	3
17	0	0	0	0	0	0	0	2	0	0	0	0	0	2	3	4	3	4	3
18	0	0	0	0	0	0	0	2	0	0	0	0	0	1	3	3	3	3	2
19	0	0	0	0	0	0	0	2	0	0	0	0	0	1	2	3	3	3	2
20	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3	3	3	2
21	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3	3	3	2
22	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3	2	2	2
23	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 4 of Chapter 18 of 2013 *ASHRAE Handbook—Fundamentals*)	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01
	F08	F08	F08	F12	F14	F15	F13	F13	F13	F13	F13	F13	M17	F13	F13	F13	F13	F13	F13
	G03	G03	G03	G05	G05	G05	G03	G03	G03	G03	G03	G03	F13	G03	G03	G03	G03	G03	M14
	F05	F05	F05	F05	F05	F05	I02	I02	I02	I02	I03	I02	G03	I03	I03	I03	I03	I03	F05
	I05	I05	I05	I05	I05	I05	G06	G06	F08	F08	F08	I03	I03	M11	M12	M13	M14	M15	I05
	G01	F05	F03	F05	F05	F05	F03	F05	F03	F05	F03	F08	F08	F03	F03	F03	F03	F03	F16
	F03	F16	—	G01	G01	G01	—	F16	—	F16	—	—	F03	—	—	—	—	—	F03
	—	F03	—	F03	F03	F03	—	F03	—	F03	—	—	—	—	—	—	—	—	—

Roof Number Descriptions

1. Metal roof, R-19 batt insulation, gyp board
2. Metal roof, R-19 batt insulation, suspended acoustical ceiling
3. Metal roof, R-19 batt insulation
4. Asphalt shingles, wood sheathing, R-19 batt insulation, gyp board
5. Slate or tile, wood sheathing, R-19 batt insulation, gyp board
6. Wood shingles, wood sheathing, R-19 batt insulation, gyp board
7. Membrane, sheathing, R-10 insulation board, wood deck
8. Membrane, sheathing, R-10 insulation board, wood deck, suspended acoustical ceiling
9. Membrane, sheathing, R-10 insulation board, metal deck
10. Membrane, sheathing, R-10 insulation board, metal deck, suspended acoustical ceiling
11. Membrane, sheathing, R-15 insulation board, metal deck
12. Membrane, sheathing, R-10 plus R-15 insulation boards, metal deck
13. 2-in. concrete roof ballast, membrane, sheathing, R-15 insulation board, metal deck
14. Membrane, sheathing, R-15 insulation board, 4-in. LW concrete
15. Membrane, sheathing, R-15 insulation board, 6-in. LW concrete
16. Membrane, sheathing, R-15 insulation board, 8-in. LW concrete
17. Membrane, sheathing, R-15 insulation board, 6-in. HW concrete
18. Membrane, sheathing, R-15 insulation board, 8-in. HW concrete
19. Membrane, 6-in HW concrete, R-19 batt insulation, suspended acoustical ceiling

Table 6 Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions for Tables 4 and 5
(Table 18, Chapter 18, 2021 *ASHRAE Handbook—Fundamentals*)

Layer ID	Description	Thickness, in.	Conductivity, Btu·in/h·ft^2·°F	Density, lb/ft^3	Specific Heat, Btu/lb·°F	Resistance, ft^2·°F·h/Btu	*R*	Mass, lb/ft^2	Thermal Capacity, Btu/ft^2·°F	Notes
F01	Outside surface resistance	—	—	—	—	0.25	0.25	—	—	1
F02	Inside vertical surface resistance	—	—	—	—	0.68	0.68	—	—	2
F03	Inside horizontal surface resistance	—	—	—	—	0.92	0.92	—	—	3
F04	Wall air space resistance	—	—	—	—	0.87	0.87	—	—	4
F05	Ceiling air space resistance	—	—	—	—	1.00	1.00	—	—	5
F06	EIFS finish	0.375	5.00	116.0	0.20	—	0.08	3.63	0.73	6
F07	1 in. stucco	1.000	5.00	116.0	0.20	—	0.20	9.67	1.93	6
F08	Metal surface	0.030	314.00	489.0	0.12	—	0.00	1.22	0.15	7
F09	Opaque spandrel glass	0.250	6.90	158.0	0.21	—	0.04	3.29	0.69	8
F10	1 in. stone	1.000	22.00	160.0	0.19	—	0.05	13.33	2.53	9
F11	Wood siding	0.500	0.62	37.0	0.28	—	0.81	1.54	0.43	10
F12	Asphalt shingles	0.125	0.28	70.0	0.30	—	0.44	0.73	0.22	
F13	Built-up roofing	0.375	1.13	70.0	0.35	—	0.33	2.19	0.77	
F14	Slate or tile	0.500	11.00	120.0	0.30	—	0.05	5.00	1.50	
F15	Wood shingles	0.250	0.27	37.0	0.31	—	0.94	0.77	0.24	
F16	Acoustic tile	0.750	0.42	23.0	0.14	—	1.79	1.44	0.20	11
F17	Carpet	0.500	0.41	18.0	0.33	—	1.23	0.75	0.25	12
F18	Terrazzo	1.000	12.50	160.0	0.19	—	0.08	13.33	2.53	13
G01	5/8 in. gyp board	0.625	1.11	50.0	0.26	—	0.56	2.60	0.68	
G02	5/8 in. plywood	0.625	0.80	34.0	0.29	—	0.78	1.77	0.51	
G03	1/2 in. fiberboard sheathing	0.500	0.47	25.0	0.31	—	1.06	1.04	0.32	14
G04	1/2 in. wood	0.500	1.06	38.0	0.39	—	0.47	1.58	0.62	15
G05	1 in. wood	1.000	1.06	38.0	0.39	—	0.94	3.17	1.24	15
G06	2 in. wood	2.000	1.06	38.0	0.39	—	1.89	6.33	2.47	15
G07	4 in. wood	4.000	1.06	38.0	0.39	—	3.77	12.67	4.94	15
I01	R-5, 1 in. insulation board	1.000	0.20	2.7	0.29	—	5.00	0.23	0.07	16
I02	R-10, 2 in. insulation board	2.000	0.20	2.7	0.29	—	10.00	0.45	0.13	16
I03	R-15, 3 in. insulation board	3.000	0.20	2.7	0.29	—	15.00	0.68	0.20	16
I04	R-11, 3-1/2 in. batt insulation	3.520	0.32	1.2	0.23	—	11.00	0.35	0.08	17
I05	R-19, 6-1/4 in. batt insulation	6.080	0.32	1.2	0.23	—	19.00	0.61	0.14	17
I06	R-30, 9-1/2 in. batt insulation	9.600	0.32	1.2	0.23	—	30.00	0.96	0.22	17
M01	4 in. brick	4.000	6.20	120.0	0.19	—	0.65	40.00	7.60	18
M02	6 in. LW concrete3 block	6.000	3.39	32.0	0.21	—	1.77	16.00	3.36	19
M03	8 in. LW concrete block	8.000	3.44	29.0	0.21	—	2.33	19.33	4.06	20
M04	12 in. LW concrete block	12.000	4.92	32.0	0.21	—	2.44	32.00	6.72	21
M05	8 in. concrete block	8.000	7.72	50.0	0.22	—	1.04	33.33	7.33	22
M06	12 in. concrete block	12.000	9.72	50.0	0.22	—	1.23	50.00	11.00	23
M07	6 in. LW concrete block (filled)	6.000	1.98	32.0	0.21	—	3.03	16.00	3.36	24
M08	8 in. LW concrete block (filled)	8.000	1.80	29.0	0.21	—	4.44	19.33	4.06	25
M09	12 in. LW concrete block (filled)	12.000	2.04	32.0	0.21	—	5.88	32.00	6.72	26
M10	8 in. concrete block (filled)	8.000	5.00	50.0	0.22	—	1.60	33.33	7.33	27
M11	4 in. lightweight concrete	4.000	3.70	80.0	0.20	—	1.08	26.67	5.33	
M12	6 in. lightweight concrete	6.000	3.70	80.0	0.20	—	1.62	40.00	8.00	
M13	8 in. lightweight concrete	8.000	3.70	80.0	0.20	—	2.16	53.33	10.67	
M14	6 in. heavyweight concrete	6.000	13.50	140.0	0.22	—	0.44	70.00	15.05	
M15	8 in. heavyweight concrete	8.000	13.50	140.0	0.22	—	0.59	93.33	20.07	
M16	12 in. heavyweight concrete	12.000	13.50	140.0	0.22	—	0.89	140.0	30.10	
M17	2 in. LW concrete roof ballast	2.000	1.30	40	0.20	—	1.54	6.7	1.33	28

Notes: The following notes give 2013 *ASHRAE Handbook—Fundamentals* sources for the data in this table.

1. Chapter 26, Table 1 for 7.5 mph wind
2. Chapter 26, Table 1 for still air, horizontal heat flow
3. Chapter 26, Table 1 for still air, downward heat flow
4. Chapter 26, Table 3 for 1.5 in. space, 90°F, horizontal heat flow, 0.82 emittance
5. Chapter 26, Table 3 for 3.5 in. space, 90°F, downward heat flow, 0.82 emittance
6. EIFS finish layers approximated by Chapter 26, Table 4 for 3/8 in. cement plaster, sand aggregate
7. Chapter 33, Table 3 for steel (mild)
8. Chapter 26, Table 4 for architectural glass
9. Chapter 26, Table 4 for marble and granite
10. Chapter 26, Table 4, density assumed same as Southern pine
11. Chapter 26, Table 4 for mineral fiberboard, wet molded, acoustical tile
12. Chapter 26, Table 4 for carpet and rubber pad, density assumed same as fiberboard
13. Chapter 26, Table 4, density assumed same as stone
14. Chapter 26, Table 4 for nail-base sheathing
15. Chapter 26, Table 4 for Southern pine
16. Chapter 26, Table 4 for expanded polystyrene
17. Chapter 26, Table 4 for glass fiber batt, specific heat per glass fiber board
18. Chapter 26, Table 4 for clay fired brick
19. Chapter 26, Table 4, 16 lb block, 8 in. × 16 in. face
20. Chapter 26, Table 4, 19 lb block, 8 in. × 16 in. face
21. Chapter 26, Table 4, 32 lb block, 8 in. × 16 in. face
22. Chapter 26, Table 4, 33 lb normal weight block, 8 in. × 16 in. face
23. Chapter 26, Table 4, 50 lb normal weight block, 8 in. × 16 in. face
24. Chapter 26, Table 4, 16 lb block, vermiculite fill
25. Chapter 26, Table 4, 19 lb block, 8 in. × 16 in. face, vermiculite fill
26. Chapter 26, Table 4, 32 lb block, 8 in. × 16 in. face, vermiculite fill
27. Chapter 26, Table 4, 33 lb normal weight block, 8 in. × 16 in. face, vermiculite fill
28. Chapter 26, Table 4 for 40 lb/ft^3 LW concrete

Resources

Table 8 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (A_n^f) for Glazing and Window Systems
(Table 10, Chapter 15, 2017 *ASHRAE Handbook—Fundamentals*)

Glazing System					Center-of-Glazing Properties							Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
					Incidence Angles							Aluminum		Other Frames		Aluminum		Other Frames	
ID	Glass Thick., in.		Center Glazing T_v		Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Uncoated Single Glazing																			
1a	1/8	CLR	0.90	SHGC	0.86	0.84	0.82	0.78	0.67	0.42	0.78	0.78	0.79	0.70	0.76	0.80	0.81	0.72	0.79
				T	0.83	0.82	0.80	0.75	0.64	0.39	0.75								
				R^f	0.08	0.08	0.10	0.14	0.25	0.51	0.14								
				R^b	0.08	0.08	0.10	0.14	0.25	0.51	0.14								
				A_1^f	0.09	0.10	0.10	0.11	0.11	0.11	0.10								
1b	1/4	CLR	0.88	SHGC	0.81	0.80	0.78	0.73	0.62	0.39	0.73	0.74	0.74	0.66	0.72	0.78	0.79	0.70	0.77
				T	0.77	0.75	0.73	0.68	0.58	0.35	0.69								
				R^f	0.07	0.08	0.09	0.13	0.24	0.48	0.13								
				R^b	0.07	0.08	0.09	0.13	0.24	0.48	0.13								
				A_1^f	0.16	0.17	0.18	0.19	0.19	0.17	0.17								
1c	1/8	BRZ	0.68	SHGC	0.73	0.71	0.68	0.64	0.55	0.34	0.65	0.67	0.67	0.59	0.65	0.61	0.61	0.54	0.60
				T	0.65	0.62	0.59	0.55	0.46	0.27	0.56								
				R^f	0.06	0.07	0.08	0.12	0.22	0.45	0.12								
				R^b	0.06	0.07	0.08	0.12	0.22	0.45	0.12								
				A_1^f	0.29	0.31	0.32	0.33	0.33	0.29	0.31								
1d	1/4	BRZ	0.54	SHGC	0.62	0.59	0.57	0.53	0.45	0.29	0.54	0.57	0.57	0.50	0.55	0.48	0.49	0.43	0.48
				T	0.49	0.45	0.43	0.39	0.32	0.18	0.41								
				R^f	0.05	0.06	0.07	0.11	0.19	0.42	0.10								
				R^b	0.05	0.68	0.66	0.62	0.53	0.33	0.10								
				A_1^f	0.46	0.49	0.50	0.51	0.49	0.41	0.48								
1e	1/8	GRN	0.82	SHGC	0.70	0.68	0.66	0.62	0.53	0.33	0.63	0.64	0.64	0.57	0.62	0.73	0.74	0.66	0.72
				T	0.61	0.58	0.56	0.52	0.43	0.25	0.53								
				R^f	0.06	0.07	0.08	0.12	0.21	0.45	0.11								
				R^b	0.06	0.07	0.08	0.12	0.21	0.45	0.11								
				A_1^f	0.33	0.35	0.36	0.37	0.36	0.31	0.35								
1f	1/4	GRN	0.76	SHGC	0.60	0.58	0.56	0.52	0.45	0.29	0.54	0.55	0.55	0.49	0.53	0.68	0.68	0.61	0.67
				T	0.47	0.44	0.42	0.38	0.32	0.18	0.40								
				R^f	0.05	0.06	0.07	0.11	0.20	0.42	0.10								
				R^b	0.05	0.06	0.07	0.11	0.20	0.42	0.10								
				A_1^f	0.47	0.50	0.51	0.51	0.49	0.40	0.49								
1g	1/8	GRY	0.62	SHGC	0.70	0.68	0.66	0.61	0.53	0.33	0.63	0.64	0.64	0.57	0.62	0.55	0.56	0.50	0.55
				T	0.61	0.58	0.56	0.51	0.42	0.24	0.53								
				R^f	0.06	0.07	0.08	0.12	0.21	0.44	0.11								
				R^b	0.06	0.07	0.08	0.12	0.21	0.44	0.11								
				A_1^f	0.33	0.36	0.37	0.37	0.37	0.32	0.35								
1h	1/4	GRY	0.46	SHGC	0.59	0.57	0.55	0.51	0.44	0.28	0.52	0.54	0.54	0.48	0.52	0.41	0.41	0.37	0.40
				T	0.46	0.42	0.40	0.36	0.29	0.16	0.38								
				R^f	0.05	0.06	0.07	0.10	0.19	0.41	0.10								
				R^b	0.05	0.06	0.07	0.10	0.19	0.41	0.10								
				A_1^f	0.49	0.52	0.54	0.54	0.52	0.43	0.51								
1i	1/4	BLUGRN	0.75	SHGC	0.62	0.59	0.57	0.54	0.46	0.30	0.55	0.57	0.57	0.50	0.55	0.67	0.68	0.60	0.66
				T	0.49	0.46	0.44	0.40	0.33	0.19	0.42								
				R^f	0.06	0.06	0.07	0.11	0.20	0.43	0.11								
				R^b	0.06	0.06	0.07	0.11	0.20	0.43	0.11								
				A_1^f	0.45	0.48	0.49	0.49	0.47	0.38	0.48								
Reflective Single Glazing																			
1j	1/4	SS on CLR 8%	0.08	SHGC	0.19	0.19	0.19	0.18	0.16	0.10	0.18	0.18	0.18	0.16	0.17	0.07	0.07	0.06	0.07
				T	0.06	0.06	0.06	0.05	0.04	0.03	0.05								
				R^f	0.33	0.34	0.35	0.37	0.44	0.61	0.36								
				R^b	0.50	0.50	0.51	0.53	0.58	0.71	0.52								
				A_1^f	0.61	0.61	0.60	0.58	0.52	0.37	0.57								

Table 8 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (A_n^f) for Glazing and Window Systems *(Continued)*

ID	Glazing System: Glass Thick., in.	Glazing System	Center Glazing T_v		Center-of-Glazing Properties, Incidence Angles: Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Total Window SHGC at Normal Incidence: Aluminum Operable	Aluminum Fixed	Other Frames Operable	Other Frames Fixed	Total Window T_v at Normal Incidence: Aluminum Operable	Aluminum Fixed	Other Frames Operable	Other Frames Fixed
1k	1/4	SS on CLR 14%	0.14	SHGC	0.25	0.25	0.24	0.23	0.20	0.13	0.23	0.24	0.24	0.21	0.22	0.12	0.13	0.11	0.12
				T	0.11	0.10	0.10	0.09	0.07	0.04	0.09								
				R^f	0.26	0.27	0.28	0.31	0.38	0.57	0.30								
				R^b	0.44	0.44	0.45	0.47	0.52	0.67	0.46								
				A_1^f	0.63	0.63	0.62	0.60	0.55	0.39	0.60								
1l	1/4	SS on CLR 20%	0.20	SHGC	0.31	0.30	0.30	0.28	0.24	0.16	0.28	0.29	0.29	0.26	0.28	0.18	0.18	0.16	0.18
				T	0.15	0.15	0.14	0.13	0.11	0.06	0.13								
				R^f	0.21	0.22	0.23	0.26	0.34	0.54	0.25								
				R^b	0.38	0.38	0.39	0.41	0.48	0.64	0.41								
				A_1^f	0.64	0.64	0.63	0.61	0.56	0.40	0.60								
1m	1/4	SS on GRN 14%	0.12	SHGC	0.25	0.25	0.24	0.23	0.21	0.14	0.23	0.24	0.24	0.21	0.22	0.11	0.11	0.10	0.11
				T	0.06	0.06	0.06	0.06	0.04	0.03	0.06								
				R^f	0.14	0.14	0.16	0.19	0.27	0.49	0.18								
				R^b	0.44	0.44	0.45	0.47	0.52	0.67	0.46								
				A_1^f	0.80	0.80	0.78	0.76	0.68	0.48	0.75								
1n	1/4	TI on CLR 20%	0.20	SHGC	0.29	0.29	0.28	0.27	0.23	0.15	0.27	0.27	0.27	0.24	0.26	0.18	0.18	0.16	0.18
				T	0.14	0.13	0.13	0.12	0.09	0.06	0.12								
				R^f	0.22	0.22	0.24	0.26	0.34	0.54	0.26								
				R^b	0.40	0.40	0.42	0.44	0.50	0.65	0.43								
				A_1^f	0.65	0.65	0.64	0.62	0.57	0.40	0.62								
1o	1/4	TI on CLR 30%	0.30	SHGC	0.39	0.38	0.37	0.35	0.30	0.20	0.35	0.36	0.36	0.32	0.35	0.27	0.27	0.24	0.26
				T	0.23	0.22	0.21	0.19	0.16	0.09	0.20								
				R^f	0.15	0.15	0.17	0.20	0.28	0.50	0.19								
				R^b	0.32	0.33	0.34	0.36	0.43	0.60	0.36								
				A_1^f	0.63	0.65	0.64	0.62	0.57	0.40	0.62								
Uncoated Double Glazing																			
5a	1/8	CLR CLR	0.81	SHGC	0.76	0.74	0.71	0.64	0.50	0.26	0.66	0.69	0.70	0.62	0.67	0.72	0.73	0.65	0.71
				T	0.70	0.68	0.65	0.58	0.44	0.21	0.60								
				R^f	0.13	0.14	0.16	0.23	0.36	0.61	0.21								
				R^b	0.13	0.14	0.16	0.23	0.36	0.61	0.21								
				A_1^f	0.10	0.11	0.11	0.12	0.13	0.13	0.11								
				A_2^f	0.07	0.08	0.08	0.08	0.07	0.05	0.07								
5b	1/4	CLR CLR	0.78	SHGC	0.70	0.67	0.64	0.58	0.45	0.23	0.60	0.64	0.64	0.57	0.62	0.69	0.70	0.62	0.69
				T	0.61	0.58	0.55	0.48	0.36	0.17	0.51								
				R^f	0.11	0.12	0.15	0.20	0.33	0.57	0.18								
				R^b	0.11	0.12	0.15	0.20	0.33	0.57	0.18								
				A_1^f	0.17	0.18	0.19	0.20	0.21	0.20	0.19								
				A_2^f	0.11	0.12	0.12	0.12	0.10	0.07	0.11								
5c	1/8	BRZ CLR	0.62	SHGC	0.62	0.60	0.57	0.51	0.39	0.20	0.53	0.57	0.57	0.50	0.55	0.55	0.56	0.50	0.55
				T	0.55	0.51	0.48	0.42	0.31	0.14	0.45								
				R^f	0.09	0.10	0.12	0.16	0.27	0.49	0.15								
				R^b	0.12	0.13	0.15	0.21	0.35	0.59	0.19								
				A_1^f	0.30	0.33	0.34	0.36	0.37	0.34	0.33								
				A_2^f	0.06	0.06	0.06	0.06	0.05	0.03	0.06								
5d	1/4	BRZ CLR	0.47	SHGC	0.49	0.46	0.44	0.39	0.31	0.17	0.41	0.45	0.45	0.40	0.43	0.42	0.42	0.38	0.41
				T	0.38	0.35	0.32	0.27	0.20	0.08	0.30								
				R^f	0.07	0.08	0.09	0.13	0.22	0.44	0.12								
				R^b	0.10	0.11	0.13	0.19	0.31	0.55	0.17								
				A_1^f	0.48	0.51	0.52	0.53	0.53	0.45	0.50								
				A_2^f	0.07	0.07	0.07	0.07	0.06	0.04	0.07								

Table 8 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (A_n^f) for Glazing and Window Systems *(Continued)*

	Glazing System				Center-of-Glazing Properties							Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
					Incidence Angles							Aluminum		Other Frames		Aluminum		Other Frames	
ID	Glass Thick., in.		Center Glazing T_v		Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
5e	1/8	GRN CLR	0.75	SHGC	0.60	0.57	0.54	0.49	0.38	0.20	0.51	0.55	0.55	0.49	0.53	0.67	0.68	0.60	0.66
				T	0.52	0.49	0.46	0.40	0.30	0.13	0.43								
				R^f	0.09	0.10	0.12	0.16	0.27	0.50	0.15								
				R^b	0.12	0.13	0.15	0.21	0.35	0.60	0.19								
				A_1^f	0.34	0.37	0.38	0.39	0.39	0.35	0.37								
				A_2^f	0.05	0.05	0.05	0.04	0.04	0.03	0.04								
5f	1/4	GRN CLR	0.68	SHGC	0.49	0.46	0.44	0.39	0.31	0.17	0.41	0.45	0.45	0.40	0.43	0.61	0.61	0.54	0.60
				T	0.39	0.36	0.33	0.29	0.21	0.09	0.31								
				R^f	0.08	0.08	0.10	0.14	0.23	0.45	0.13								
				R^b	0.10	0.11	0.13	0.19	0.31	0.55	0.17								
				A_1^f	0.49	0.51	0.05	0.53	0.52	0.43	0.50								
				A_2^f	0.05	0.05	0.05	0.05	0.04	0.03	0.05								
5g	1/8	GRY CLR	0.56	SHGC	0.60	0.57	0.54	0.48	0.37	0.20	0.51	0.55	0.55	0.49	0.53	0.50	0.50	0.45	0.49
				T	0.51	0.48	0.45	0.39	0.29	0.12	0.42								
				R^f	0.09	0.09	0.11	0.16	0.26	0.48	0.14								
				R^b	0.12	0.13	0.15	0.21	0.34	0.59	0.19								
				A_1^f	0.34	0.37	0.39	0.40	0.41	0.37	0.37								
				A_2^f	0.05	0.06	0.06	0.05	0.05	0.03	0.05								
5h	1/4	GRY CLR	0.41	SHGC	0.47	0.44	0.42	0.37	0.29	0.16	0.39	0.43	0.43	0.38	0.42	0.36	0.37	0.33	0.36
				T	0.36	0.32	0.29	0.25	0.18	0.07	0.28								
				R^f	0.07	0.07	0.08	0.12	0.21	0.43	0.12								
				R^b	0.10	0.11	0.13	0.18	0.31	0.55	0.17								
				A_1^f	0.51	0.54	0.56	0.57	0.56	0.47	0.53								
				A_2^f	0.07	0.07	0.07	0.06	0.05	0.03	0.06								
5i	1/4	BLUGRN CLR	0.67	SHGC	0.50	0.47	0.45	0.40	0.32	0.17	0.43	0.46	0.46	0.41	0.44	0.60	0.60	0.54	0.59
				T	0.40	0.37	0.34	0.30	0.22	0.10	0.32								
				R^f	0.08	0.08	0.10	0.14	0.24	0.46	0.13								
				R^b	0.11	0.11	0.14	0.19	0.31	0.55	0.17								
				A_1^f	0.47	0.49	0.50	0.51	0.50	0.42	0.48								
				A_2^f	0.06	0.06	0.06	0.05	0.04	0.03	0.05								
5j	1/4	HI-P GRN CLR	0.59	SHGC	0.39	0.37	0.35	0.31	0.25	0.14	0.33	0.36	0.36	0.32	0.35	0.53	0.53	0.47	0.52
				T	0.28	0.26	0.24	0.20	0.15	0.06	0.22								
				R^f	0.06	0.07	0.08	0.12	0.21	0.43	0.11								
				R^b	0.10	0.11	0.13	0.19	0.31	0.55	0.17								
				A_1^f	0.62	0.65	0.65	0.65	0.62	0.50	0.63								
				A_2^f	0.03	0.03	0.03	0.03	0.02	0.01	0.03								
Reflective Double Glazing																			
5k	1/4	SS on CLR 8%, CLR	0.07	SHGC	0.13	0.12	0.12	0.11	0.10	0.06	0.11	0.13	0.13	0.11	0.12	0.06	0.06	0.06	0.06
				T	0.05	0.05	0.04	0.04	0.03	0.01	0.04								
				R^f	0.33	0.34	0.35	0.37	0.44	0.61	0.37								
				R^b	0.38	0.37	0.38	0.40	0.46	0.61	0.40								
				A_1^f	0.61	0.61	0.60	0.58	0.53	0.37	0.56								
				A_2^f	0.01	0.01	0.01	0.01	0.01	0.01	0.01								
5l	1/4	SS on CLR 14%, CLR	0.13	SHGC	0.17	0.17	0.16	0.15	0.13	0.08	0.16	0.17	0.16	0.14	0.15	0.12	0.12	0.10	0.11
				T	0.08	0.08	0.08	0.07	0.05	0.02	0.07								
				R^f	0.26	0.27	0.28	0.31	0.38	0.57	0.30								
				R^b	0.34	0.33	0.34	0.37	0.44	0.60	0.36								
				A_1^f	0.63	0.64	0.64	0.63	0.61	0.56	0.60								
				A_2^f	0.02	0.02	0.02	0.02	0.02	0.02	0.02								

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Table 8 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (A_n^f) for Glazing and Window Systems *(Continued)*

	Glazing System		Center Glazing T_v		Center-of-Glazing Properties							Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
					Incidence Angles							Aluminum		Other Frames		Aluminum		Other Frames	
ID	Glass Thick., in.				Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
5m	1/4	SS on CLR 20%, CLR	0.18	SHGC	0.22	0.21	0.21	0.19	0.16	0.09	0.20	0.21	0.21	0.18	0.20	0.16	0.16	0.14	0.16
				T	0.12	0.11	0.11	0.09	0.07	0.03	0.10								
				R^f	0.21	0.22	0.23	0.26	0.34	0.54	0.25								
				R^b	0.30	0.30	0.31	0.34	0.41	0.59	0.33								
				A_1^f	0.64	0.64	0.63	0.62	0.57	0.41	0.61								
				A_2^f	0.03	0.03	0.03	0.03	0.02	0.02	0.03								
5n	1/4	SS on GRN 14%, CLR	0.11	SHGC	0.16	0.16	0.15	0.14	0.12	0.08	0.14	0.16	0.16	0.14	0.14	0.10	0.10	0.09	0.10
				T	0.05	0.05	0.05	0.04	0.03	0.01	0.04								
				R^f	0.14	0.14	0.16	0.19	0.27	0.49	0.18								
				R^b	0.34	0.33	0.34	0.37	0.44	0.60	0.36								
				A_1^f	0.80	0.80	0.79	0.76	0.69	0.49	0.76								
				A_2^f	0.01	0.01	0.01	0.01	0.01	0.01	0.01								
5o	1/4	TI on CLR 20%, CLR	0.18	SHGC	0.21	0.20	0.19	0.18	0.15	0.09	0.18	0.20	0.20	0.18	0.19	0.16	0.16	0.14	0.16
				T	0.11	0.10	0.10	0.08	0.06	0.03	0.09								
				R^f	0.22	0.22	0.24	0.27	0.34	0.54	0.26								
				R^b	0.32	0.31	0.32	0.35	0.42	0.59	0.35								
				A_1^f	0.65	0.66	0.65	0.63	0.58	0.41	0.62								
				A_2^f	0.02	0.02	0.02	0.02	0.02	0.01	0.02								
5p	1/4	TI on CLR 30%, CLR	0.27	SHGC	0.29	0.28	0.27	0.25	0.20	0.12	0.25	0.27	0.27	0.24	0.26	0.24	0.24	0.22	0.24
				T	0.18	0.17	0.16	0.14	0.10	0.05	0.15								
				R^f	0.15	0.15	0.17	0.20	0.29	0.51	0.19								
				R^b	0.27	0.27	0.28	0.31	0.40	0.58	0.31								
				A_1^f	0.64	0.64	0.63	0.62	0.58	0.43	0.61								
				A_2^f	0.04	0.04	0.04	0.04	0.03	0.02	0.04								

KEY:
CLR = clear, BRZ = bronze, GRN = green, GRY = gray, BLUGRN = blue-green, SS = stainless steel reflective coating, TI = titanium reflective coating
Reflective coating descriptors include percent visible transmittance as *x*%.
HI-P GRN = high-performance green tinted glass, LE = low-emissivity coating

T_v = visible transmittance, T = solar transmittance, SHGC = solar heat gain coefficient, and H. = hemispherical SHGC
ID #s refer to U-factors in Table 4, except for products 49 and 50.

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Table 9 Interior Solar Attenuation Coefficients (IAC) for Single or Double Glazings Shaded by Interior Venetian Blinds or Roller Shades

Glazing System[a]	Nominal Thickness[b] Each Pane, in.	Glazing Solar Transmittance[b]		Glazing SHGC[b]	IAC				
					Venetian Blinds		Roller Shades		
		Outer Pane	Single or Inner Pane		Medium	Light	Opaque Dark	Opaque White	Translucent Light
Single Glazing Systems									
Clear, residential	1/8[c]		0.87 to 0.80	0.86	0.75[d]	0.68[d]	0.82	0.40	0.45
Clear, commercial	1/4 to 1/2		0.80 to 0.71	0.82					
Clear, pattern	1/8 to 1/2		0.87 to 0.79						
Heat absorbing, pattern	1/8			0.59					
Tinted	3/16, 7/32		0.74, 0.71						
Above glazings, automated blinds[e]				0.86	0.64	0.59			
Above glazings, tightly closed vertical blinds				0.85	0.30	0.26			
Heat absorbing[f]	1/4		0.46	0.59	0.84	0.78	0.66	0.44	0.47
Heat absorbing, pattern	1/4								
Tinted	1/8, 1/4		0.59, 0.45						
Heat absorbing or pattern			0.44 to 0.30	0.59	0.79	0.76	0.59	0.41	0.47
Heat absorbing	3/8		0.34						
Heat absorbing or pattern			0.29 to 0.15						
			0.24	0.37	0.99	0.94	0.85	0.66	0.73
Reflective coated glass				0.26 to 0.52	0.83	0.75			
Double Glazing Systems[g]									
Clear double, residential	1/8	0.87	0.87	0.76	0.71[d]	0.66[d]	0.81	0.40	0.46
Clear double, commercial	1/4	0.80	0.80	0.70					
Heat absorbing double[f]	1/4	0.46	0.8	0.47	0.72	0.66	0.74	0.41	0.55
Reflective double				0.17 to 0.35	0.90	0.86			
Other Glazings (Approximate)					0.83	0.77	0.74	0.45	0.52
± Range of Variation[h]					0.15	0.17	0.16	0.21	0.21

[a] Systems listed in the same table block have same IAC.

[b] Values or ranges given for identification of appropriate IAC value; where paired, solar transmittances and thicknesses correspond. SHGC is for unshaded glazing at normal incidence.

[c] Typical thickness for residential glass.

[d] From measurements by Van Dyke and Konen (1982) for 45° open venetian blinds, 35° solar incidence, and 35° profile angle.

[e] Use these values only when operation is automated for exclusion of beam solar (as opposed to daylight maximization). Also applies to tightly closed horizontal blinds.

[f] Refers to gray, bronze, and green tinted heat-absorbing glass (on exterior pane in double glazing)

[g] Applies either to factory-fabricated insulating glazing units or to prime windows plus storm windows.

[h] The listed approximate IAC value may be higher or lower by this amount, due to glazing/shading interactions and variations in the shading properties (e.g., manufacturing tolerances).

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Table 10 Between-Glass Solar Attenuation Coefficients (BAC) for Double Glazing with Between-Glass Shading

Type of Glass	Nominal Thickness, Each Pane	Solar Transmittance[a] Outer Pane	Solar Transmittance[a] Inner Pane	Description of Air Space	Type of Shading: Venetian Blinds Light	Venetian Blinds Medium	Louvered Sun Screen
Clear out, clear in	3/32, 1/8 in.	0.87	0.87	Shade in contact with glass or shade separated from glass by air space	0.33	0.36	0.43
Clear out, clear in	1/4 in.	0.80	0.80	Shade in contact with glass-voids filled with plastic	—	—	0.49
Heat-absorbing[b] out, clear in				Shade in contact with glass or shade separated from glass by air space	0.28	0.30	0.37
	1/4 in.	0.46	0.80	Shade in contact with glass-voids filled with plastic	—	—	0.41

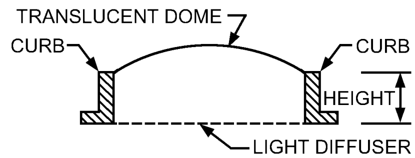
[a]Refer to manufacturers' literature for exact values.
[b]Refers to gray, bronze and green tinted heat-absorbing glass.

Table 11 Properties of Representative Indoor Shading Devices Shown in Tables 9 and 10

Indoor Shade	Solar-Optical Properties (Normal Incidence): Transmittance	Reflectance	Absorptance
Venetian blinds[a] (ratio of slat width to slat spacing 1.2, slat angle 45°)			
Light-colored slat	0.05	0.55	0.40
Medium-colored slat	0.05	0.35	0.60
Vertical blinds			
White louvers	0.00	0.77	0.23
Roller shades			
Light shades (translucent)	0.25	0.60	0.15
White shade (opaque)	0.00	0.65	0.35
Dark-colored shade (opaque)	0.00	0.20	0.80

[a] Values in this table are based on horizontal venetian blinds. However, tests show that these values can be used for vertical blinds with good accuracy.

Table 12 Solar Heat Gain Coefficients for Domed Horizontal Skylights
(Table 11, Chapter 15, 2017 *ASHRAE Handbook—Fundamentals*)



Dome	Light Diffuser (Translucent)	Curb		Solar Heat Gain Coefficient	Visible Transmittance
		Height, in.	Width-to-Height Ratio		
Clear	Yes	0	¥	0.53	0.56
τ = 0.86	τ = 0.58	9	5	0.50	0.58
		12	2.5	0.44	0.59
Clear		0	¥	0.86	0.91
τ = 0.86	None	9	5	0.77	0.91
		12	2.5	0.70	0.91
Translucent		0	¥	0.50	0.46
τ = 0.52	None	12	2.5	0.40	0.32
Translucent		0	¥	0.30	0.25
τ = 0.27	None	9	5	0.26	0.21
		12	2.5	0.24	0.18

Source: Laouadi et al. (2003), Schutrum and Ozisik (1961).

Table 13 Representative Solar RTS Values for Light to Heavy Construction
(Table 20, Chapter 18, 2021 *ASHRAE Handbook—Fundamentals*)

	Light						Medium						Heavy					
%	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet		
Glass	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
Hour	Radiant Time Factor, %																	
0	53	55	56	44	45	46	52	54	55	28	29	29	47	49	51	26	27	28
	17	17	17	19	20	20	16	16	15	15	15	15	11	12	12	12	13	13
	9	9	9	11	11	11	8	8	8	10	10	10	6	6	6	7	7	7
	5	5	5	7	7	7	5	4	4	7	7	7	4	4	3	5	5	5
	3	3	3	5	5	5	3	3	3	6	6	6	3	3	3	4	4	4
	2	2	2	3	3	3	2	2	2	5	5	5	2	2	2	4	4	4
	2	2	2	3	2	2	2	1	1	4	4	4	2	2	2	3	3	3
	1	1	1	2	2	2	1	1	1	4	3	3	2	2	2	3	3	3
	1	1	1	1	1	1	1	1	1	3	3	3	2	2	2	3	3	3
	1	1	1	1	1	1	1	1	1	3	3	3	2	2	2	3	3	3
	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3
	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	3	3	2
	1	1	1	1	1	0	1	1	1	2	2	2	2	1	1	2	2	2
	1	1	0	1	0	0	1	1	1	2	2	2	2	1	1	2	2	2
	1	0	0	0	0	0	1	1	1	1	1	1	2	1	1	2	2	2
	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	1	1
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	1	1
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 14 Representative Nonsolar RTS Values for Light to Heavy Construction

(Table 19, Chapter 18, 2021 *ASHRAE Handbook—Fundamentals*)

	Light						Medium						Heavy						Interior Zones					
																			Light		Medium		Heavy	
	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet								
% Glass	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	With Carpet	No Carpet	With Carpet	No Carpet	With Carpet	No Carpet
Hour	Radiant Time Factor, %																							
0	47	50	53	41	43	46	46	49	52	31	33	35	34	38	42	22	25	28	46	40	46	31	33	21
	19	18	17	20	19	19	18	17	16	17	16	15	9	9	9	10	9	9	19	20	18	17	9	9
	11	10	9	12	11	11	10	9	8	11	10	10	6	6	5	6	6	6	11	12	10	11	6	6
	6	6	5	8	7	7	6	5	5	8	7	7	4	4	4	5	5	5	6	8	6	8	5	5
	4	4	3	5	5	5	4	3	3	6	5	5	4	4	4	5	5	4	4	5	3	6	4	5
	3	3	2	4	3	3	2	2	2	4	4	4	4	3	3	4	4	4	3	4	2	4	4	4
	2	2	2	3	3	2	2	2	2	4	3	3	3	3	3	4	4	4	2	3	2	4	3	4
	2	1	1	2	2	2	1	1	1	3	3	3	3	3	3	4	4	4	2	2	1	3	3	4
	1	1	1	1	1	1	1	1	1	3	2	2	3	3	3	4	3	3	1	1	1	3	3	4
	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2	3	3	3	1	1	1	2	3	3
	1	1	1	1	1	1	1	1	1	2	2	2	3	2	2	3	3	3	1	1	1	2	3	3
	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	1	1	1	2	2	3
	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	1	1	1	1	2	3
	1	1	1	0	1	0	1	1	1	1	1	1	2	2	2	3	3	2	1	1	1	1	2	3
	0	0	1	0	1	0	1	1	1	1	1	1	2	2	2	3	2	2	1	0	1	1	2	3
	0	0	1	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	2
	0	0	0	0	0	0	1	1	1	1	1	1	2	2	1	2	2	2	0	0	1	1	2	2
	0	0	0	0	0	0	0	1	0	0	1	1	2	2	1	2	2	2	0	0	1	0	2	2
	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	2	2	2	0	0	0	0	1	2
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	1	0	0	0	0	1	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 15 RTS Representative Zone Construction for Tables 13 and 14

(Table 21, Chapter 18, 2021 *ASHRAE Handbook—Fundamentals*)

Construction Class	Exterior Wall	Roof/Ceiling	Partitions	Floor	Furnishings
Light	Steel siding, 2 in. insulation, air space, 3/4 in. gyp	4 in. LW concrete, ceiling air space, acoustic tile	3/4 in. gyp, air space, 3/4 in. gyp	Acoustic tile, ceiling air space, 4 in. LW concrete	1 in. wood at 50% of floor area
Medium	4 in. face brick, 2 in. insulation, air space, 3/4 in. gyp	4 in. HW concrete, ceiling air space, acoustic tile	3/4 in. gyp, air space, 3/4 in. gyp	Acoustic tile, ceiling air space, 4 in. HW concrete	1 in. wood at 50% of floor area
Heavy	4 in. face brick, 8 in. HW concrete air space, 2 in. insulation, 3/4 in. gyp	8 in. HW concrete, ceiling air space, acoustic tile	3/4 in. gyp, 8 in. HW concrete block, 3/4 in. gyp	Acoustic tile, ceiling air space, 8 in. HW concrete	1 in. wood at 50% of floor area