CHAPTER 28

NONRESIDENTIAL COOLING AND HEATING LOAD CALCULATIONS

THIS chapter presents three methods of calculating air-conditioning cooling load for sizing cooling equipment and a general procedure for calculating heating load, for nonresidential applications. In addition, the fundamental principles for calculating heating loads are presented as a counterpart to cooling load calculation. For residential applications, consult Chapter 27. For information on cooling and/or heating equipment energy use, consult Chapter 30.

The heat balance approach is a fundamental concept in calculating cooling loads. While generally cumbersome for widespread or routine use, this underlying concept is the basis for each of the three simplified procedures outlined for varying purposes.

The cooling calculation procedure most closely approximating the heat balance concept is the transfer function method (TFM), first introduced in the 1972 *ASHRAE Handbook of Fundamentals*. This computer-based procedure takes place in two steps, first establishing the heat gain from all sources and then determining the conversion of such heat gain into cooling load. Developed as an hour-by-hour calculation procedure oriented to simulate annual energy use, its normalizing characteristics make it particularly appropriate for that application.

A simplified version of the TFM, which can be used with certain types of buildings for which application data are available, was presented in the 1977 *ASHRAE Handbook of Fundamentals*. This one-step procedure uses cooling load temperature differences (CLTD), solar cooling load factors (SCL), and internal cooling load factors (CLF), to calculate cooling loads as an approximation of the TFM. Where applicable, this method may be suitable for hand calculation use.

An alternative simplification of the heat balance technique uses total equivalent temperature differential values and a system of time-averaging (TETD/TA) to calculate cooling loads. Also a computer-based, two-step procedure (heat gain, then cooling load), first introduced in the 1967 *ASHRAE Handbook of Fundamentals*, this method gives valid broad-range results to experienced users.

COOLING LOAD PRINCIPLES

The variables affecting cooling load calculations are numerous, often difficult to define precisely, and always intricately interrelated. Many cooling load components vary in magnitude over a wide range during a 24-h period. Since these cyclic changes in load components are often not in phase with each other, each must be analyzed to establish the resultant maximum cooling load for a building or zone. A zoned system (a system of conditioning equipment serving several independent areas, each with its own temperature control) need recognize no greater total cooling load capacity than the largest hourly summary of simultaneous zone loads throughout a design day; however, it must handle the peak cooling load for each zone at its individual peak hour. At certain times of the day during the heating or intermediate seasons, some zones may require heating while others require cooling.

Calculation accuracy. The concept of determining the cooling load for a given building must be kept in perspective. A proper cooling load calculation gives values adequate for proper performance. Variation in the heat transmission coefficients of typical building materials and composite assemblies, the differing motivations and skills of those who physically construct the building, and the manner in which the building is actually operated are some of the variables that make a numerically precise calculation impossible. While the designer uses reasonable procedures to account for these factors, the calculation can never be more than a good estimate of the actual cooling load.

Heat flow rates. In air-conditioning design, four related heat flow rates, each of which varies with time, must be differentiated: (1) space heat gain, (2) space cooling load, (3) space heat extraction rate, and (4) cooling coil load.

Space heat gain. This instantaneous rate of heat gain is the rate at which heat enters into and/or is generated within a space at a given instant. Heat gain is classified by (1) the mode in which it enters the space and (2) whether it is a sensible or latent gain.

Mode of entry. The modes of heat gain may be as (1) solar radiation through transparent surfaces; (2) heat conduction through exterior walls and roofs; (3) heat conduction through interior partitions, ceilings, and floors; (4) heat generated within the space by occupants, lights, and appliances; (5) energy transfer as a result of ventilation and infiltration of outdoor air; or (6) miscellaneous heat gains.

Sensible or latent heat. Sensible heat gain is directly added to the conditioned space by conduction, convection, and/or radiation. Latent heat gain occurs when moisture is added to the space (e.g., from vapor emitted by occupants and equipment). To maintain a constant humidity ratio, water vapor must condense on cooling apparatus at a rate equal to its rate of addition into the space. The amount of energy required to offset the latent heat gain essentially equals the product of the rate of condensation and the latent heat of condensation. In selecting cooling apparatus, it is necessary to distinguish

The preparation of this chapter is assigned to TC 4.1, Load Calculation Data and Procedures.

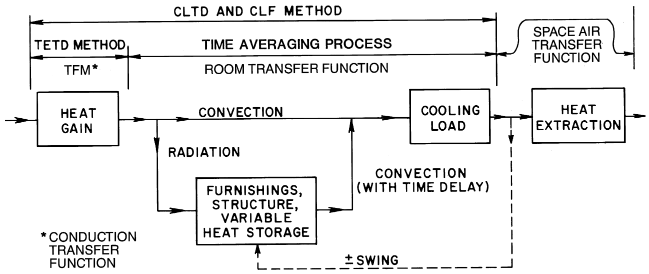


Fig. 1 Origin of Difference Between Magnitude of Instantaneous Heat Gain and Instantaneous Cooling Load

between sensible and latent heat gain. Every cooling apparatus has a maximum sensible heat removal capacity and a maximum latent heat removal capacity for particular operating conditions.

Space cooling load. This is the rate at which heat must be removed from the space to maintain a constant space air temperature. The sum of all space instantaneous heat gains at any given time does not necessarily (or even frequently) equal the cooling load for the space at that same time.

Radiant heat gain. Space heat gain by radiation is not immediately converted into cooling load. Radiant energy must first be absorbed by the surfaces that enclose the space (walls, floor, and ceiling) and the objects in the space (furniture, etc.). As soon as these surfaces and objects become warmer than the space air, some of their heat is transferred to the air in the space by convection. The composite heat storage capacity of these surfaces and objects determines the rate at which their respective surface temperatures increase for a given radiant input, and thus governs the relationship between the radiant portion of heat gain and its corresponding part of the space cooling load (Figure 1). The thermal storage effect is critically important in differentiating between instantaneous heat gain for a given space and its cooling load for that moment. Predicting the nature and magnitude of this elusive phenomenon in order to estimate a realistic cooling load for a particular combination of circumstances has long been a subject of major interest to design engineers. The bibliography lists some of the early work on the subject.

Space Heat Extraction Rate

The rate at which heat is removed from the conditioned space equals the space cooling load only to the degree that room air temperature is held constant. In conjunction with intermittent operation of the cooling equipment, the control system characteristics usually permit a minor cyclic variation or swing in room temperature. Therefore, a proper simulation of the control system gives a more realistic value of energy removal over a fixed time period than using the values of the space cooling load. This concept is primarily important for estimating energy use over time (see Chapter 30); however, it is not needed to calculate design peak cooling load for equipment selection. Space heat extraction rate calculation is discussed later in this chapter; see also Mitalas (1972).

Cooling Coil Load

The rate at which energy is removed at the cooling coil that serves one or more conditioned spaces equals the sum of the instantaneous space cooling loads (or space heat extraction rate if it is assumed that the space temperature does not vary) for all the spaces served by the coil, plus any external loads. Such external loads include heat gain by the distribution system between the individual spaces and the cooling equipment, and outdoor air heat and moisture introduced into the distribution system through the cooling equipment.

SPACE COOLING LOAD CALCULATION TECHNIQUES

Heat Balance Fundamentals

The estimation of cooling load for a space involves calculating a surface-by-surface conductive, convective, and radiative heat balance for each room surface and a convective heat balance for the room air. Sometimes called "the exact solution," these principles form the foundation for all other methods described in this chapter.

To calculate space cooling load directly by heat balance procedures requires a laborious solution of energy balance equations involving the space air, surrounding walls and windows, infiltration and ventilation air, and internal energy sources. To demonstrate the calculation principle, consider a sample room enclosed by four walls, a ceiling, and a floor, with infiltration air, ventilation air, and normal internal energy sources. The calculations that govern energy exchange at each inside surface at a given time are:

$$q_{i,\theta} = \left[h_{ci}(t_{a,\theta} - t_{i,\theta}) + \sum_{j=1, j \neq i}^{m} g_{ij}(t_{j,\theta} - t_{i,\theta}) \right] A_i + RS_{i,\theta} + RL_{i,\theta} + RE_{i,\theta} \text{ for } i = 1, 2, 3, 4, 5, 6 \quad (1)$$

where

m = number of surfaces in room (6 in this case)
$q_{i,\theta}$ = rate of heat conducted into surface i at inside surface at time θ
A_i = area of surface i
h_{ci} = convective heat transfer coefficient at interior surface i
g_{ij} = radiation heat transfer factor between interior surface i and interior surface j
$t_{a,\theta}$ = inside air temperature at time θ
$t_{i,\theta}$ = average temperature of interior surface i at time θ
$t_{j,\theta}$ = average temperature of interior surface j at time θ
$RS_{i,\theta}$ = rate of solar energy coming through windows and absorbed by surface i at time θ
$RL_{i,\theta}$ = rate of heat radiated from lights and absorbed by surface i at time θ
$RE_{i,\theta}$ = rate of heat radiated from equipment and occupants and absorbed by surface i at time θ

Conduction transfer functions. The equations governing conduction within the six surfaces cannot be solved independently of Equation (1), since the energy exchanges occurring within the room affect the inside surface conditions, in turn affecting the internal conduction. Consequently, the above mentioned six formulations of Equation (1) must be solved simultaneously with the governing equations of conduction within the six surfaces in order to calculate the space cooling load. Typically, these equations are formulated as conduction transfer functions in the form

$$q_{in,\theta} = \sum_{m=1}^{M} Y_{k,m} t_{o,\theta-m+1} - \sum_{m=1}^{M} Z_{k,m} t_{in,\theta-m+1} + \sum_{m=1}^{M} F_m q_{in,\theta-m} \quad (2)$$

where

q = rate of heat conducted into a specific surface at a specific hour
in = inside surface subscript
k = order of CTF
m = time index variable
M = number of nonzero CTF values
o = outside surface subscript
t = temperature
θ = time
x = exterior CTF values
Y = cross CTF values
Z = interior CTF values
F_m = flux (heat flow rate) history coefficients

Space air energy balance. Note that the interior surface temperature, $t_{i,\theta}$ in Equation (1) and $t_{in,\theta}$ in Equation (2), requires simultaneous solution. In addition, Equation (3) representing an energy balance on the space air must also be solved simultaneously

$$Q_{L,\theta} = \left[\sum_{i=1}^{m} h_{ci}(t_{i,\theta} - t_{a,\theta})\right] A_i + \rho C V_{L,\theta}(t_{o,\theta} - t_{a,\theta}) + \rho C V_{v,\theta}(t_{v,\theta} - t_{a,\theta}) + RS_{a,\theta} + RL_{a,\theta} + RE_{a,\theta} \quad (3)$$

where

ρ = air density
C = air specific heat
$V_{L,\theta}$ = volume flow rate of outdoor air infiltrating into room at time θ
$t_{o,\theta}$ = outdoor air temperature at time θ
$V_{v,\theta}$ = volume rate of flow of ventilation air at time θ
$t_{v,\theta}$ = ventilation air temperature at time θ
$RS_{a,\theta}$ = rate of solar heat coming through windows and convected into room air at time θ
$RL_{a,\theta}$ = rate of heat from lights convected into room air at time θ
$RE_{a,\theta}$ = rate of heat from equipment and occupants and convected into room air at time θ

Note that the ventilation air component in Equation (3) is assumed to enter the space directly, rather than through any associated cooling apparatus. Note also that the space air temperature is allowed to float. By fixing the space air temperature, the cooling load need not be determined simultaneously.

This rigorous approach to calculating space cooling load is impractical without the speed at which some computations can be done by modern digital computers. Computer programs in use where instantaneous space cooling loads are calculated in this exact manner are primarily oriented to energy use calculations over extended periods because hourly outdoor temperatures are normalized increments rather than peak design temperature profiles (Mitalas and Stephenson 1967, Buchberg 1958, Walton 1982).

The transfer function concept is a simplification to the strict heat balance calculation procedure. In the transfer function concept, Mitalas and Stephenson (1967) used room thermal response factors. In their procedure, room surface temperatures and cooling load were first calculated by the rigorous method just described, for several typical constructions representing offices, schools, and dwellings of heavy, medium, and light construction. In these calculations, components such as solar heat gain, conduction heat gain, or heat gain from the lighting, equipment, and occupants were simulated by pulses of unit strength. The transfer functions were then calculated as numerical constants representing the cooling load corresponding to the input excitation pulses. Once these transfer functions were determined for typical constructions they were assumed independent of input pulses, thus permitting cooling loads to be determined without the more rigorous calculation. Instead, the calculation requires simple multiplication of the transfer functions by a time-series representation of heat gain and subsequent summation of these products, which can be carried out on a small computer. The same transfer function concept can be applied to calculating heat gain components themselves, as explained later.

Total Equivalent Temperature Differential Method

In the total equivalent temperature differential (TETD) method, the response factor technique is used with a number of representative wall and roof assemblies from which data are derived to calculate TETD values as functions of sol-air temperature and maintained room temperature. Various components of space heat gain are calculated using associated TETD values, and the results are added to internal heat gain elements to get an instantaneous total rate of space heat gain. This gain is converted to an instantaneous space cooling load by the time-averaging (TA) technique of averaging the radiant portions of the heat gain load components for the current hour with related values from an appropriate period of immediately preceding hours. This technique provides a rational means to deal quantitatively with the thermal storage phenomenon, but it is best solved by computer because of its complexity. Its fundamental weakness is that simple averaging of radiant load components is a poor approximation of the actual physics involved, and choosing an appropriate averaging period is subjective and depends on user experience.

Transfer Function Method

Although similar in principle to TETD/TA, the transfer function method (TFM) (Mitalas 1972) applies a series of weighting factors, or conduction transfer function (CTF) coefficients to the various exterior opaque surfaces and to differences between sol-air temperature and inside space temperature to determine heat gain with appropriate reflection of thermal inertia of such surfaces. Solar heat gain through glass and various forms of internal heat gain are calculated directly for the load hour of interest. The TFM next applies a second series of weighting factors, or coefficients of room transfer functions (RTF), to heat gain and cooling load values from all load elements having radiant components, to account for the thermal storage effect in converting heat gain to cooling load. Both evaluation series consider data from several previous hours as well as the current hour. RTF coefficients relate specifically to the spatial geometry, configuration, mass, and other characteristics of the space so as to reflect weighted variations in thermal storage effect on a time basis rather than a straight-line average.

Transfer Functions. These coefficients relate an output function at a given time to the value of one or more driving functions at a given time and at a set period immediately preceding. The CTF described in this chapter is no different from the thermal response factor used for calculating wall or roof heat conduction, while the RTF is the weighting factor for obtaining cooling load components (ASHRAE 1975). The bibliography lists reports of various experimental work that has validated the predictive accuracy of the TFM. While the TFM is scientifically appropriate and technically sound for a specific cooling load analysis, several immediately previous 24-h periods are assumed to be the same as the load hour of interest. Also, a computer is required for effective application in a commercial design environment.

CLTD/SCL/CLF Method

Rudoy and Duran (1975) compared the TETD/TA and TFM. As part of this work, data obtained by using the TFM on a group of applications considered representative were then used to generate cooling load temperature differential (CLTD) data, for direct one-step calculation of cooling load from conduction heat gain through sunlit walls and roofs and conduction through glass exposures (see Bibliography). Cooling load factors (CLF) for similar one-step calculation of solar load through glass and for loads from internal sources were also developed. More recent research (McQuiston 1992) developed an improved factor for solar load through glass, the solar cooling load (SCL) factor, which allows additional influencing parameters to be considered for greater accuracy. CLTDs, SCLs, and CLFs all include the effect of (1) time lag in conductive heat gain through opaque exterior surfaces and (2) time delay by thermal storage in converting radiant heat gain to cooling load. This simplification allows cooling loads to be calculated manually; thus, when data are available and are appropriately used, the results are consistent with those from the TFM, thus making the method popular for instruction.

Application Experience

The CLTD and CLF tables published in previous editions of the Fundamentals volume and in the original *Cooling and Heating Load Calculation Manual* (ASHRAE 1979) are normalized data, based on applications of the original TFM data presented in the 1972 Fundamentals volume. Subsequent studies investigating the effects of 1981 to 1985 RTF data indicated results generally less conservative than those computed with the 1972 data. More recent research, however, suggests otherwise (McQuiston 1992), and the revised values for 1993, including the new SCLs, are currently considered more realistic for design load purposes.

CLTD Data. The originally developed CLTD data were so voluminous that they were first limited to 13 representative flat roof assemblies (with and without ceilings, for 26 total cases) and 7 wall groups (into which 41 different wall assemblies can be categorized). Twenty-four hourly CLTD values were tabulated for each of the 26 roof cases and each of the 7 wall groups, broken down for walls into 8 primary orientations. Adjustments were then required for specific north latitude and month of calculation. Reliability of adjustments was reasonably consistent during summer months but became much less realistic for early and late hours during traditionally noncooling load months.

Solar Heat Gain Data. Solar heat gain through glass required similar data compression to present a corresponding range of conditions. Tables of maximum solar heat gain factors (SHGF) were listed for every 4° of north latitude between 0 and 64°, for each month and by 16 compass directions and horizontal. Cooling load factors (CLF), decimal multipliers for SHGF data, were tabulated for unshaded glass in spaces having carpeted or uncarpeted floors and for inside-shaded glass with any room construction. Unshaded CLFs were presented for each of 24 hours by 8 compass directions plus horizontal, further categorized by light, medium, or heavy room construction. Inside-shaded CLFs disregarded construction mass but included 16 orientations plus horizontal. The product of the selected CLTD and CLF values represented cooling load per unit area as a single process. CLF values published in the *Handbook* were derived for the period May through September as normally the hottest months for load calculation purposes. As with CLTDs, the reliability of CLF data deteriorated rapidly for applications during early and late hours of months considered “noncooling load” periods.

ASHRAE Sponsored Research. For some space geometries and building constructions, the tabulated CLTD and CLF data published through 1989 were found also to be too restrictive or limited. The weighting factors used to generate these data, based on representative spaces in schools, offices, and dwellings at the time of the original research, did not reflect current design and construction practices. ASHRAE research investigated the sensitivity of the weighting factors to variations in space construction, size, exposure, and related conditions to update the tabular data. However, the investigators discovered that the range and amplitude of this sensitivity was much broader than previously thought, rendering even more impractical the generation of enough tabular material to cover the majority of normal applications. Accordingly, two significant changes in direction have occurred:

1. The section describing the CLTD/CLF in the 1985 and 1989 editions of the Fundamentals volume recommended caution in application of this procedure for general practice, and this cautionary notice was also added as an insert to the *Cooling and Heating Load Calculation Manual* (McQuiston and Spitler 1992).
2. The system itself was modified for more specific tabulation of data, abandoning the maximum SHGF concept and incorporating solar cooling load (SCL) factors for estimating cooling load from glass.

The main thrust of ASHRAE sponsored research between 1989 and 1993 was to update the *Cooling and Heating Load Calculation Manual*, published in revised form in 1993. Information from earlier research was used to revise the original factors by incorporating additional parameters, including separating solar load through glass from the CLF category and creating more appropriate SCL factors for that component. Still faced with too much tabular data, information was tabulated only for limited use and representative examples, but it was accompanied by instructions for customizing similar data for specific application; a microcomputer database was also provided to facilitate such calculations. Certain limitations resulting from normalization of data remain, for which anticipated error ranges are listed to aid in evaluating results. The section in this chapter describing the CLTD/SCL/CLF method has incorporated this latest 1993 research, but it does not provide the microcomputer program.

Dissatisfaction with the limitations of CLTD/SCL/CLF led to a reappraisal of prospects for improvement. Because adding flexibility mandated massive extrapolation of tabular material and/or the computational equivalent, the ASHRAE technical committee for load calculations (TC 4.1) decided to leave this method at its present level of development and to direct future research effort toward more promising goals.

TFM Method. Like the CLTD/SCL/CLF method, the TFM method represents, compared to fundamental heat balance principles, a significant compromise with several important physical concepts. Also, the complex computations required of the heat balance method can now be handled by today’s desktop computers. For these reasons, ASHRAE is supporting research to clarify heat balance procedures for more general use. Results of this research will appear in the next edition of this Handbook.

TETD/TA Method. Prior to introduction of the CLTD/CLF, most users had turned to computer-based versions of the time-averaging technique, proven successful and practical in ten years of heavy use. Most users, however, recognized the subjectivity of determining the relative percentages of radiant heat in the various heat gain components and selecting the number of hours over which to average such loads—both of which must rely on the individual experience of the user rather than on research or support in the scientific literature. Harris and McQuiston (1988) developed decrement factors and time lag values. In this chapter, these factors have been keyed to typical walls and roofs. All other tabular data pertaining to this method has been deleted, so that since 1989, information has been confined to basic algorithms intended for continued computer applications.

The lack of scientific validation of the time-averaging process led to suspension of further development of TETD/TA. But the need to retain a more simplified computation than heat balance alone led to a study of Radiant Time Series (RTS) coefficients to convert radiant heat gain components to cooling load. Some preliminary results of the relative percentages of various kinds and types of radiant heat gain as compared to convective are included in this chapter.

Alternative Procedures. TFM, CLTD/SCL/CLF and TETD/TA procedures, tables, and related data will continue to be appropriate and dependable when applied within the limits discussed in this chapter. Users will likely incorporate heat balance relationships when developing custom CLTD/SCL/CLF or TETD/TA tabular data for specific projects.

INITIAL DESIGN CONSIDERATIONS

To calculate a space cooling load, detailed building design information and weather data at selected design conditions are required. Generally, the following steps should be followed:

Data Assembly

1. **Building characteristics.** Obtain characteristics of the building. Building materials, component size, external surface colors and shape are usually determined from building plans and specifications.

2. **Configuration.** Determine building location, orientation and external shading from building plans and specifications. Shading from adjacent buildings can be determined by a site plan or by visiting the proposed site, but should be carefully evaluated as to its probable permanence before it is included in the calculation. The possibility of abnormally high ground-reflected solar radiation (i.e., from adjacent water, sand, or parking lots), or solar load from adjacent reflective buildings should not be overlooked.
3. **Outdoor design conditions.** Obtain appropriate weather data and select outdoor design conditions. Weather data can be obtained from local weather stations or from the National Climatic Center, Asheville, NC 28801. For outdoor design conditions for a large number of weather stations, see Chapter 26. Note, however, that the scheduled values for the design dry-bulb and mean coincident wet-bulb temperatures can vary considerably from data traditionally used in various areas. Use judgment to ensure that results are consistent with expectations. Also, consider prevailing wind velocity and the relationship of a project site to the selected weather station.
4. **Indoor design conditions.** Select indoor design conditions, such as indoor dry-bulb temperature, indoor wet-bulb temperature, and ventilation rate. Include permissible variations and control limits.
5. **Operating schedules.** Obtain a proposed schedule of lighting, occupants, internal equipment, appliances, and processes that contribute to the internal thermal load. Determine the probability that the cooling equipment will be operated continuously or shut off during unoccupied periods (e.g., nights and/or weekends).
6. **Date and time.** Select the time of day and month to do the cooling load calculation. Frequently, several different times of day and several different months must be analyzed to determine the peak load time. The particular day and month are often dictated by peak solar conditions, as tabulated in Tables 15 through 21 in Chapter 29. For southern exposures in north latitudes above 32° having large fenestration areas, the peak space cooling load usually occurs in December or January. To calculate a space cooling load under these conditions, the warmest temperature for the winter months must be known. These data can be found in the National Climatic Center's Climatic Atlas of the United States.

Use of Data. Once the data are assembled, the space cooling load at design conditions may be calculated as outlined in the following sections of this chapter.

Additional Considerations

The proper design and sizing of all-air or air-and-water central air-conditioning systems require more than calculation of the cooling load in the space to be conditioned. The type of air-conditioning system, fan energy, fan location, duct heat loss and gain, duct leakage, heat extraction lighting systems, and type of return air system all affect system load and component sizing. Adequate system design and component sizing require that system performance be analyzed as a series of psychrometric processes. Chapter 3 of the 2000 *ASHRAE Handbook—Systems and Equipment* describes some elements of this technique in detail, while others are delineated in this chapter.

HEAT GAIN CALCULATION CONCEPTS

Heat Gain through Fenestration Areas

The primary weather-related variable influencing the cooling load for a building is solar radiation. The effect of solar radiation is more pronounced and immediate in its impact on exposed non-opaque surfaces. The calculation of solar heat gain and conductive heat transfer through various glazing materials and associated mounting frames, with or without interior and/or exterior shading devices, is discussed in Chapter 29. This chapter covers the application of such data to the overall heat gain evaluation and the conversion of the calculated heat gain into a composite cooling load for the conditioned space.

Heat Gain through Exterior Surfaces

Heat gain through exterior opaque surfaces is derived from the same elements of solar radiation and thermal gradient as that for fenestration areas. It differs primarily as a function of the mass and nature of the wall or roof construction, since those elements affect the rate of conductive heat transfer through the composite assembly to the interior surface.

Sol-Air Temperature

Sol-air temperature 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 the outdoor air.

Heat Flux into Exterior Sunlit Surfaces. The heat balance at a sunlit surface gives the heat flux into the surface q/A as

$$q/A = \alpha I_t + h_o(t_o - t_s) - \varepsilon \Delta R \tag{4}$$

where

α = absorptance of surface for solar radiation
I_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)
t_o = outdoor air temperature, °F
t_s = surface temperature, °F
ε = 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)

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

$$q/A = h_o(t_e - t_s) \tag{5}$$

and from Equations (4) and (5)

$$t_e = t_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \tag{6}$$

Horizontal Surfaces. For horizontal surfaces that receive long-wave radiation from the sky only, an appropriate value of ΔR is about 20 Btu/(h·ft^2), so that if $\varepsilon = 1$ and $h_o = 3.0$ Btu/(h·ft^2·°F), the long-wave correction term is about −7°F (Bliss 1961).

Vertical surfaces. Because vertical surfaces receive long-wave 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 long-wave radiation compensates to some extent for the sky's low emittance. Therefore, it is common practice to assume $\Delta R = 0$ for vertical surfaces.

Tabulated Temperature Values. The sol-air temperatures in Table 1 have been calculated based on $\varepsilon \Delta R / h_o$ being 7°F for horizontal surfaces and 0°F for vertical surfaces; total solar intensity values used for the calculations were the same as those used to evaluate the solar heat gain factors (SHGF) for July 21 at 40°N latitude (Chapter 29). 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 1); the value of 0.15 is appropriate for a light-colored surface, while 0.30 represents the usual maximum

Table 1 Sol-Air Temperatures 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 N	NE	E	SE	S	SW	W	NW	HOR
1	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
4	74	74	74	74	74	74	74	74	74	67
5	74	74	74	74	74	74	74	74	74	67
6	74	80	93	95	84	76	76	76	76	72
7	75	80	99	106	94	78	78	78	78	81
8	77	81	99	109	101	82	81	81	81	92
9	80	85	96	109	106	88	85	85	85	102
10	83	88	91	105	107	95	88	88	88	111
11	87	93	93	99	106	102	93	93	93	118
12	90	96	96	96	102	106	102	96	96	122
13	93	99	99	99	99	108	112	105	99	124
14	94	99	99	99	99	106	118	116	102	122
15	95	100	100	100	100	103	121	124	111	117
16	94	98	98	98	98	99	118	126	116	109
17	93	98	96	96	96	96	112	124	117	99
18	91	97	93	93	93	93	101	112	110	89
19	87	87	87	87	87	87	87	87	87	80
20	85	85	85	85	85	85	85	85	85	78
21	83	83	83	83	83	83	83	83	83	76
22	81	81	81	81	81	81	81	81	81	74
23	79	79	79	79	79	79	79	79	79	72
24	77	77	77	77	77	77	77	77	77	70
Avg.	**83**	**86**	**88**	**90**	**90**	**87**	**90**	**90**	**88**	**90**

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

value for this parameter (i.e., for a dark-colored surface, or any surface for which the permanent lightness can not reliably be anticipated).

Air Temperature Cycle. The air temperature cycle used to calculate the sol-air temperatures is given in Column 2, Table 1. Sol-air temperatures can be adjusted to any other air temperature cycle simply by adding or subtracting the difference between the desired air temperature and the air temperature value given in Column 2.

Adjustments. Sol-air temperature cycles can be estimated for other dates and latitudes by using the data in Tables 15 through 21, Chapter 29. For any of the times, dates, and wall orientations listed in those tables, the value of I_t is approximately 1.15 × SHGF. However, the 1.15 factor is approximate and only accounts for the solar energy excluded by a single sheet of ordinary window glass. For surfaces with other orientations or slope angles of other than 0°, and for more accurate estimates at incident angles above 50° (particularly critical for southern exposures), the solar intensity can be found by the method outlined in Chapter 29.

Average Sol-Air Temperature. The average daily sol-air temperature t_{ea} can be calculated for any of the situations covered by Tables 15 through 21 of Chapter 29:

$$t_{ea} = t_{oa} + \frac{\alpha}{h_o}\left(\frac{I_{DT}}{24}\right) - \frac{\varepsilon \Delta R}{h_o} \quad (7)$$

where I_{DT} is the sum of two appropriate half-day totals of solar heat gain in Btu/(h·ft²). For example, the average sol-air temperature for a wall facing southeast at 40°N latitude on August 21 would be

$$t_{ea} = t_{oa} + \frac{\alpha}{h_o}\left[\frac{1.15(956 + 205)}{24}\right]$$

The daily solar heat gain of double-strength sheet glass is 956 + 205 Btu/(h·ft²) in a southeast facade at this latitude and date (Table 18, Chapter 29); and $\varepsilon \Delta R / h_o$ is assumed to be zero for this vertical surface.

Table 2 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

Hourly Air Temperatures. The hourly air temperatures in Column 2, Table 1 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 from Table 1 of Chapter 26 and note the outdoor daily range. For each hour, take the percentage of the daily range indicated in Table 2 of this chapter and subtract from the design temperature.

Example 1. Air temperature calculation. Calculate the summer dry-bulb temperature at 1200 h for Reno, Nevada.

Solution: From Table 1, Chapter 26, the daily range is 37.3°F and the 1% design dry-bulb temperature is 95°F. From Table 2, the percentage of the daily range at 1200 hours is 23%. Thus, the dry-bulb temperature at 1200 is Design dry-bulb – (Percentage fraction × Daily range) = 95 – (0.23 × 37.3) = 86.4°F.

Data limitations. The outdoor daily range is the difference between the average daily maximum and average daily minimum temperatures during the warmest month. More reliable results could be obtained by determining or estimating the shape of the temperature curve for typical hot days at the building site and considering each month separately.

Peak cooling load is often determined by solar heat gain through fenestration; this peak may occur in winter months and/or at a time of day when outside air temperature is not at its peak.

Heat Gain through Fenestration

The sections that include Equations (39) through (47) in Chapter 29 describe one method used to calculate space cooling load resulting from heat transfer through fenestration. The solar heat gain profiles listed in Chapter 29 are for fenestration areas with no external shading. The equations for calculating shade angles (Chapter 29) can be used to determine the shape and area of moving shadow falling across a given window from external shading elements during the course of a design day. Thus, a subprofile of heat gain for that window can be created by separating its sunlit and shaded areas for each hour; modifying multipliers for inside shading devices can also be included.

Exterior Shading. Nonuniform exterior shading, caused by roof overhangs, side fins, or building projections, require separate hourly calculations for the externally shaded and unshaded areas of the window in question, with the SC 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. Sun (1968) developed fundamental algorithms for analysis of shade patterns. McQuiston and Spitler (1992) provide graphical data to facilitate shadow line calculation, and the north exposure SHGF may be taken for shaded glass (with some loss of accuracy at latitudes less than 24° north).

An alternate, more accurate, method suggested by Todorovic and Curcija (1984) first calculates cooling loads as if the external shading were absent, then adjusts (reduces) the result to account for the shading effect. This correction applies a "negative cooling load factor," calculated in much the same way as a conventional cooling load but using the time-varying area of the shaded portion of the glass as the heat gain element. Todorovic (1987) describes the solution of the moving shade line problem in the context of consequent cooling load.

Temperature Considerations. To estimate the conduction of heat through fenestration at any time, applicable values of the outdoor and indoor dry-bulb temperatures must be used. Chapter 26 gives design values of summer outdoor dry-bulb temperatures for many locations. These are generally mid-afternoon temperatures; for other times, local weather stations or NOAA can supply temperature data. Winter design temperatures should not be used in Equation (15), since such data are for heating design rather than coincident conduction heat gain with sunlit glass during the heating season.

Heat Gain through Interior Surfaces

Whenever a conditioned space is adjacent to a space with a different temperature, transfer of heat through the separating physical section must be considered. The heat transfer rate is given by

$$q = UA(t_b - t_i) \tag{8}$$

where

q = heat transfer rate, Btu/h
U = coefficient of overall heat transfer between adjacent and conditioned space, Btu/(h·ft²·°F)
A = area of separating section concerned, ft²
t_b = average air temperature in adjacent space, °F
t_i = air temperature in conditioned space, °F

Values of U can be obtained from Chapter 24. Temperature t_b may range widely from that in the conditioned space. The temperature in a kitchen or boiler room, for example, may be as much as 15 to 50°F above the outdoor air temperature. Actual temperatures in adjoining spaces should be measured when possible. Where nothing is known, except that the adjacent space is of conventional construction, contains no heat sources, and itself receives no significant solar heat gain, $t_b - t_i$ may be considered the difference between the outdoor air and conditioned space design dry-bulb temperatures minus 5°F. In some cases, the air temperature in the adjacent space will correspond to the outdoor air temperature or higher.

Floors. For floors directly in contact with the ground, or over an underground basement that is neither ventilated nor conditioned, heat transfer may be neglected for cooling load estimates.

HEAT SOURCES IN CONDITIONED SPACES

People

Table 3 gives representative rates at which heat and moisture are given off by human beings in different states of activity. Often these sensible and latent heat gains constitute a large fraction of the total load. Even for short-term occupancy, the extra heat and moisture brought in by people may be significant. Chapter 8 should be referred to for detailed information; however, Table 3 summarizes design data representing conditions commonly encountered.

The conversion of sensible heat gain from people to space cooling load is affected by the thermal storage characteristics of that space and is thus subject to application of appropriate room transfer functions (RTF). Latent heat gains are considered instantaneous.

Lighting

Since lighting is often the major space load component, an accurate estimate of the space heat gain it imposes is needed. Calculation of this load component is not straightforward; the rate of heat gain at any given moment can be quite different from the heat equivalent of power supplied instantaneously to those lights.

Only part of the energy from lights is in the form of convective heat, which is picked up instantaneously by the air-conditioning apparatus. The remaining portion is in the form of radiation, which affects the conditioned space only after having been absorbed and rereleased by walls, floors, furniture, etc. This absorbed energy contributes to space cooling load only after a time lag, with some part of such energy still present and reradiating after the lights have been switched off (Figure 2).

There is always significant delay between the time of switching lights on and a point of equilibrium where reradiated light energy equals that being instantaneously stored. Time lag effect must be considered when calculating cooling load, since load felt by the space can be considerably lower than the instantaneous heat gain being generated, and peak load for the space may be affected significantly.

Instantaneous Heat Gain from Lighting. The primary source of heat from lighting comes from light-emitting elements, or lamps, although significant additional heat may be generated from associated appurtenances in the light fixtures that house such lamps. Generally, the instantaneous rate of heat gain from electric lighting may be calculated from

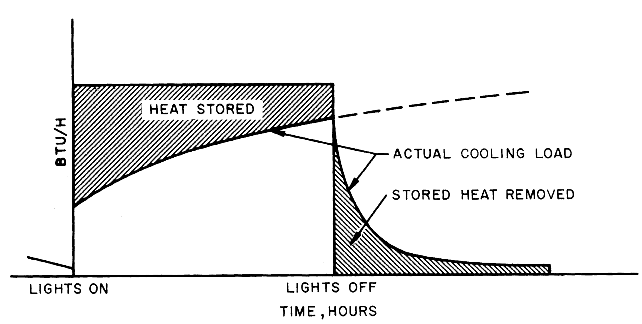


Fig. 2 Thermal Storage Effect in Cooling Load from Lights

Table 3 Rates of Heat Gain from Occupants of Conditioned Spaces

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

Notes:

1. Tabulated values are based on 75°F room dry-bulb temperature. For 80°F room dry bulb, the total heat remains the same, but the sensible heat values should be decreased by approximately 20%, and the latent heat values increased accordingly.
2. Also refer to Table 4, Chapter 8, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 Btu/h.

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

[b] Values approximated from data in Table 6, Chapter 8, where is air velocity with limits shown in that table.

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

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

$$q_{el} = 3.41 W F_{ul} F_{sa} \qquad (9)$$

where

q_{el} = heat gain, Btu/h
W = total light wattage
F_{ul} = lighting use factor
F_{sa} = lighting special allowance factor

The *total light wattage* is obtained from the ratings of all lamps installed, both for general illumination and for display use.

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

The *special allowance factor* is for fluorescent fixtures and/or fixtures that are either ventilated or installed so that only part of their heat goes to the conditioned space. For fluorescent fixtures, the special allowance factor accounts primarily for ballast losses, and can be as high as 2.19 for 32 W single lamp high-output fixtures on 277 V circuits. Rapid-start, 40 W lamp fixtures have special allowance factors that vary from a low of 1.18 for two lamps at 277 V to a high of 1.30 for one lamp at 118 V, with a recommended value of 1.20 for general applications. Industrial fixtures other than fluorescent, such as sodium lamps, may have special allowance factors varying from 1.04 to 1.37, depending on the manufacturer, and should be dealt with individually.

For ventilated or recessed fixtures, manufacturers' or other data must be sought to establish the fraction of the total wattage that may be expected to enter the conditioned space directly (and subject to time lag effect), versus that which must be picked up by return air or in some other appropriate manner.

Light Heat Components. Cooling load caused by lights recessed into ceiling cavities is made up of two components: one part comes from the light heat directly contributing to the space heat gain, and the other is the light heat released into the above-ceiling cavity, which (if used as a return air plenum) is mostly picked up by the return air that passes over or through the light fixtures. In such a ceiling return air plenum, this second part of the load (sometimes referred to as heat-to-return) never enters the conditioned space. It does, however, add to the overall load and significantly influences the load calculation.

Even though the total cooling load imposed on the cooling coil from these two components remains the same, the larger the fraction of heat output picked up by the return air, the more the space cooling load is reduced. The minimum required airflow rate for the conditioned space is decreased as the space cooling load becomes less. Supply fan power reduces accordingly, which ultimately results in reduced energy consumption for the system, and, possibly reduced equipment size as well.

For ordinary design load estimation, the heat gain for each component may simply be calculated as a fraction of the total lighting load by using judgment to estimate heat-to-space and heat-to-return percentages (Mitalas and Kimura 1971).

Return Air Light Fixtures. Two generic types of return air light fixture are available—those that allow and those that do not allow return air to flow through the lamp chamber. The first type is sometimes called a heat-of-light fixture. The percentage of light heat released through the plenum side of various ventilated fixtures can be obtained from lighting fixture manufacturers. For representative data, see Nevens et al. (1971). Even unventilated fixtures lose some heat to plenum spaces; however, most of the heat ultimately enters the conditioned space from a dead-air plenum or is picked up by return air via ceiling return air openings. The percentage of heat to return air ranges from 40 to 60% for heat-to-return ventilated fixtures or 15 to 25% for unventilated fixtures.

Plenum Temperatures. As heat from lighting is picked up by the return air, the temperature differential between the ceiling space and the conditioned space causes part of that heat to flow from the ceiling back to the conditioned space. Return air from the conditioned space can be ducted to capture light heat without passing through a ceiling plenum as such, or the ceiling space can be used as a return air plenum, causing the distribution of light heat to be handled in distinctly different ways. Most plenum temperatures do not rise more than 1 to 3°F above space temperature, thus generating only a relatively small thermal gradient for heat transfer through plenum surfaces but a relatively large percentage reduction in space cooling load. (Many engineers believe that a major reason for plenum temperatures not becoming more elevated is due to leakage into the plenum from supply air duct work normally concealed there, but consideration of this elusive factor is beyond the scope of this chapter.)

Energy Balance. Where the ceiling space is used as a return air plenum, an energy balance requires that the heat picked up from the lights into the return air (1) becomes a part of the cooling load to the return air (represented by a temperature rise of the return air as it passes through the ceiling space), (2) is partially transferred back into the conditioned space through the ceiling material below, and/or (3) may be partially "lost" (from the space) through the floor surfaces above the plenum. In a multistory building, the conditioned space frequently gains heat through its floor from a similar plenum below, offsetting the loss just mentioned. The radiant component of heat leaving the ceiling or floor surface of a plenum is normally so small that all such heat transfer is considered convective for calculation purposes.

Figure 3 shows a schematic diagram of a typical return air plenum. Equations (10) through (14), using the sign convention as shown in Figure 3, represent the heat balance of a return air plenum design for a typical interior room in a multifloor building, as

$$q_1 = U_c A_c (t_p - t_r) \quad (10)$$

$$q_2 = U_f A_f (t_p - t_{fa}) \quad (11)$$

$$q_3 = 1.1 Q (t_p - t_r) \quad (12)$$

$$q_{lp} - q_2 - q_1 - q_3 = 0 \quad (13)$$

$$Q = \frac{q_r + q_1}{1.1(t_r - t_s)} \quad (14)$$

where

q_1 = heat gain to space from plenum through ceiling, Btu/h
q_2 = heat loss from plenum through floor above, Btu/h
q_3 = heat gain "pickup" by return air, Btu/h
Q = return airflow, cfm
q_{lp} = light heat gain to plenum via return air, Btu/h
q_{lr} = light heat gain to space, Btu/h
q_f = heat gain from plenum below, through floor, Btu/h
q_w = heat gain from exterior wall, Btu/h
q_r = space cooling load, Btu/h, including appropriate treatment of q_{lr}, q_f, and/or q_w
t_p = plenum temperature, °F
t_r = space temperature, °F
t_{fa} = space temperature of floor above, °F
t_s = supply air temperature, °F

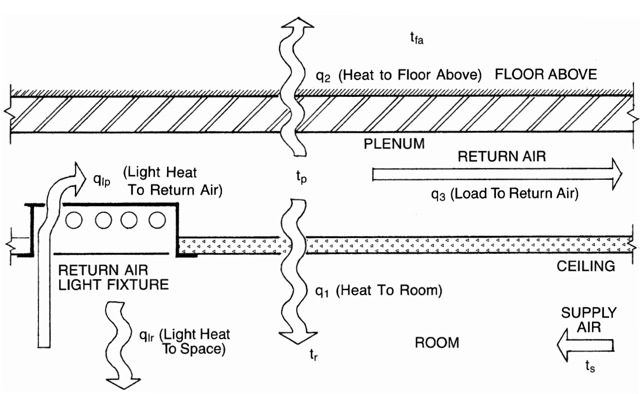


Fig. 3 Heat Balance of Typical Ceiling Return Plenum

By substituting Equations (10), (11), (12), and (14) into heat balance Equation (13), t_p can be found as the resultant return air temperature or plenum temperature, by means of a quadratic equation. The results, although rigorous and best solved by computer, are important in determining the cooling load, which affects equipment size selection, future energy consumption, and other factors.

Equations (10) through (14) are simplified to illustrate the heat balance relationship. Heat gain into a return air plenum is not limited to the heat of lights alone. Exterior walls directly exposed to the ceiling space will transfer heat directly to or from the return air. For single-story buildings or the top floor of a multistory building, the roof heat gain or loss enters or leaves the ceiling plenum rather than entering or leaving the conditioned space directly. The supply air quantity calculated by Equation (14) is for the conditioned space under consideration only, and is assumed equal to the return air quantity.

The amount of airflow through a return plenum above a conditioned space may not be limited to that supplied into the space under consideration; it will, however, have no noticeable effect on plenum temperature if the surplus comes from an adjacent plenum operating under similar conditions. Where special conditions exist, heat balance Equations (10) through (14) must be modified appropriately. Finally, even though the building's thermal storage has some effect, the amount of heat entering the return air is small and may be considered as convective for calculation purposes.

Power

Instantaneous heat gain from equipment operated by electric motors within a conditioned space is calculated as

$$q_{em} = 2545(P/E_M)F_{UM}F_{LM} \quad (15)$$

where

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

The motor use factor may be applied when motor use is known to be intermittent with significant nonuse during all hours of operation (e.g., overhead door operator). For conventional applications, its value would be 1.0.

The motor load factor is the fraction of the rated load being delivered under the conditions of the cooling load estimate. In Equation (15), it is assumed that both the motor and the driven equipment are within the conditioned space. If the motor is outside the space or airstream

$$q_{em} = 2545 P F_{UM} F_{LM} \quad (16)$$

When the motor is inside the conditioned space or airstream but the driven machine is outside

$$q_{em} = 2545P\left(\frac{1.0 - E_M}{E_m}\right)F_{UM}F_{LM} \quad (17)$$

Equation (17) also applies to a fan or pump in the conditioned space that exhausts air or pumps fluid outside that space.

Average efficiencies, and related data representative of typical electric motors, generally derived from the lower efficiencies reported by several manufacturers of open, drip-proof motors, are given in Tables 4 and 5. These reports indicate that TEFC (totally enclosed fan-cooled) are slightly more efficient. For speeds lower or higher than those listed, efficiencies may be 1 to 3% lower or higher, depending on the manufacturer. Should actual voltages at motors be appreciably higher or lower than rated nameplate voltage, efficiencies in either case will be lower. If electric motor load is an appreciable portion of cooling load, the motor efficiency should be

Table 4 Heat Gain from Typical Electric Motors

Motor Name-plate or Rated Horse-power	Motor Type	Nominal rpm	Full Load Motor Effi-ciency, %	Location of Motor and Driven Equipment with Respect to Conditioned Space or Airstream: A — Motor in, Driven Equip-ment in, Btu/h	B — Motor out, Driven Equip-ment in, Btu/h	C — Motor in, Driven Equip-ment out, Btu/h
0.05	Shaded pole	1500	35	360	130	240
0.08	Shaded pole	1500	35	580	200	380
0.125	Shaded pole	1500	35	900	320	590
0.16	Shaded pole	1500	35	1160	400	760
0.25	Split phase	1750	54	1180	640	540
0.33	Split phase	1750	56	1500	840	660
0.50	Split phase	1750	60	2120	1270	850
0.75	3-Phase	1750	72	2650	1900	740
1	3-Phase	1750	75	3390	2550	850
1.5	3-Phase	1750	77	4960	3820	1140
2	3-Phase	1750	79	6440	5090	1350
3	3-Phase	1750	81	9430	7640	1790
5	3-Phase	1750	82	15,500	12,700	2790
7.5	3-Phase	1750	84	22,700	19,100	3640
10	3-Phase	1750	85	29,900	24,500	4490
15	3-Phase	1750	86	44,400	38,200	6210
20	3-Phase	1750	87	58,500	50,900	7610
25	3-Phase	1750	88	72,300	63,600	8680
30	3-Phase	1750	89	85,700	76,300	9440
40	3-Phase	1750	89	114,000	102,000	12,600
50	3-Phase	1750	89	143,000	127,000	15,700
60	3-Phase	1750	89	172,000	153,000	18,900
75	3-Phase	1750	90	212,000	191,000	21,200
100	3-Phase	1750	90	283,000	255,000	28,300
125	3-Phase	1750	90	353,000	318,000	35,300
150	3-Phase	1750	91	420,000	382,000	37,800
200	3-Phase	1750	91	569,000	509,000	50,300
250	3-Phase	1750	91	699,000	636,000	62,900

Table 5 Typical Overload Limits with Standard Motors

Horsepower	0.05-0.25	0.16-0.33	0.67-0.75	1 and up
AC open	1.4	1.35	1.25	1.15
AC TEFC[a] and DC	—	1.0	1.0	1.0

Note: Some shaded pole, capacitor start, and special purpose motors have a service factor varying from 1.0 up to 1.75.
[a]Some totally enclosed fan-cooled (TEFC) motors have a service factor above 1.0.

obtained from the manufacturer. Also, depending on design, the maximum efficiency might occur anywhere between 75 to 110% of full load; if underloaded or overloaded, the efficiency could vary from the manufacturer's listing.

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

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

Appliances

In a cooling load estimate, heat gain from all appliances—electrical, gas, or steam—should be taken into account. Because of the variety of appliances, applications, schedules, use, and installations, estimates can be very subjective. Often, the only information available about heat gain from equipment is that on its nameplate. For electric office equipment in particular, Wilkins (1994) found nameplate data to be very misleading, overstating actual normal usage as much as 400%.

Cooking Appliances. These appliances include common heat-producing cooking equipment found in conditioned commercial kitchens. Marn (1962) concluded that appliance surfaces contributed most of the heat to commercial kitchens and that when installed under an effective hood, the cooling load was independent of the fuel or energy used for similar equipment performing the same operations.

Gordon et al. (1994) and Smith et al. (1995) found that gas appliances may exhibit slightly higher heat gains than their electric counterparts under wall-canopy hoods operated at typical ventilation rates. This is due to the fact that the heat contained in the combustion products exhausted from a gas appliance may increase temperatures of the appliance and surrounding surfaces as well as the hood above the appliance more than that of its electric counterpart. These higher-temperature surfaces radiate heat to the kitchen, adding moderately to the radiant gain directly associated with the appliance cooking surface.

Marn (1962) confirmed that where the appliances are installed under an effective hood, only radiant gain adds to the cooling load; convected and latent heat from the cooking process and combustion products are exhausted and do not enter the kitchen. Gordon et al. (1994) and Smith et al. (1995) substantiated these findings.

Calculating Sensible Heat Gain for Hooded Cooking Appliances. To establish a heat gain value, actual nameplate energy input ratings may should be used with appropriate usage and radiation factors. Where specific rating data are not available (nameplate missing, equipment not yet purchased, etc.) or as an alternative approach, recommended heat gains tabulated in this chapter for a wide variety of commonly encountered equipment items may be used. In estimating the appliance load, probabilities of simultaneous use and operation for different appliances located in the same space must be considered.

The radiant heat gain from hooded cooking equipment can range from 15 to 45% of the actual appliance energy consumption (Talbert et al. 1973, Gordon et al. 1994, Smith et al. 1995). This ratio of heat gain to appliance energy consumption may be expressed as a radiation factor. It is a function of both appliance type and fuel source. The radiant factor, F_R, is applied to the average rate of appliance energy consumption, determined by applying F_U to the nameplate or rated energy input. Marn (1962) found that radiant heat temperature rise can be substantially reduced by shielding the fronts of cooking appliances. Although this approach may not always be practical in a commercial kitchen, radiant gains can aso be reduced by adding side panels or partial enclosures that are integrated with the exhaust hood.

Heat Gain from Meals. For each meal served, the heat transferred to the dining space is approximately 50 Btu/h, of which 75% is sensible and 25% is latent.

Heat Gain for Electric and Steam Appliances. The average rate of appliance energy consumption can be estimated from the nameplate or rated energy input q_{input} by applying a duty cycle or usage factor F_U. Thus the sensible heat gain $q_{sensible}$ for generic types of electric, steam and gas appliances installed under a hood can be estimated using the following equation.

$$q_{sensible} = q_{input} F_U F_R \qquad (18)$$

or

$$q_{sensible} = q_{input} F_L \qquad (19)$$

where F_L is defined as the ratio of sensible heat gain to the manufacturers rated energy input.

Table 6 Heat Gain Factors of Typical Electric Appliances Under Hood

Appliance	Usage Factor F_U	Radiation Factor F_R	Load Factor $F_L = F_U F_R$ Elec/Steam
Griddle	0.16	0.45	0.07
Fryer	0.06	0.43	0.03
Convection oven	0.42	0.17	0.07
Charbroiler	0.83	0.29	0.24
Open-top range			
without oven	0.34	0.46	0.16
Hot-top range			
without oven	0.79	0.47	0.37
with oven	0.59	0.48	0.28
Steam cooker	0.13	0.30	0.04

Table 7 Heat Gain Factors of Typical Gas Appliances Under Hood

Appliance	Usage Factor F_U	Radiation Factor F_R	Load Factor $F_L = F_U F_R$ Gas
Griddle	0.25	0.25	0.06
Fryer	0.07	0.35	0.02
Convection oven	0.42	0.20	0.08
Charbroiler	0.62	0.18	0.11
Open-top range			
without oven	0.34	0.17	0.06

Table 6 lists usage factors, radiation factors, and load factors based on appliance energy consumption rate for typical electrical and steam appliances under standby or idle conditions (Alereza and Breen 1984, Fisher 1996); Table 7 lists usage factors, radiation factors, and load factors for comparable gas equipment (Fisher 1996).

Unhooded Equipment. For all cooking appliances not installed under an exhaust hood or directly vent-connected and located in the conditioned area, the heat gain may be estimated as 50% (usage factor = 0.50) or the rated hourly input, regardless of the type of energy or fuel used. On average, 34% of the heat may be assumed to be latent and the remaining 66% sensible heat. Note that cooking appliances ventilated by "ductless" hoods should be treated as unhooded appliances from the perspective of estimating heat gain. In other words, all energy consumed by the appliance and all moisture produced by the cooking process is introduced to the kitchen as a sensible or latent cooling load.

Recommended Heat Gain Values. As an alternative procedure, Table 8 lists recommended rates of heat gain from typical commercial cooking appliances (Alereza and Breen 1984, Fisher 1996). The data in the "with hood" columns assume installation under a properly designed exhaust hood connected to a mechanical fan exhaust system.

Hospital and Laboratory Equipment. Hospital and laboratory equipment items are major sources of heat gain in conditioned spaces. Care must be taken in evaluating the probability and duration of simultaneous usage when many components are concentrated in one area, such as laboratory, operating room, etc. Commonly, heat gain from equipment in a laboratory ranges from 15 to 70 Btu/(h·ft^2) or, in laboratories with outdoor exposure, as much as four times the heat gain from all other sources combined.

Office Appliances. Electric typewriters, calculators, checkwriters, teletype units, posting machines, etc., can generate 3 to 4 Btu/(h·ft^2) for general offices or 6 to 7 Btu/(h·ft^2) for purchasing and accounting departments. However, in offices having computer display terminals at most desks, heat gains range up to 15 Btu/(h·ft^2) (Table 9A).

A commonly encountered office environment includes a desktop computer and monitor at each workstation, along with a variety of shared devices such as printers, scanners, copy machines, and facsimile (FAX) machines. Nameplate ratings of such equipment should be significantly discounted. Diversity in usage patterns must be considered separately, as peak use of all equipment is unlikely to occur simultaneously. Table 9B summarizes average test results for 270,000 ft^2 of office space measured in five different buildings, in which the average electrical appliance heat gain was approximately 1 W/ft^2 (Wilkins 1994).

Diversity of usage will vary significantly with various types of equipment and the work habits of the occupants. Additionally, earlier models of microcomputers and monitors show little difference in heat generation whether in use or idle, while contemporary units normally have "Power Saver" features that significantly reduce power consumption when idle.

Environmental variations can also have an effect on the heat gain from appliances, primarily with regard to the percent of heat gain that is radiative versus convective. Table 9C illustrates typical measured data for several appliances (Wilkins 1994).

Computer rooms housing mainframe or minicomputer equipment must be considered individually. Computer manufacturers have data pertaining to various individual components. Additional insight should be sought from data processing managers as to schedules, near-term future planning, etc. Heat gain rates from digital computer equipment range from 75 to 175 Btu/(h·ft^2). While the trend in hardware development is toward less heat release on a component basis, the associated miniaturization tends to offset such unitary reduction by a higher concentration of equipment. Chapter 16 of the 1999 *ASHRAE Handbook—Applications* gives further information on the air conditioning of data processing areas.

INFILTRATION AND VENTILATION HEAT GAIN

Ventilation

Outdoor air must be introduced to ventilate conditioned spaces. Chapter 25 suggests minimum outdoor air requirements for representative applications, but the minimum levels are not necessarily adequate for all psychological attitudes and physiological responses. Where maximum economy in space and load is essential, as in submarines or other restricted spaces, as little as 1 cfm of outdoor air per person can be sufficient, provided that recirculated air is adequately decontaminated (Consolazio and Pecora 1947).

Local codes and ordinances frequently specify ventilation requirements for public places and for industrial installations. For example, minimum requirements for safe practice in hospital operating rooms are given in NFPA *Standard* 99. Although 100% outdoor air is sometimes used in operating rooms, this standard does not require it, and limiting the outdoor air to 6 to 8 changes per hour is finding increasing acceptance.

ASHRAE Standard 62 recommends minimum ventilation rates for most common applications. For general applications, such as offices, 20 cfm per person is suggested.

Ventilation air is normally introduced at the air-conditioning apparatus rather than directly into the conditioned space, and thus becomes a cooling coil load component instead of a space load component. Calculations for estimating this heat gain are discussed later.

Reducing heat gain from outdoor air by using filtered recirculated air in combination with outdoor air should be considered. Recirculated air can also be treated to control odor (see Chapter 13 of this volume and Chapter 44 of the 1999 *ASHRAE Handbook—Applications*).

Infiltration

The principles of estimating infiltration in buildings, with emphasis on the heating season, are discussed in Chapter 25. For the cooling

Table 8 Recommended Rate of Heat Gain from Restaurant Equipment Located in Air-Conditioned Areas

		Energy Rate, Btu/h		Recommended Rate of Heat Gain,[a] Btu/h			
				Without Hood			With Hood
Appliance	Size	Rated	Standby	Sensible	Latent	Total	Sensible
Electric, No Hood Required							
Barbeque (pit), per pound of food capacity	80 to 300 lb	136	—	86	50	136	42
Barbeque (pressurized), per pound of food capacity	44 lb	327	—	109	54	163	50
Blender, per quart of capacity	1 to 4 qt	1550	—	1000	520	1520	480
Braising pan, per quart of capacity	108 to 140 qt	360	—	180	95	275	132
Cabinet (large hot holding)	16.2 to 17.3 ft^3	7100	—	610	340	960	290
Cabinet (large hot serving)	37.4 to 406 ft^3	6820	—	610	310	920	280
Cabinet (large proofing)	16 to 17 ft^3	693	—	610	310	920	280
Cabinet (small hot holding)	3.2 to 6.4 ft^3	3070	—	270	140	410	130
Cabinet (very hot holding)	17.3 ft^3	21000	—	1880	960	2830	850
Can opener		580	—	580	—	580	0
Coffee brewer	12 cup/2 brnrs	5660	—	3750	1910	5660	1810
Coffee heater, per boiling burner	1 to 2 brnrs	2290	—	1500	790	2290	720
Coffee heater, per warming burner	1 to 2 brnrs	340	—	230	110	340	110
Coffee/hot water boiling urn, per quart of capacity	11.6 qt	390	—	256	132	388	123
Coffee brewing urn (large), per quart of capacity	23 to 40 qt	2130	—	1420	710	2130	680
Coffee brewing urn (small), per quart of capacity	10.6 qt	1350	—	908	445	1353	416
Cutter (large)	18 in. bowl	2560	—	2560	—	2560	0
Cutter (small)	14 in. bowl	1260	—	1260	—	1260	0
Cutter and mixer (large)	30 to 48 qt	12730	—	12730	—	12730	0
Dishwasher (hood type, chemical sanitizing), per 100 dishes/h	950 to 2000 dishes/h	1300	—	170	370	540	170
Dishwasher (hood type, water sanitizing), per 100 dishes/h	950 to 2000 dishes/h	1300	—	190	420	610	190
Dishwasher (conveyor type, chemical sanitizing), per 100 dishes/h	5000 to 9000 dishes/h	1160	—	140	330	470	150
Dishwasher (conveyor type, water sanitizing), per 100 dishes/h	5000 to 9000 dishes/h	1160	—	150	370	520	170
Display case (refrigerated), per 10 ft^3 of interior	6 to 67 ft^3	1540	—	617	0	617	0
Dough roller (large)	2 rollers	5490	—	5490	—	5490	0
Dough roller (small)	1 roller	1570	—	140	—	140	0
Egg cooker	12 eggs	6140	—	2900	1940	4850	1570
Food processor	2.4 qt	1770	—	1770	—	1770	0
Food warmer (infrared bulb), per lamp	1 to 6 bulbs	850	—	850	—	850	850
Food warmer (shelf type), per square foot of surface	3 to 9 ft^2	930	—	740	190	930	260
Food warmer (infrared tube), per foot of length	39 to 53 in.	990	—	990	—	990	990
Food warmer (well type), per cubic foot of well	0.7 to 2.5 ft^3	3620	—	1200	610	1810	580
Freezer (large)	73	4570	—	1840	—	1840	0
Freezer (small)	18	2760	—	1090	—	1090	0
Griddle/grill (large), per square foot of cooking surface	4.6 to 11.8 ft^2	9200	—	615	343	958	343
Griddle/grill (small), per square foot of cooking surface	2.2 to 4.5 ft^2	8300	—	545	308	853	298
Hot dog broiler	48 to 56 hot dogs	3960	—	340	170	510	160
Hot plate (double burner, high speed)		16720	—	7810	5430	13240	6240
Hot plate (double burner, stockpot)		13650	—	6380	4440	10820	5080
Hot plate (single burner, high speed)		9550	—	4470	3110	7580	3550
Hot water urn (large), per quart of capacity	56 qt	416	—	161	52	213	68
Hot water urn (small), per quart of capacity	8 qt	738	—	285	95	380	123
Ice maker (large)	220 lb/day	3720	—	9320	—	9320	0
Ice maker (small)	110 lb/day	2560	—	6410	—	6410	0
Microwave oven (heavy duty, commercial)	0.7 ft^3	8970	—	8970	—	8970	0
Microwave oven (residential type)	1 ft^3	2050 to 4780	—	2050 to 4780	—	2050 to 4780	0
Mixer (large), per quart of capacity	81 qt	94	—	94	—	94	0
Mixer (small), per quart of capacity	12 to 76 qt	48	—	48	—	48	0
Press cooker (hamburger)	300 patties/h	7510	—	4950	2560	7510	2390
Refrigerator (large), per 10 ft^3 of interior space	25 to 74 ft^3	753	—	300	—	300	0
Refrigerator (small), per 10 ft^3 of interior space	6 to 25 ft^3	1670	—	665	—	665	0
Rotisserie	300 hamburgers/h	10920	—	7200	3720	10920	3480
Serving cart (hot), per cubic foot of well	1.8 to 3.2 ft^3	2050	—	680	340	1020	328
Serving drawer (large)	252 to 336 dinner rolls	3750	—	480	34	510	150
Serving drawer (small)	84 to 168 dinner rolls	2730	—	340	34	380	110
Skillet (tilting), per quart of capacity	48 to 132 qt	580	—	293	161	454	218
Slicer, per square foot of slicing carriage	0.65 to 0.97 ft^2	680	—	682	—	682	216
Soup cooker, per quart of well	7.4 to 11.6 qt	416	—	142	78	220	68
Steam cooker, per cubic foot of compartment	32 to 64 qt	20700	—	1640	1050	2690	784
Steam kettle (large), per quart of capacity	80 to 320 qt	300	—	23	16	39	13
Steam kettle (small), per quart of capacity	24 to 48 qt	840	—	68	45	113	32
Syrup warmer, per quart of capacity	11.6 qt	284	—	94	52	146	45

Table 8 Recommended Rate of Heat Gain from Restaurant Equipment Located in Air-Conditioned Areas (*Concluded*)

		Energy Rate, Btu/h		Recommended Rate of Heat Gain,[a] Btu/h			
				Without Hood			With Hood
Appliance	**Size**	**Rated**	**Standby**	**Sensible**	**Latent**	**Total**	**Sensible**
Toaster (bun toasts on one side only)	1400 buns/h	5120	—	2730	2420	5150	1640
Toaster (large conveyor)	720 slices/h	10920	—	2900	2560	5460	1740
Toaster (small conveyor)	360 slices/h	7170	—	1910	1670	3580	1160
Toaster (large pop-up)	10 slice	18080	—	9590	8500	18080	5800
Toaster (small pop-up)	4 slice	8430	—	4470	3960	8430	2700
Waffle iron	75 in^2	5600	—	2390	3210	5600	1770
Electric, Exhaust Hood Required							
Broiler (conveyor infrared), per square foot of cooking area/minute	2 to 102 ft^2	19230	—	—	—	—	3840
Broiler (single deck infrared), per square foot of broiling area	2.6 to 9.8 ft^2	10870	—	—	—	—	2150
Charbroiler, per linear foot of cooking surface	2 to 8 linear ft	11,000	9300	—	—	—	2800
Fryer (deep fat)	35 - 50 lb oil	48,000	2900	—	—	—	1200
Fryer (pressurized), per pound of fat capacity	13 to 33 lb	1565	—	—	—	—	59
Oven (full-size convection)		41,000	4600	—	—	—	2900
Oven (large deck baking with 537 ft^3 decks), per cubic foot of oven space	15 to 46 ft^3	1670	—	—	—	—	69
Oven (roasting), per cubic foot of oven space	7.8 to 23 ft^3	27350	—	—	—	—	113
Oven (small convection), per cubic foot of oven space	1.4 to 5.3 ft^3	10340	—	—	—	—	147
Oven (small deck baking with 272 ft^3 decks), per cubic foot of oven space	7.8 to 23 ft^3	2760	—	—	—	—	113
Open range top, per 2 element section	2 to 6 elements	14,000	4600	—	—	—	2100
Range (hot top/fry top), per square foot of cooking surface	4 to 8 ft^2	7260	—	—	—	—	2690
Range (oven section), per cubic foot of oven space	4.2 to 11.3 ft^3	3940	—	—	—	—	160
Griddle, per linear foot of cooking surface	2 to 8 linear feet	19,500	3100	—	—	—	1400
Gas, No Hood Required							
Broiler, per square foot of broiling area	2.7 ft^2	14800	660[b]	5310	2860	8170	1220
Cheese melter, per square foot of cooking surface	2.5 to 5.1 ft^2	10300	660[b]	3690	1980	5670	850
Dishwasher (hood type, chemical sanitizing), per 100 dishes/h	950 to 2000 dishes/h	1740	660[b]	510	200	710	230
Dishwasher (hood type, water sanitizing), per 100 dishes/h	950 to 2000 dishes/h	1740	660[b]	570	220	790	250
Dishwasher (conveyor type, chemical sanitizing), per 100 dishes/h	5000 to 9000 dishes/h	1370	660[b]	330	70	400	130
Dishwasher (conveyor type, water sanitizing), per 100 dishes/h	5000 to 9000 dishes/h	1370	660[b]	370	80	450	140
Griddle/grill (large), per square foot of cooking surface	4.6 to 11.8 ft^2	17000	330	1140	610	1750	460
Griddle/grill (small), per square foot of cooking surface	2.5 to 4.5 ft^2	14400	330	970	510	1480	400
Hot plate	2 burners	19200	1325[b]	11700	3470	15200	3410
Oven (pizza), per square foot of hearth	6.4 to 12.9 ft^2	4740	660[b]	623	220	843	85
Gas, Exhaust Hood Required							
Braising pan, per quart of capacity	105 to 140 qt	9840	660[b]	—	—	—	2430
Broiler, per square foot of broiling area	3.7 to 3.9 ft^2	21800	530	—	—	—	1800
Broiler (large conveyor, infrared), per square foot of cooking area/minute	2 to 102 ft^2	51300	1990	—	—	—	5340
Broiler (standard infrared), per square foot of broiling area	2.4 to 9.4 ft^2	1940	530	—	—	—	1600
Charbroiler (large), per linear foot of cooking area	2 to 8 linear feet	36,000	22,000	—	—	—	3800
Fryer (deep fat)	35 to 50 oil cap.	80,000	5600	—	—	—	1900
Oven (bake deck), per cubic foot of oven space	5.3 to 16.2 ft^3	7670	660[b]	—	—	—	140
Oven (convection), full size		70,000	29,400	—	—	—	5700
Oven (pizza), per square foot of oven hearth	9.3 to 25.8 ft^2	7240	660[b]	—	—	—	130
Oven (roasting), per cubic foot of oven space	9 to 28 ft^3	4300	660[b]	—	—	—	77
Oven (twin bake deck), per cubic foot of oven space	11 to 22 ft^3	4390	660[b]	—	—	—	78
Range (burners), per 2 burner section	2 to 10 brnrs	33600	1325	—	—	—	6590
Range (hot top or fry top), per square foot of cooking surface	3 to 8 ft^2	11800	330	—	—	—	3390
Range (large stock pot)	3 burners	100000	1990	—	—	—	19600
Range (small stock pot)	2 burners	40000	1330	—	—	—	7830
Griddle, per linear foot of cooking surface	2 to 8 linear feet	25,000	6300				1600
Range top, open burner (per 2 burner section)	2 to 6 elements	40,000	13,600				2200
Steam							
Compartment steamer, per pound of food capacity/h	46 to 450 lb	280	—	22	14	36	11
Dishwasher (hood type, chemical sanitizing), per 100 dishes/h	950 to 2000 dishes/h	3150	—	880	380	1260	410
Dishwasher (hood type, water sanitizing), per 100 dishes/h	950 to 2000 dishes/h	3150	—	980	420	1400	450
Dishwasher (conveyor, chemical sanitizing), per 100 dishes/h	5000 to 9000 dishes/h	1180	—	140	330	470	150
Dishwasher (conveyor, water sanitizing), per 100 dishes/h	5000 to 9000 dishes/h	1180	—	150	370	520	170
Steam kettle, per quart of capacity	13 to 32 qt	500	—	39	25	64	19

[a]In some cases, heat gain data are given per unit of capacity. In those cases, the heat gain is calculated by: q = (recommended heat gain per unit of capacity) * (capacity)

[b]Standby input rating is given for entire appliance regardless of size.

Table 9A Rate of Heat Gain from Selected Office Equipment

Appliance	Size	Maximum Input Rating, Btu/h	Standby Input Rating, Btu/h	Recommended Rate of Heat Gain, Btu/h
Check processing workstation	12 pockets	16400	8410	8410
Computer devices				
Card puncher	—	2730 to 6140	2200 to 4800	2200 to 4800
Card reader	—	7510	5200	5200
Communication/transmission	—	6140 to 15700	5600 to 9600	5600 to 9600
Disk drives/mass storage	—	3410 to 34100	3412 to 22420	3412 to 22420
Magnetic ink reader	—	3280 to 16000	2600 to 14400	2600 to 14400
Microcomputer	16 to 640 Kbyte[a]	340 to 2050	300 to 1800	300 to 1800
Minicomputer	—	7500 to 15000	7500 to 15000	7500 to 15000
Optical reader	—	10240 to 20470	8000 to 17000	8000 to 17000
Plotters	—	256	128	214
Printers				
Letter quality	30 to 45 char/min	1200	600	1000
Line, high speed	5000 or more lines/min	4300 to 18100	2160 to 9040	2500 to 13000
Line, low speed	300 to 600 lines/min	1540	770	1280
Tape drives	—	4090 to 22200	3500 to 15000	3500 to 15000
Terminal	—	310 to 680	270 to 600	270 to 600
Copiers/Duplicators				
Blue print	—	3930 to 42700	1710 to 17100	3930 to 42700
Copiers (large)	30 to 67[a] copies/min	5800 to 22500	3070	5800 to 22500
Copiers (small)	6 to 30[a] copies/min	1570 to 5800	1020 to 3070	1570 to 5800
Feeder	—	100	—	100
Microfilm printer	—	1540	—	1540
Sorter/collator	—	200 to 2050	—	200 to 2050
Electronic equipment				
Cassette recorders/players	—	200	—	200
Receiver/tuner	—	340	—	340
Signal analyzer	—	90 to 2220	—	90 to 2220
Mailprocessing				
Folding machine	—	430	—	270
Inserting machine	3600 to 6800 pieces/h	2050 to 11300	—	1330 to 7340
Labeling machine	1500 to 30000 pieces/h	2050 to 22500	—	1330 to 14700
Postage meter	—	780	—	510
Wordprocessors/Typewriters				
Letter quality printer	30 to 45 char/min	1200	600	1000
Phototypesetter	—	5890	—	5180
Typewriter	—	270	—	230
Wordprocessor	—	340 to 2050	—	300 to 1800
Vending machines				
Cigarette	—	250	51 to 85	250
Cold food/beverage	—	3920 to 6550	—	1960 to 3280
Hot beverage	—	5890	—	2940
Snack	—	820 to 940	—	820 to 940
Miscellaneous				
Barcode printer	—	1500	—	1260
Cash registers	—	200	—	160
Coffee maker	10 cups	5120	—	3580 sens., 1540 latent
Microfiche reader	—	290	—	290
Microfilm reader	—	1770	—	1770
Microfilm reader/printer	—	3920	—	3920
Microwave oven	1 ft^3	2050	—	1360
Paper shredder	—	850 to 10240	—	680 to 8250
Water cooler	32 qt/h	2390	—	5970

[a] Input is not proportional to capacity.

Table 9B Heat Gain Versus Nameplate Rating From Electrical Office Equipment

Equipment Tested	Nameplate Rating, W	Measured Total Power Consumption, W	Radiant Power, W	Radiant Power, %	Convective Power, %
15 in. monitor energy saver (white screen)	220	78	28.8	37.1	62.9
Laser printer	836	248	26.6	10.7	89.3
Desktop copier	1320	181	25.9	14.3	85.7
Personal computer (Brand 1) and 17 in. monitor (white screen)	575	133	29.7	22.3	77.7
Personal computer (Brand 2) and 17 in. monitor (white screen)	420	125	35.7	28.6	71.4

Table 9C Environmental Effects on Radiant-Convective Split of 15 in. Energy Saver Monitor

(Nominal measured total power consumption = 80 W, Nameplate rating = 220 W)

I. Room Air Velocity and Temperature Effects			
	Radiative Power, %		
	60°F room air	70°F room air	80°F room air
Normal air velocity	35.6	40.7	45
Reduced air velocity	36	37.1	45.7

II. Room Air Temperature Fluctuation Effects (±6°F about mean room of 70°F)		
	Radiative Power, %	
	With air temp. fluctuation	Without air temperature fluctuation
Normal air velocity	37.7	40.7
Reduced air velocity	38.2	37.1

III. Room Wall Temperature Effects (Room air at 70°F)		
	Radiative Power, %	
	With uniform wall temperature	With nonuniform wall temperature (one wall heated)
Reduced air velocity	37.1	27

season, infiltration calculations are usually limited to doors and windows. Air leakage through doors can be estimated using the information in Chapter 25. Table 3, Chapter 25, adjusted for the average wind velocity in the locality, may be used to compute infiltration for windows. In calculating window infiltration for an entire structure, the total window area on all sides of the building is not involved, since wind does not act on all sides simultaneously. In any case, infiltration from all windows in any two adjacent wall exposures should be included. A knowledge of the prevailing wind direction and velocity is helpful in selecting exposures.

When economically feasible, sufficient outdoor air should be introduced as ventilation air through the air-conditioning equipment to maintain a constant outward escape of air, and thus eliminate the infiltration portion of the gain. The pressure maintained must overcome wind pressure through cracks and door openings. When the quantity of outside air introduced through the cooling equipment is not sufficient to maintain the required pressure to eliminate infiltration, the entire infiltration load should be included in the space heat gain calculations.

Standard Air Defined

Because the specific volume of air varies appreciably, calculations will be more accurate when made on the basis of air mass instead of volume. However, volume values are often required for selection of coils, fans, ducts, etc., in which cases volume values based on measurement at standard conditions may be used for accurate results. One standard value is 0.075 lb (dry air)/ft^3 (13.33 ft^3/lb). This density corresponds to about 60°F at saturation, and 69°F dry air (at 14.7 psia). Because air usually passes through the coils, fans, ducts, etc. at a density close to standard, the accuracy desired normally requires no correction. When airflow is to be measured at a particular condition or point, such as at a coil entrance or exit, the corresponding specific volume can be read from the psychrometric chart.

Example 2. Standard air calculations. Assume outdoor air at standard conditions is flowing at 1000 cfm. What is the flow rate when the outdoor air is at 95°F dry-bulb and 75°F wet-bulb (14.3 ft^3/lb)? The measured rate at that condition should be 1000(14.3/13.33) = 1070 cfm.

Solution: Air-conditioning design often requires calculation of:

1. Total heat

Total heat gain corresponding to the change of a given standard flow rate Q_s through an enthalpy difference Δh

$$\begin{aligned}\text{Total heat change} &= 60 \times 0.075 Q_s \Delta h \\ &= 4.5 Q_s \Delta h\end{aligned} \quad (20)$$

where 60 = min/h and 0.075 = lb (dry air)/ft^3.

2. Sensible heat

Sensible heat gain corresponding to the change of dry-bulb temperature Δt for given airflow (standard conditions) Q_s, or sensible heat change q_s, in Btu/h, is

$$q_s = 60 \times 0.075 (0.24 + 0.45 W) Q_s \Delta t \quad (21)$$

where

0.24 = specific heat of dry air, Btu/(lb · °F)
W = humidity ratio, lb (water)/lb (dry air)
0.45 = specific heat of water vapor, Btu/(lb · °F)

The specific heats are for a range from about −100 to 200°F. When $W = 0$, the value of $60 \times 0.075(0.24 + 0.45W) = 1.08$; when $W = 0.01$, the value is 1.10; when $W = 0.02$, the value is 1.12; and when $W = 0.03$, the value is 1.14. Thus, because a value of $W = 0.01$ approximates conditions found in many air-conditioning problems, the sensible heat change (in Btu/h) can normally be found as

$$q_s = 1.10 Q_s \Delta t \quad (22)$$

3. Latent heat

Latent heat gain corresponding to the change of humidity ratio (ΔW) for given air flow (standard conditions) Q_s is

$$\begin{aligned}q_l &= 60 \times 0.075 \times 1076 Q_s \Delta W \\ &= 4840 Q_s \Delta W\end{aligned} \quad (23)$$

where 1076 is the approximate heat content of 50% rh vapor at 75°F, less the heat content of water at 50°F. The 50% rh at 75°F is a common design condition for the space, and 50°F is normal condensate temperature from cooling and dehumidifying coils.

The constants 4.5, 1.10, and 4840 are useful in air-conditioning calculations at sea level (14.7 psia) and for normal temperatures and moisture ratios. For other conditions, more precise values should be used. For an altitude of 5000 ft (12.2 psia), appropriate values are 3.73, 0.92, and 4020.

Latent Heat Gain from Moisture through Permeable Building Materials

The diffusion of moisture through all common building materials is a natural phenomenon that is always present. Chapters 22 and 23 cover the principles and specific methods used to control moisture. Moisture transfer through walls is often neglected in the usual comfort air-conditioning application, because the actual rate is quite small, and the corresponding latent heat gain is insignificant. The permeability and permeance values for various building materials are given in Table 9, Chapter 24. Vapor retarders are frequently installed to keep moisture transfer to a minimum.

Special Conditions. Certain industrial applications call for a low moisture content to be maintained in a conditioned space. In such cases, the latent heat gain accompanying moisture transfer through walls may be greater than any other latent heat gain. This gain is computed by

$$q_m = (M/7000) A \Delta p_v (h_g - h_f) \quad (24)$$

where

q_m = latent heat gain, Btu/h
M = permeance of wall assembly in perms, or grains/(ft^2 · h · in Hg)
7000 = grains/lb
A = area of wall surface, ft^2
Δp_v = vapor pressure difference, in. Hg
h_g = enthalpy at room conditions, Btu/lb
h_f = enthalpy of water condensed at cooling coil, Btu/lb
= 1076 Btu/lb when room temperature is 75°F and condensate off coil is 50°F

Heat Gain from Miscellaneous Sources

The calculation of the cooling load is affected by such factors as (1) type of HVAC system, (2) effectiveness of heat exchange surfaces, (3) fan location, (4) duct heat gain or loss, (5) duct leakage, (6) heat-extraction lighting systems, (7) type of return air system, and (8) sequence of controls. System performance needs to be analyzed as a sequence of individual psychrometric processes. The most straightforward method first defines all known (or desired) state points on a psychrometric chart. Next, the actual entering and leaving dry- and wet-bulb conditions are calculated for such components as the cooling and/or heating coils (based on zone or space load), the amount of outside air introduced into the system through the equipment, and the amount of heat gain or loss at various points.

This overall process must verify that the space conditions originally sought can actually be met by the designed system by considering all sensible and latent heat changes to the air as it travels from the space conditions through the return air system and equipment back to the conditioned space. If the design is successful (i.e., within the degree of correctness of the various design assumptions), appropriate equipment components can safely be selected. If not, the designer must judge if the results will be “close enough” to satisfy the needs of the project, or if one or more assumptions and/or design criteria must first be modified and the calculations rerun.

Heat Gain from Fans. Fans that circulate air through HVAC systems add energy to the system by one or all of the following processes:

- Temperature rise in the airstream from fan inefficiency. Depending on the equipment, fan efficiencies generally range between 50 and 70%, with an average value of 65%. Thus, some 35% of the energy required by the fan appears as instantaneous heat gain to the air being transported.
- Temperature rise in the airstream as a consequence of air static and velocity pressure. The “useful” 65% of the total fan energy that creates pressure to move air spreads out throughout the entire air transport system in the process of conversion to sensible heat. Designers commonly assume that the temperature change equivalent of this heat occurs at a single point in the system, depending on fan location as noted below.
- Temperature rise from heat generated by motor and drive inefficiencies. The relatively small gains from fan motors and drives are normally disregarded unless the motor and/or drive are physically located within the conditioned airstream. Equations (15), (16), and (17) may be used to estimate heat gains from typical motors. Belt drive losses are often estimated as 3% of the motor power rating. Conversion to temperature rise is calculated by Equation (22).

The location of each fan relative to other elements (primarily the cooling coil), and the type of system (e.g., single zone, multizone, double-duct, terminal reheat, VAV) along with the concept of equipment control (space temperature alone, space temperature and relative humidity, etc.) must be known before the analysis can be completed. A fan located upstream of the cooling coil (blowthrough supply fan, return air fan, outside air fan) adds the heat equivalent of its inefficiency to the airstream at that point; thus, a slightly elevated entering dry-bulb temperature to the cooling coil results. A fan located downstream of the cooling coil raises the dry-bulb temperature of air leaving the cooling coil. This rise can be offset by reducing the cooling coil temperature, or alternatively, by increasing airflow across the cooling coil as long as its impact on space conditions is considered.

Duct Heat Gain and Leakage. Unless return air duct systems are extensive or subjected to rigorous conditions, only the heat gained or lost by supply duct systems is significant; it is normally estimated as a percentage of space sensible cooling load (usually about 1%) and applied to the dry-bulb temperature of the air leaving the coil in the form of an equivalent temperature reduction.

Duct Leakage. Air leakage out of (or into) duct work can have much greater impact than conventional duct heat gain or loss, but it is normally about the same or less. Outward leakage from supply ducts is a direct loss of cooling and/or dehumidifying capacity and must be offset by increased airflow (sometimes reduced supply air temperatures) unless it enters the conditioned space directly. Inward leakage to return ducts causes temperature and/or humidity variations, but these are often ignored under ordinary circumstances due to the low temperature and pressure differentials involved. Chapter 32 has further details on duct sealing and leakage.

A well-designed and installed duct system should not leak more than 1 to 3% of the total system airflow. All HVAC equipment and volume control units connected into a duct system are usually delivered from manufacturers with allowable leakage not exceeding 1 or 2% of maximum airflow rating. Where duct systems are specified to be sealed and leak tested, both low and medium pressure types can be constructed and required to fall within this range, and designers normally assume this loss to approximate 1% of the space load, handled in a similar manner to that for duct heat gain. Latent heat considerations are frequently ignored.

Poorly designed or installed duct systems can have leakage rates of 10 to 30%. Leakage from low-pressure lighting troffer connections lacking proper taping and sealing can be 35% or more of the terminal air supply. Improperly sealed high-pressure systems can leak as much as 10% or more from the high-pressure side alone, before considering the corresponding low-pressure side of such systems. Such extremes destroy the validity of any load calculation procedures. Although not always affecting overall system loads enough to cause problems, they will, however, always adversely impact required supply air quantities for most air-conditioning systems. Also, using uninsulated supply duct work running through return air plenums results in high “thermal leakage,” thus loss of space cooling capability by the supply air, and potential condensation difficulties during a warm startup.

HEATING LOAD PRINCIPLES

Techniques for estimating design heating load for commercial, institutional, and industrial applications are essentially the same as for those estimating design cooling loads for such uses, except that (1) temperatures outside the conditioned spaces are generally lower than the space temperatures maintained; (2) credit for solar heat gains or for internal heat gains is not included; and (3) the thermal storage effect of building structure or content is ignored. Heat losses (negative heat gains) are thus considered to be instantaneous, heat transfer essentially conductive, and latent heat treated only as a function of replacing space humidity lost to the exterior environment.

Justification of this simplified approach derives from the purpose of a heating load estimate, as identification of “worst case” conditions that can reasonably be anticipated during a heating season. Traditionally this is considered as the load that must be met under design interior and exterior conditions, including infiltration and/or ventilation, but in the absence of solar effect (at night or cloudy winter days) and before the periodic presence of people, lights, and appliances can begin to have an offsetting effect. The primary orientation is thus toward identification of adequately sized heating equipment to handle the normal worst-case condition.

Safety Factors and Load Allowances. Before mechanical cooling of buildings became a usual procedure, buildings included much less insulation, large operable windows, and generally more infiltration-prone assemblies than the energy-efficient and much tighter buildings typical of post-1975 design. Allowances of 10 to 20% of the net calculated heating load for piping losses to unheated spaces, and 10 to 20% more for a warm-up load were common practice, along with occasional other safety factors reflecting the experience and/or concern of the individual designer. Such measures are infrequently used in estimating heating loads for contemporary buildings, with the uncompensated net heating load normally considered as having an adequate margin for error.

Cooling Needs During Noncooling Months. Perimeter spaces exposed to high solar heat gain often justify mechanical cooling during sunlit portions of traditional heating months, as will completely interior spaces with significant internal heat gain. These conditions require special attention by the system designer for proper accommodation as needed, but such spaces can also represent significant heating loads during nonsunlit hours or after periods of nonoccupancy when adjacent spaces have been allowed to cool below interior design temperatures. The loads involved can be estimated conventionally for the purpose of designing the means to offset or to compensate for them and prevent overheating, but they have no direct relationship to design heating loads for the spaces in question.

Other Considerations. Calculation of design heating load estimates for this general category of applications has essentially become a subset of the more involved and complex estimation of cooling loads for such spaces. Chapter 30 discusses using the heating load estimate to predict or analyze energy consumption over time. Special provisions to deal with atypical problems are relegated to appropriate chapters in the *Systems and Equipment* and *Applications* volumes.

TRANSFER FUNCTION METHOD CALCULATION PROCEDURE

BASIC COOLING LOAD ANALYSIS

The basic procedures for estimating the maximum design cooling load for a conditioned space were developed when all design calculations were performed manually. For this reason, extensive design analysis was not part of the primary load estimate. Today, with computers used for routine design calculations, the individual load elements may be evaluated more thoroughly and a comprehensive design analysis can be included with the results. The TFM method makes it possible to estimate the cooling load for a conditioned space on an hour-by-hour basis and to predict resultant conditions that can be expected in that space for various system types, control strategies, and operating schedules. The equations and sequence of the TFM Procedure in general are summarized in Table 10.

HEAT GAIN BY CONDUCTION THROUGH EXTERIOR WALLS AND ROOFS

Sensible Heat Gain

The transfer function method (TFM) is particularly well suited for use with a computer. This method is a special case of the calculation of heat flow through building components outlined in Chapter 22. This approach uses (1) sol-air temperature to represent outdoor conditions, and (2) an assumed constant indoor air temperature. Furthermore, both indoor and outdoor surface heat transfer coefficients are assumed constant (Mitalas 1968). Thus, the heat gain through a wall or roof is given by

$$q_{e,\theta} = A\left[\sum_{n=0} b_n(t_{e,\theta-n\delta}) - \sum_{n=1} \frac{d_n(q_{e,\theta-n\delta})}{A} - t_{rc}\sum_{n=0} c_n\right] \quad (25)$$

where

$q_{e,\theta}$ = heat gain through wall or roof, at calculation hour θ
A = indoor surface area of a wall or roof
θ = time
δ = time interval
n = summation index (each summation has as many terms as there are non-negligible values of coefficients)
$t_{e,\theta-n\delta}$ = sol-air temperature at time $\theta - n\delta$
t_{rc} = constant indoor room temperature
b_n, c_n, d_n = conduction transfer function coefficients

Conduction Transfer Function Coefficients. Conduction transfer function (CTF) coefficients are usually calculated using combined outdoor heat transfer coefficient h_o = 3.0 Btu/(h·ft²·°F), indoor coefficient h_i = 1.46 Btu/(h·ft²·°F), and the wall or roof constructions, as may be appropriate. The use of h_o = 3.0 limits the application of these coefficients to cases with similarly calculated sol-air temperature values. Specific CTF coefficients for different constructions can be calculated using the procedure and computer program outlined in Mitalas and Arseneault (1970) or as discussed by McQuiston and Spitler (1992) and with the microcomputer software issued with that publication.

Representative Walls and Roofs. Harris and McQuiston (1988) investigated the thermal behavior of approximately 2600 walls and 500 roofs as they influenced transmission of heat gain to conditioned spaces. This work identified 41 representative wall assemblies and 42 roof assemblies with widely varying components, insulating values, and mass, and with the predominant mass concentrated near the inside surface (mass in), outside surface (mass out), or essentially homogeneous (mass integral) with the overall construction. These prototypical assemblies can be used to reflect the overall range of conditions. The CTF and associated data pertaining to these conditions are listed in Tables 11 through 19.

Approximate values of CTF coefficients can be obtained by selecting a set of data from Tables 13 and 14 for a roof construction or Tables 18 and 19 for a wall that is nearly the same as the roof or wall under consideration, and multiplying the s and s by the ratio of the U-factor of the roof or wall under consideration over the U-factor of the selected representative roof or wall.

The physical and thermal properties of the various layers that make up roof and wall assemblies are listed in Table 11. Group numbers for various arrangements of layers with differing insulation R value and placement for roofs are listed in Table 12 and those for walls are listed in Tables 15, 16 and 17. Data from these tables identify prototypical roof or wall CTFs and associated data tabulated in Tables 13, 14, 18, and 19.

Example 3. Heat gain through wall. A light-colored wall is constructed of 4 in. heavy concrete, 2 in. insulation (2.0 lb/ft³, R = 6.667 h·ft²·°F/Btu), 3/4 in. indoor plaster, and with outdoor and indoor surface resistances of 0.333 and 0.68 h·ft²·°F/Btu, respectively. There is an air space between the plaster and the insulation. Find the heat gain through 1 ft² of the wall area (i.e., A = 1.0 ft²) with sol-air temperature as listed in Table 1 for July 21, 40°North latitude, West, α/h_0 = 0.15, a room temperature of 75°F, and assuming that the daily sol-air temperature cycle is repeated on several consecutive days.

Solution: The calculation of heat gain for a particular time requires sol-air temperature values at that and preceding times, as well as the heat flow at preceding times. Heat flow is assumed as zero to start the calculations. The effect of this assumption becomes negligible as the calculation is repeated for successive 24-h cycles.

Sol-Air Temperatures (from Table 1)

Time, h	t_e, °F	Time, h	t_e, °F
1	76	13	110
2	76	14	121
3	75	15	129
4	74	16	131
5	74	17	127
6	75	18	114
7	78	19	87
8	81	20	85
9	85	21	83
10	89	22	81
11	93	23	79
12	97	24	77

For θ > 24, $t_{e,\theta} = t_{e,\theta-24}$.

Table 10 Summary of TFM Load Calculation Procedures

External Heat Gain

$$t_e = t_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \quad (6)$$

$$t_{ea} = t_{oa} + \alpha / h_o (I_{DT} / 24) - \varepsilon \Delta R / h_o \quad (7)$$

where

t_e = sol-air temperature
t_o = current hour dry-bulb temperature, from design db (Chapter 26) adjusted by Table 2 daily range % values

α = absorptance of surface for solar radiation
α/h_o = surface color factor = 0.026 for light colors, 0.052 for dark
I_t = total incident solar load = 1.15 (SHGF), with SHGF per Chapter 29, Tables 15 through 21
$\varepsilon\Delta R/h_o$ = long-wave radiation factor = −7°F for horizontal surfaces, 0°F for vertical
t_e = 24-h average sol-air temperature
t_{oa} = 24-h average dry-bulb temperature
I_{DT} = total daily solar heat gain (Chapter 29, Tables 15 through 21)

Roofs and Walls

$$q_{e,\theta} = A\left[\sum_{n=0} b_n(t_{e,\theta-n\delta}) - \sum_{n=1} d_n[(q_{e,\theta-n\delta})/A] - t_{rc} - \sum_{n=0} c_n\right] \quad (28)$$

where

b and d = conduction transfer coefficients—roof, Table 13; wall, Table 18
c and U_{table} = conduction transfer coefficients—roof, Table 14; wall, Table 19
U_{actual} = design heat transfer coefficient for roof or wall, from Chapter 24, Table 4

Adjust b and c coefficients by ratio U_{actual}/U_{table}.

Roofs

Identify layers of roof construction from Table 11. With R-value of dominant layer, identify R-value Range number R and Roof Group number from Table 12. Proceed to Table 13.

Walls

Identify layers of wall construction from Table 11. With R-value of dominant layer, identify R-value Range number and Wall Group number from Table 15, 16, or 17. Proceed to Table 14.

θ = hour for which calculation is made
δ = time interval (1 h)
n = number of hours for which and values are significant
e = element under analysis, roof or wall assembly
A = area of element under analysis

Glass

Convective $q = UA(t_o - t_i)$
Solar $q = A$(SC)(SHGF)

U = design heat transfer coefficients, glass—Chapter 29
SC = shading coefficient—Chapter 29
SHGF = solar heat gain factor by orientation, north latitude, hour, and month—Chapter 29, Tables 15 to 21.

Partitions, Ceilings, Floors

$$q = UA\,(t_b - t_i) \quad (8)$$

t_b = temperature in adjacent space
t_i = inside design temperature in conditioned space

Internal Heat Gain

People

$q_{sensible} = N$(Sensible heat gain)
$q_{latent} = N$(Latent heat gain)

N = number of people in space, from best available source. Sensible and latent heat gain from occupancy—Table 3, or Chapter 8; adjust as required.

Lights

$$q_{el} = 3.41\,W F_{ul} F_{sa} \quad (9)$$

where

W = watts input from electrical plans or lighting fixture data
F_{ul} = lighting use factor, from the first section, as appropriate
F_{sa} = special allowance factor, from first section, as appropriate

Power

$$q_p = 2545\,P E_F \quad (15), (16), (17)$$

where

P = power rating from electrical plans or manufacturer's data
E_F = efficiency factors and arrangements to suit circumstances

Appliances

where $$q_{sensible} = q_{input} F_U F_R \quad (18)$$

or $$q_{sensible} = q_{input} F_L \quad (19)$$

q_{input} = rated energy input from appliances—Tables 5 to 9, or manufacturer's data (set latent heat = 0, if appliance is under exhaust hood)
F_U, F_R, F_L = usage factors, radiation factors, and load factors

Ventilation and Infiltration Air

$$q_{sensible} = 1.10\,Q(t_o - t_i) \quad (22)$$

$$q_{latent} = 4840\,Q(W_o - W_i) \quad (23)$$

$$q_{total} = 4.5\,Q(H_o - H_i) \quad (20)$$

Q = ventilation airflow—ASHRAE *Standard* 62; infiltration cfm—Chapter 25
t_o, t_i = outside, inside air temperature, °F
W_o, W_i = outside, inside air humidity ratio, lb (water)/lb (da)
H_o, H_i = outside, inside air enthalpy, Btu/lb (dry air)

Cooling Load

Sensible $Q\theta = Q_{rf} + Q_{sc}$

$$Q_{tf} = \sum_{i=1} (v_0 q_{\theta,i} + v_1 q_{\theta,i-\delta} + v_2 q_{\theta,i-2\delta} + \ldots) - (w_1 Q_{\theta-\delta} + w_2 Q_{\theta-2\delta} + \ldots) \quad (28)$$

$$Q_{sc} = \sum_{j=1} (q_{c,j}) \quad (30)$$

Q_{tf} = sensible cooling load from heat gain elements having convective and radiant components
v and w = room transfer function coefficients, Tables 24 and 25; select per element type, circulation rate, mass, and/or fixture type
q_θ = each of i heat gain elements having a radiant component; select appropriate fractions for processing, per Tables 24, 25, and 42
δ = time interval (1 h)
Q_{sc} = sensible cooling load from heat gain elements having only convective components
q_c = each of j heat gain elements having only convective component

Latent $Q_l = \sum_{n=1} (q_{c,n})$

q_c = each of n latent heat gain elements

Table 11 Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions for Tables 12 and 13

Code Number	Description	Thickness and Thermal Properties					
		L	*k*	ρ	c_p	*R*	Mass
A0	Outside surface resistance	0.0	0.0	0.0	0.0	0.33	0.0
A1	1 in. Stucco	0.0833	0.4	116.0	0.20	0.21	9.7
A2	4 in. Face brick	0.333	0.77	125.0	0.22	0.43	41.7
A3	Steel siding	0.005	26.0	480.0	0.10	0.00	2.4
A4	1/2 in. Slag	0.0417	0.11	70.0	0.40	0.38	2.2
A5	Outside surface resistance	0.0	0.0	0.0	0.0	0.33	0.0
A6	Finish	0.0417	0.24	78.0	0.26	0.17	3.3
A7	4 in. Face brick	0.333	0.77	125.0	0.22	0.43	41.7
B1	Air space resistance	0.0	0.0	0.0	0.0	0.91	0.0
B2	1 in. Insulation	0.083	0.025	2.0	0.2	3.33	0.2
B3	2 in. Insulation	0.167	0.025	2.0	0.2	6.67	0.3
B4	3 in. Insulation	0.25	0.025	2.0	0.2	10.0	0.5
B5	1 in. Insulation	0.0833	0.025	5.7	0.2	3.33	0.5
B6	2 in. Insulation	0.167	0.025	5.7	0.2	6.67	1.0
B7	1 in. Wood	0.0833	0.07	37.0	0.6	1.19	3.1
B8	2.5 in. Wood	0.2083	0.07	37.0	0.6	2.98	7.7
B9	4 in. Wood	0.333	0.07	37.0	0.6	4.76	12.3
B10	2 in. Wood	0.167	0.07	37.0	0.6	2.39	6.2
B11	3 in. Wood	0.25	0.07	37.0	0.6	3.57	9.3
B12	3 in. Insulation	0.25	0.025	5.7	0.2	10.00	1.4
B13	4 in. Insulation	0.333	0.025	5.7	0.2	13.33	1.9
B14	5 in. Insulation	0.417	0.025	5.7	0.2	16.67	2.4
B15	6 in. Insulation	0.500	0.025	5.7	0.2	20.00	2.9
B16	0.15 in. Insulation	0.0126	0.025	5.7	0.2	0.50	0.1
B17	0.3 in. Insulation	0.0252	0.025	5.7	0.2	1.00	0.1
B18	0.45 in. Insulation	0.0379	0.025	5.7	0.2	1.50	0.2
B19	0.61 in. Insulation	0.0505	0.025	5.7	0.2	2.00	0.3
B20	0.76 in. Insulation	0.0631	0.025	5.7	0.2	2.50	0.4
B21	1.36 in. Insulation	0.1136	0.025	5.7	0.2	4.50	0.6
B22	1.67 in. Insulation	0.1388	0.025	5.7	0.2	5.50	0.8
B23	2.42 in. Insulation	0.2019	0.025	5.7	0.2	8.00	1.2
B24	2.73 in. Insulation	0.2272	0.025	5.7	0.2	9.00	1.3
B25	3.33 in. Insulation	0.2777	0.025	5.7	0.2	11.00	1.6
B26	3.64 in. Insulation	0.3029	0.025	5.7	0.2	12.00	1.7
B27	4.54 in. Insulation	0.3786	0.025	5.7	0.2	15.00	2.2
C1	4 in. Clay tile	0.333	0.33	70.0	0.2	1.01	23.3
C2	4 in. Lightweight concrete block	0.333	0.22	38.0	0.2	1.51	12.7
C3	4 in. Heavyweight concrete block	0.333	0.47	61.0	0.2	0.71	20.3
C4	4 in. Common brick	0.333	0.42	120.0	0.2	0.79	40.0
C5	4 in. Heavyweight concrete	0.333	1.0	140.0	0.2	0.33	46.7
C6	8 in. Clay tile	0.667	0.33	70.0	0.2	2.00	46.7
C7	8 in. Lightweight concrete block	0.667	0.33	38.0	0.2	2.00	25.3
C8	8 in. Heavyweight concrete block	0.667	0.6	61.0	0.2	1.11	40.7
C9	8 in. Common brick	0.667	0.42	120.0	0.2	1.59	80.0
C10	8 in. Heavyweight concrete	0.667	1.0	140.0	0.2	0.67	93.4
C11	12 in. Heavyweight concrete	1.0	1.0	140.0	0.2	1.00	140.0
C12	2 in. Heavyweight concrete	0.167	1.0	140.0	0.2	0.17	23.3
C13	6 in. Heavyweight concrete	0.5	1.0	140.0	0.2	0.50	70.0
C14	4 in. Lightweight concrete	0.333	0.1	40.0	0.2	3.33	13.3
C15	6 in. Lightweight concrete	0.5	0.1	40.0	0.2	5.00	20.0
C16	8 in. Lightweight concrete	0.667	0.1	40.0	0.2	6.67	26.7
C17	8 in. Lightweight concrete block (filled)	0.667	0.08	18.0	0.2	8.34	12.0
C18	8 in. Heavyweight concrete block (filled)	0.667	0.34	53.0	0.2	1.96	35.4
C19	12 in. Lightweight concrete block (filled)	1.000	0.08	19.0	0.2	12.50	19.0
C20	12 in. Heavyweight concrete block (filled)	1.000	0.39	56.0	0.2	2.56	56.0
E0	Inside surface resistance	0.0	0.0	0.0	0.0	0.69	0.0
E1	3/4 in. Plaster or gypsum	0.0625	0.42	100.0	0.2	0.15	6.3
E2	1/2 in. Slag or stone	0.0417	0.83	55.0	0.40	0.05	2.3
E3	3/8 in. Felt and membrane	0.0313	0.11	70.0	0.40	0.29	2.2
E4	Ceiling air space	0.0	0.0	0.0	0.0	1.00	0.0
E5	Acoustic tile	0.0625	0.035	30.0	0.2	1.79	1.9

L = thickness, ft
k = thermal conductivity, Btu/h·ft·°F
ρ = density, lb/ft^3
c_p = specific heat, Btu/lb·°F
R = thermal resistance, $°F \cdot ft^2 \cdot h/Btu$
Mass = unit mass, lb/ft^2

Table 12 Roof Group Numbers

Roofs without Suspended Ceilings

Roof Materials[a]		Mass In						Integral Mass						Mass Out					
		R-Value Range Numbers[b]						R-Value Range Numbers[b]						R-Value Range Numbers[b]					
No.	**Codes**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
1	B7							1	2	2	4	4							
2	B8							4	5	9	10	18							
3	B9							19	21	27	27	28							
4	C5	6	7	7	10	10		3						6	7	7	10	11	
5	C12	2	2	4	4	5		2						2	3	4	5	5	
6	C13	7	12	13	13	20		5						7	12	13	13	20	
7	C14		4	5	9	9		2	2						4	5	9	9	
8	C15		5	10	18	18	18		4						5	10	10	18	18
9	C16		9	19	20	27	27		9						9	18	20	27	27
10	A3							1	1	1	2	2							
11	Attic							1	2	2	2	4							
Roof Terrace Systems																			
12	C12-C12							4	5	9	9	9		5	5	7	9	9	
13	C12-C5							6	11	12	18	18		7	12	12	12	20	
14	C12-C13							11	20	20	21	27		12	13	21	21	21	
15	C5-C12							5	10	10	17	17		5	10	11	11	18	
16	C5-C5							10	20	20	26	26		10	13	21	21	21	
17	C5-C13							20	27	28	28	35		20	22	22	22	28	
18	C13-C12							10	18	20	20	26		10	13	20	29	21	
19	C13-C5							18	27	27	28	35		20	22	22	28	28	
20	C13-C13							21	29	30	36	36		21	29	30	31	36	

Roofs with Suspended Ceilings

Roof Materials[a]		Mass In						Integral Mass						Mass Out					
		R-Value Range Numbers[b]						R-Value Range Numbers[b]						R-Value Range Numbers[b]					
No.	**Codes**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
1	B7								4	5	9	10	10						
2	B8								9	20	21	22	28						
3	B9								20	28	30	37	38						
4	C5	8	15	18	18	23		6						7	7	7	10	10	
5	C12	5	8	13	13	14		3						3	3	4	5		
6	C13		18	24	25	25		11	11						12	13	13	20	
7	C14		4	10	11	18	20		4						4	5	9	9	17
8	C15		10	18	21	21	28		9						9	10	18	19	26
9	C16			20	28	29	36			18						18	26	27	27
10	A3							1	1	2	2	4							
11	Attic																		
Roof Terrace Systems																			
12	C12-C12							6	13	22	22	22		5	5	7	9	9	
13	C12-C5							10	21	23	24	31			12	12	18	20	
14	C12-C13							13	23	24	33	33			13	21	21	21	
15	C5-C12							10	20	22	28	29			10	12	18	18	
16	C5-C5							13	23	32	32	33			20	21	21	21	
17	C5-C13							21	32	34	40				22	22	28	28	
18	C13-C12							12	28	30	31	37			13	20	20	21	
19	C13-C5							21	31	39	40	40			22	22	28	28	
20	C13-C13								39	41	41	42	42		29	30	31	36	37

[a]Blank spaces denote a roof that is not possible with the chosen combinations of parameters. Numbers 12 through 20 are roof terrace systems. First material is outer layer, second material is inner layer. Massive material numbers are: 4, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, and 20. Nonmassive material numbers are: 1, 2, 3, 10, and 11.

[b]R-Value ranges in $h \cdot ft^2 \cdot °F/Btu$ are:

No.	Range	No.	Range	No.	Range
1	0 to 5	3	10 to 15	5	20 to 25
2	5 to 10	4	15 to 20	6	25 to 30

Table 13 Roof Conduction Transfer Function Coefficients (*b* and *d* Factors)

Roof Group	(Layer Sequence Left to Right = Inside to Outside)		*n* = 0	*n* = 1	*n* = 2	*n* = 3	*n* = 4	*n* = 5	*n* = 6
1	Layers E0 A3 B25 E3 E2 A0	b_n	0.00487	0.03474	0.01365	0.00036	0.00000	0.00000	0.00000
	Steel deck with 3.33 in. insulation	d_n	1.00000	–0.35451	0.02267	–0.00005	0.00000	0.00000	0.00000
2	Layers E0 A3 B14 E3 E2 A0	b_n	0.00056	0.01202	0.01282	0.00143	0.00001	0.00000	0.00000
	Steel deck with 5 in. insulation	d_n	1.00000	–0.60064	0.08602	–0.00135	0.00000	0.00000	0.00000
3	Layers EO E5 E4 C12 E3 E2 A0	b_n	0.00613	0.03983	0.01375	0.00025	0.00000	0.00000	0.00000
	2 in. h.w. concrete deck with suspended ceiling	d_n	1.00000	–0.75615	0.01439	–0.00006	0.00000	0.00000	0.00000
4	Layers E0 E1 B15 E4 B7 A0	b_n	0.00000	0.00065	0.00339	0.00240	0.00029	0.00000	0.00000
	Attic roof with 6 in. insulation	d_n	1.00000	–1.34658	0.59384	–0.09295	0.00296	–0.00001	0.00000
5	Layers E0 B14 C12 E3 E2 A0	b_n	0.00006	0.00256	0.00477	0.00100	0.00002	0.00000	0.00000
	5 in. insulation with 2 in. h.w. concrete deck	d_n	1.00000	–1.10395	0.26169	–0.00475	0.00002	0.00000	0.00000
6	Layers E0 C5 B17 E3 E2 A0	b_n	0.00290	0.03143	0.02114	0.00120	0.00000	0.00000	0.00000
	4 in. h.w. concrete deck with 0.3 in. insulation	d_n	1.00000	–0.97905	0.13444	–0.00272	0.00000	0.00000	0.00000
7	Layers E0 B22 C12 E3 E2 C12 A0	b_n	0.00059	0.00867	0.00688	0.00037	0.00000	0.00000	0.00000
	1.67 in. insulation with 2 in. h.w. concrete RTS	d_n	1.00000	–1.11766	0.23731	–0.00008	0.00000	0.00000	0.00000
8	Layers E0 B16 C13 E3 E2 A0	b_n	0.00098	0.01938	0.02083	0.00219	0.00001	0.00000	0.00000
	0.15 in. insul. with 6 in. h.w. concrete deck	d_n	1.00000	–1.10235	0.20750	–0.00287	0.00000	0.00000	0.00000
9	Layers E0 E5 E4 B12 C14 E3 E2 A0	b_n	0.00000	0.00024	0.00217	0.00251	0.00055	0.00002	0.00000
	3 in. insul. w/4 in. l.w. conc. deck and susp. clg.	d_n	1.00000	–1.40605	0.58814	–0.09034	0.00444	–0.00006	0.00000
10	Layers E0 E5 E4 C15 B16 E3 E2 A0	b_n	0.00000	0.00025	0.00241	0.00303	0.00074	0.00004	0.00000
	6 in. l.w. conc. dk w/0.15 in. ins. and susp. clg.	d_n	1.00000	–1.55701	0.73120	–0.11774	0.00600	–0.00008	0.00000
11	Layers E0 C5 B15 E3 E2 A0	b_n	0.00000	0.00013	0.00097	0.00102	0.00020	0.00001	0.00000
	4 in. h.w. concrete deck with 6 in. insulation	d_n	1.00000	–1.61467	0.79142	–0.13243	0.00611	–0.00008	0.00000
12	Layers E0 C13 B16 E3 E2 C12 A0	b_n	0.00005	0.00356	0.01058	0.00404	0.00019	0.00000	0.00000
	6 in. h.w. deck w/0.15 in. ins. and 2 in. h.w. RTS	d_n	1.00000	–1.59267	0.72160	–0.08275	0.00029	0.00000	0.00000
13	Layers E0 C13 B6 E3 E2 A0	b_n	0.00002	0.00136	0.00373	0.00129	0.00006	0.00000	0.00000
	6 in. h.w. concrete deck with 2 in. insulation	d_n	1.00000	–1.34451	0.44285	–0.04344	0.00016	0.00000	0.00000
14	Layers E0 E5 E4 C12 B13 E3 E2 A0	b_n	0.00000	0.00046	0.00143	0.00057	0.00003	0.00000	0.00000
	2 in. l.w. conc. deck w/4 in. ins. and susp. clg.	d_n	1.00000	–1.33741	0.41454	–0.03346	0.00031	0.00000	0.00000
15	Layers E0 E5 E4 C5 B6 E3 E2 A0	b_n	0.00001	0.00066	0.00163	0.00049	0.00002	0.00000	0.00000
	1 in. insul. w/4 in. h.w. conc. deck and susp. clg.	d_n	1.00000	–1.24348	0.28742	–0.01274	0.00009	0.00000	0.00000
16	Layers E0 E5 E4 C13 B20 E3 E2 A0	b_n	0.00001	0.00060	0.00197	0.00086	0.00005	0.00000	0.00000
	6 in. h.w. deck w/0.76 in. insul. and susp. clg.	d_n	1.00000	–1.39181	0.46337	–0.04714	0.00058	0.00000	0.00000
17	Layers E0 E5 E4 B15 C14 E3 E2 A0	b_n	0.00000	0.00001	0.00021	0.00074	0.00053	0.00010	0.00000
	6 in. insul. w/4 in. l.w. conc. deck and susp. clg.	d_n	1.00000	–1.87317	1.20950	–0.32904	0.03799	–0.00169	0.00002
18	Layers E0 C12 B15 E3 E2 C5 A0	b_n	0.00000	0.00002	0.00027	0.00052	0.00019	0.00002	0.00000
	2 in. h.w. conc. dk w/6 in. ins. and 2 in. h.w. RTS	d_n	1.00000	–2.10928	1.50843	–0.40880	0.03249	–0.00068	0.00000
19	Layers E0 C5 B27 E3 E2 C12 A0	b_n	0.00000	0.00009	0.00073	0.00078	0.00015	0.00000	0.00000
	4 in. h.w. deck w/4.54 in. ins. and 2 in. h.w. RTS	d_n	1.00000	–1.82851	1.02856	–0.17574	0.00556	–0.00003	0.00000
20	Layers E0 B21 C16 E3 E2 A0	b_n	0.00000	0.00002	0.00044	0.00103	0.00049	0.00005	0.00000
	1.36 in. insulation with 8 in. l.w. concrete deck	d_n	1.00000	–1.91999	1.21970	–0.30000	0.02630	–0.00061	0.00000
21	Layers E0 C13 B12 E3 E2 C12 A0	b_n	0.00000	0.00009	0.00072	0.00077	0.00015	0.00000	0.00000
	6 in. h.w. deck w/3 in. insul. and 2 in. h.w. RTS	d_n	1.00000	–1.84585	1.03238	–0.17182	0.00617	–0.00003	0.00000
22	Layers E0 B22 C5 E3 E2 C13 A0	b_n	0.00000	0.00014	0.00100	0.00094	0.00015	0.00000	0.00000
	1.67 in. ins. w/4 in. h.w. deck and 6 in. h.w. RTS	d_n	1.00000	–1.79981	0.94786	–0.13444	0.00360	–0.00001	0.00000
23	Layers E0 E5 E4 C12 B14 E3 E2 C12 A0	b_n	0.00000	0.00002	0.00022	0.00031	0.00008	0.00000	0.00000
	Susp. clg, 2 in. h.w. dk, 5 in. ins, 2 in. h.w. RTS	d_n	1.00000	–1.89903	1.13575	–0.23586	0.01276	–0.00015	0.00000
24	Layers E0 E5 E4 C5 E3 E2 B6 B1 C12 A0	b_n	0.00000	0.00008	0.00047	0.00039	0.00006	0.00000	0.00000
	Susp. clg, 4 in. h.w. dk, 2 in. ins, 2 in. h.w. RTS	d_n	1.00000	–1.73082	0.85681	–0.11614	0.00239	–0.00001	0.00000
25	Layers E0 E5 E4 C13 B13 E3 E2 A0	b_n	0.00000	0.00002	0.00021	0.00031	0.00009	0.00001	0.00000
	6 in. h.w. conc. deck w/4 in. ins. and susp. clg.	d_n	1.00000	–1.63446	0.78078	–0.14422	0.00940	–0.00011	0.00000
26	Layers E0 E5 E4 B15 C15 E3 E2 A0	b_n	0.00000	0.00000	0.00002	0.00014	0.00024	0.00011	0.00002
	6 in. insul. w/6 in. l.w. conc. deck and susp. clg.	d_n	1.00000	–2.29459	1.93694	–0.75741	0.14252	–0.01251	0.00046
27	Layers E0 C13 B15 E3 E2 C12 A0	b_n	0.00000	0.00000	0.00007	0.00024	0.00016	0.00003	0.00000
	6 in. h.w. deck w/6 in. ins. and 2 in. h.w. RTS	d_n	1.00000	–2.27813	1.82162	–0.60696	0.07696	–0.00246	0.00001
28	Layers E0 B9 B14 E3 E2 A0	b_n	0.00000	0.00000	0.00001	0.00010	0.00017	0.00009	0.00001
	4 in. wood deck with 5 in. insulation	d_n	1.00000	–2.41915	2.17932	–0.93062	0.19840	–0.02012	0.00081
29	Layers E0 E5 E4 C12 B13 E3 E2 C5 A0	b_n	0.00000	0.00001	0.00018	0.00026	0.00007	0.00000	0.00000
	Susp. clg, 2 in. h.w. dk, 4 in. ins, 4 in. h.w. RTS	d_n	1.00000	–1.99413	1.20218	–0.20898	0.01058	–0.00010	0.00000
30	Layers E0 E5 E4 B9 B6 E3 E2 A0	b_n	0.00000	0.00000	0.00003	0.00016	0.00018	0.00005	0.00000
	4 in. wood deck w/2 in. insul. and susp. ceiling	d_n	1.00000	–2.29665	1.86386	–0.65738	0.10295	–0.00631	0.00012
31	Layers E0 B27 C13 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00003	0.00014	0.00014	0.00003	0.00000
	4.54 in. ins. w/6 in. h.w. deck and 6 in. h.w. RTS	d_n	1.00000	–2.29881	1.85733	–0.64691	0.10024	–0.00593	0.00006
32	Layers E0 E5 E4 C5 B20 E3 E2 C13 A0	b_n	0.00000	0.00002	0.00024	0.00037	0.00011	0.00001	0.00000
	Susp. clg, 4 in. h.w. dk, 0.76 in. ins, 4 in. h.w. RTS	d_n	1.00000	–2.09344	1.35118	–0.26478	0.01281	–0.00018	0.00000
33	Layers E0 E5 E4 C5 B13 E3 E2 C5 A0	b_n	0.00000	0.00000	0.00005	0.00013	0.00007	0.00001	0.00000
	Susp. clg, 4 in. h.w. dk, 4 in. ins, 4 in. h.w. RTS	d_n	1.00000	–2.07856	1.33963	–0.27670	0.02089	–0.00058	0.00000
34	Layers E0 E5 E4 C13 B23 E3 E2 C5 A0	b_n	0.00000	0.00000	0.00005	0.00013	0.00007	0.00001	0.00000
	Susp. clg, 6 in. h.w. dk, 2.42 in. ins, 4 in. h.w. RTS	d_n	1.00000	–2.13236	1.43448	–0.32023	0.02188	–0.00038	0.00000

Table 13 Roof Conduction Transfer Function Coefficients (*b* and *d* Factors) (*Concluded*)

Roof Group	(Layer Sequence Left to Right = Inside to Outside)		$n = 0$	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$
35	Layers E0 C5 B15 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00002	0.00010	0.00011	0.00003	0.00000
	4 in. h.w. deck w/6 in. ins. and 6 in. h.w. RTS	d_n	1.00000	−2.51234	2.25816	−0.87306	0.14066	−0.00785	0.00016
36	Layers E0 C13 B27 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00002	0.00009	0.00011	0.00003	0.00000
	6 in. h.w. deck w/4.54 in. ins. and 6 in. h.w. RTS	d_n	1.00000	−2.50269	2.23944	−0.88012	0.15928	−0.01176	0.00018
37	Layers E0 E5 E4 B15 C13 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00000	0.00002	0.00005	0.00004	0.00001
	Susp. clg, 6 in. ins, 6 in. h.w. dk, 6 in. h.w. RTS	d_n	1.00000	−2.75535	2.88190	−1.44618	0.36631	−0.04636	0.00269
38	Layers E0 E5 E4 B9 B15 E3 E2 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00003	0.00003	0.00001
	4 in. wood deck with 6 in. insul. and susp. ceiling	d_n	1.00000	−2.81433	3.05064	−1.62771	0.45499	−0.06569	0.00455
39	Layers E0 E5 E4 C13 B20 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00007	0.00019	0.00011	0.00001	0.00000
	Susp. clg, 6 in. h.w. dk, 0.76 in. ins, 6 in. h.w. RTS	d_n	1.00000	−2.30711	1.77588	−0.52057	0.05597	−0.00118	0.00001
40	Layers E0 E5 E4 C5 B26 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00002	0.00007	0.00006	0.00001	0.00000
	Susp. clg, 4 in. h.w. dk, 3.64 in. ins, 6 in. h.w. RTS	d_n	1.00000	−2.26975	1.68337	−0.45628	0.04712	−0.00180	0.00002
41	Layers E0 E5 E4 C13 B6 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00002	0.00007	0.00006	0.00001	0.00000
	Susp. clg, 6 in. h.w. deck, 2 in. ins, 6 in. h.w. RTS	d_n	1.00000	−2.35843	1.86626	−0.56900	0.06466	−0.00157	0.00001
42	Layers E0 E5 E4 C13 B14 E3 E2 C13 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00002	0.00001	0.00000
	Susp. clg, 6 in. h.w. deck, 5 in. ins, 6 in. h.w. RTS	d_n	1.00000	−2.68628	2.63091	−1.16847	0.24692	−0.02269	0.00062

Table 14 Roof Conduction Transfer Function Coefficients Σc_n, Time Lag, U-Factors, and Decrement Factors

Roof Group		Σc_n	TL, h	*U*	DF
1	Layers E0 A3 B25 E3 E2 A0	0.05362	1.63	0.080	0.97
2	Layers E0 A3 B14 E3 E2 A0	0.02684	2.43	0.055	0.94
3	Layers EO E5 E4 C12 E3 E2 A0	0.05997	3.39	0.232	0.75
4	Layers E0 E1 B15 E4 B7 A0	0.00673	4.85	0.043	0.82
5	Layers E0 B14 C12 E3 E2 A0	0.00841	4.82	0.055	0.68
6	Layers E0 C5 B17 E3 E2 A0	0.05668	4.57	0.371	0.60
7	Layers E0 B22 C12 E3 E2 C12 A0	0.01652	5.00	0.138	0.56
8	Layers E0 B16 C13 E3 E2 A0	0.04340	5.45	0.424	0.47
9	Layers E0 E5 E4 B12 C14 E3 E2 A0	0.00550	6.32	0.057	0.60
10	Layers E0 E5 E4 C15 B16 E3 E2 A0	0.00647	7.14	0.104	0.49
11	Layers E0 C5 B15 E3 E2 A0	0.00232	7.39	0.046	0.43
12	Layers E0 C13 B16 E3 E2 C12 A0	0.01841	7.08	0.396	0.40
13	Layers E0 C13 B6 E3 E2 A0	0.00645	6.73	0.117	0.33
14	Layers E0 E5 E4 C12 B13 E3 E2 A0	0.00250	7.06	0.057	0.26
15	Layers E0 E5 E4 C5 B6 E3 E2 A0	0.01477	7.16	0.090	0.16
16	Layers E0 E5 E4 C13 B20 E3 E2 A0	0.00349	7.54	0.140	0.15
17	Layers E0 E5 E4 B15 C14 E3 E2 A0	0.00159	8.23	0.036	0.50
18	Layers E0 C12 B15 E3 E2 C5 A0	0.00101	9.21	0.046	0.41
19	Layers E0 C5 B27 E3 E2 C12 A0	0.00176	8.42	0.059	0.37
20	Layers E0 B21 C16 E3 E2 A0	0.00202	8.93	0.080	0.32
21	Layers E0 C13 B12 E3 E2 C12 A0	0.00174	8.93	0.083	0.26
22	Layers E0 B22 C5 E3 E2 C13 A0	0.00222	8.99	0.129	0.20
23	Layers E0 E5 E4 C12 B14 E3 E2 C12 A0	0.00064	9.26	0.047	0.16
24	Layers E0 E5 E4 C5 E3 E2 B6 B1 C12 A0	0.00100	8.84	0.082	0.12
25	Layers E0 E5 E4 C13 B13 E3 E2 A0	0.00063	8.77	0.056	0.09
26	Layers E0 E5 E4 B15 C15 E3 E2 A0	0.00053	10.44	0.034	0.30
27	Layers E0 C13 B15 E3 E2 C12 A0	0.00050	10.48	0.045	0.24
28	Layers E0 B9 B14 E3 E2 A0	0.00038	11.18	0.044	0.19
29	Layers E0 E5 E4 C12 B13 E3 E2 C5 A0	0.00053	10.57	0.056	0.16
30	Layers E0 E5 E4 B9 B6 E3 E2 A0	0.00042	11.22	0.064	0.13
31	Layers E0 B27 C13 E3 E2 C13 A0	0.00034	11.27	0.057	0.12
32	Layers E0 E5 E4 C5 B20 E3 E2 C13 A0	0.00075	11.31	0.133	0.10
33	Layers E0 E5 E4 C5 B13 E3 E2 C5 A0	0.00026	11.47	0.055	0.08
34	Layers E0 E5 E4 C13 B23 E3 E2 C5 A0	0.00026	11.63	0.077	0.06
35	Layers E0 C5 B15 E3 E2 C13 A0	0.00026	12.29	0.045	0.18
36	Layers E0 C13 B27 E3 E2 C13 A0	0.00025	12.67	0.057	0.13
37	Layers E0 E5 E4 B15 C13 E3 E2 C13 A0	0.00012	13.02	0.040	0.11
38	Layers E0 E5 E4 B9 B15 E3 E2 A0	0.00008	13.33	0.035	0.09
39	Layers E0 E5 E4 C13 B20 E3 E2 C13 A0	0.00039	12.23	0.131	0.07
40	Layers E0 E5 E4 C5 B26 E3 E2 C13 A0	0.00016	12.68	0.059	0.06
41	Layers E0 E5 E4 C13 B6 E3 E2 C13 A0	0.00016	12.85	0.085	0.05
42	Layers E0 E5 E4 C13 B14 E3 E2 C13 A0	0.00005	14.17	0.046	0.03

Table 15 Wall Group Numbers, Walls for Mass-In Case—Dominant Wall Material

R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Combined with Wall Material A1, E1, or Both																									
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	*	*	*
2	*	5	*	*	*	*	*	*	*	5	*	*	*	*	11	*	2	6	*	*	*	*	*	*	*
3	*	5	*	*	*	3	*	2	5	6	*	*	5	*	12	18	2	6	*	*	*	*	*	*	*
4	*	5	*	*	*	4	2	2	5	6	*	*	6	12	12	19	2	7	*	*	*	*	*	*	*
5	*	5	*	*	*	4	2	3	6	6	10	4	6	17	12	19	2	7	*	*	*	*	5	*	*
6	*	6	*	*	*	5	2	4	6	6	11	5	10	17	13	19	2	11	*	*	*	*	10	*	16
7	*	6	*	*	*	5	2	4	6	6	11	5	10	18	13	20	2	11	2	*	*	*	10	*	16
8	*	6	*	*	*	5	2	5	10	7	12	5	11	18	13	26	2	12	2	*	*	*	10	*	17
9	*	6	*	*	*	5	4	5	11	7	16	10	11	18	13	20	3	12	4	5	*	*	11	*	18
10	*	6	*	*	*	5	4	5	11	7	17	10	11	18	13	20	3	12	4	9	10	*	11	*	18
11	*	6	*	*	*	5	4	5	11	7	17	10	11	19	13	27	3	12	4	10	15	4	11	*	18
12	*	6	*	*	*	5	4	5	11	11	17	10	11	19	19	27	3	12	4	10	16	4	11	*	24
13	*	10	*	*	*	10	4	5	11	11	17	10	11	19	18	27	4	12	5	11	17	9	12	15	25
14	*	10	*	*	*	10	5	5	11	11	18	11	12	25	19	27	4	12	5	11	17	10	16	16	25
15	*	11	*	*	*	10	5	9	11	11	18	15	16	26	19	28	4	12	5	11	17	10	16	22	25
16	*	11	*	*	*	10	9	9	16	11	18	15	16	26	19	34	4	17	9	16	23	10	16	23	25
17	*	*	*	*	*	*	*	*	*	*	24	16	*	*	*	*	*	*	9	16	24	15	17	24	25
Combined with Wall Material A3 or A6																									
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*
2	*	3	*	*	*	*	*	2	3	5	*	*	*	*	11	*	2	6	*	*	*	*	*	*	*
3	*	5	*	*	*	2	*	2	5	3	*	*	5	*	12	18	2	6	*	*	*	*	*	*	*
4	*	5	*	*	*	3	1	2	5	5	*	*	5	11	12	19	2	7	*	*	*	*	*	*	*
5	*	5	*	*	*	3	2	2	5	5	6	3	5	12	12	19	2	7	*	*	*	*	5	*	*
6	*	6	*	*	*	4	2	2	5	5	10	4	6	12	12	19	2	7	*	*	*	*	5	*	11
7	*	6	*	*	*	5	2	2	6	6	11	5	6	17	13	20	2	7	2	*	*	*	6	*	12
8	*	6	*	*	*	5	2	3	6	6	11	5	6	18	13	20	2	7	2	*	*	*	6	*	17
9	*	6	*	*	*	5	2	3	6	6	11	5	6	18	13	20	2	8	2	5	*	*	10	*	17
10	*	6	*	*	*	5	2	3	6	6	12	5	6	18	14	21	2	12	2	5	10	*	11	*	17
11	*	6	*	*	*	5	2	3	6	6	12	5	6	18	14	21	3	12	4	5	11	4	11	*	18
12	*	6	*	*	*	5	2	3	6	7	12	6	11	19	14	21	3	12	4	10	16	4	11	*	18
13	*	6	*	*	*	5	2	4	6	7	12	10	11	19	14	27	3	12	5	10	17	5	11	10	18
14	*	10	*	*	*	6	4	4	10	7	17	10	11	19	18	27	4	12	5	11	17	9	11	16	18
15	*	10	*	*	*	10	4	4	10	11	17	10	11	25	18	28	4	12	5	11	17	10	11	16	18
16	*	11	*	*	*	10	4	5	11	11	17	10	11	25	18	28	4	12	9	11	18	10	16	17	24
17	*	*	*	*	*	*	*	*	*	*	17	10	*	*	*	*	*	*	9	16	24	11	16	23	25
Combined with Wall Material A2 or A7																									
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	3	*	*	*	*	*	*	*	*	11	*	*	*	*	*	*	6	*	*	*	*	*	*	*	*
3	5	11	*	*	*	*	*	6	11	12	*	*	*	*	18	*	6	12	*	*	*	*	*	*	*
4	5	12	5	*	*	11	*	11	12	12	*	*	12	*	19	26	7	13	*	*	*	*	*	*	*
5	5	12	6	*	*	12	6	12	12	13	*	*	12	24	19	27	7	14	*	*	*	*	*	*	*
6	6	13	6	10	*	13	10	12	12	13	17	11	17	25	20	27	7	18	*	*	*	*	16	*	24
7	6	13	6	11	*	18	11	12	13	13	18	16	17	26	20	28	7	19	11	*	*	*	17	*	25
8	6	13	6	11	*	18	11	12	13	13	24	17	18	26	20	28	12	19	11	*	*	*	17	*	25
9	6	13	6	11	24	18	11	13	18	13	25	17	18	27	20	29	12	19	11	16	*	*	18	*	26
10	6	13	10	16	25	19	11	13	18	13	25	17	18	27	26	35	12	19	11	17	23	*	18	*	26
11	6	14	10	16	32	19	11	13	18	14	25	17	18	33	21	35	12	19	16	23	24	16	18	*	33
12	6	14	10	16	32	19	11	13	18	14	26	18	18	34	27	35	12	19	16	24	31	16	19	*	33
13	6	18	11	16	33	19	12	13	18	18	26	18	18	34	27	36	12	20	17	24	32	17	25	30	33
14	10	18	11	17	33	19	12	13	18	18	26	18	18	34	27	36	12	20	17	24	32	23	25	31	34
15	10	18	11	17	34	19	16	18	18	18	26	24	25	34	27	36	12	20	17	25	33	24	25	32	34
16	11	19	15	23	39	26	16	18	24	19	32	24	25	34	27	36	17	26	23	31	33	24	25	32	34
17	*	*	*	23	39	*	16	*	*	*	33	24	*	35	*	*	*	*	23	32	38	24	25	38	39

R-Value Ranges, h·ft²·°F/Btu	
1	0.0 - 2.0
2	2.0 - 2.5
3	2.5 - 3.0
4	3.0 - 3.5
5	3.5 - 4.0
6	4.0 - 4.75
7	4.75 - 5.5
8	5.5 - 6.5
9	6.5 - 7.75
10	7.75 - 9.0
11	9.0 - 10.75
12	10.75 - 12.75
13	12.75 - 15.0
14	15.0 - 17.5
15	17.5 - 20.0
16	20.0 - 23.0
17	23.0 - 27.0

Wall Materials Layers (Table 11)	
1	A1,A3,A6, or E1
2	A2 or A7
3	B7
4	B10
5	B9
6	C1
7	C2
8	C3
9	C4
10	C5
11	C6
12	C7
13	C8
14	C9
15	C10
16	C11
17	C12
18	C13
19	C14
20	C15
21	C16
22	C17
23	C18
24	C19
25	C20

*Denotes a wall not possible with chosen combination of parameters.

Table 16 Walls for Integral Mass Case—Dominant Wall Material

Combined with Wall Material A1, E1, or Both

R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	3	*	*	*	*	*	1	3	3	*	*	*	*	11	*	2	5	*	*	*	*	*	*	*
2	1	3	1	*	*	2	*	2	4	4	*	*	5	*	11	17	2	5	*	*	*	*	*	*	*
3	1	4	1	*	*	2	2	2	4	4	*	*	5	10	12	17	4	5	*	*	*	*	*	*	*
4	1	*	1	*	*	2	2	*	*	*	10	4	5	10	*	17	*	*	*	*	*	*	4	*	*
5	1	*	1	2	*	*	4	*	*	*	10	4	*	10	*	*	*	*	*	*	*	*	4	*	10
6	1	*	1	2	*	*	*	*	*	*	10	4	*	*	*	*	*	*	2	*	*	*	4	*	10
7	1	*	1	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	10
8	1	*	2	4	10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*	*	*
9	1	*	2	4	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*	*	*
10	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	*	*	*	*
11	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	4	*	*	*
12	1	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*
13	2	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15	*
14	2	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15	*
15	2	*	2	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	2	*	4	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	*	*	*	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Combined with Wall Material A3 or A6

R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	3	*	*	*	*	*	1	3	2	*	*	*	*	6	*	1	5	*	*	*	*	*	*	*
2	1	3	1	*	*	2	*	1	3	2	*	*	3	*	6	12	1	5	*	*	*	*	*	*	*
3	1	4	1	*	*	2	1	2	4	4	*	*	3	10	11	12	2	5	*	*	*	*	*	*	*
4	1	*	1	*	*	4	1	*	*	*	5	2	4	10	*	12	*	*	*	*	*	*	4	*	*
5	1	*	1	2	*	*	2	*	*	*	5	2	*	10	*	*	*	*	*	*	*	*	4	*	10
6	1	*	1	2	*	*	*	*	*	*	10	4	*	*	*	*	*	*	2	*	*	*	4	*	10
7	1	*	1	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	10
8	1	*	1	2	10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*	*	*
9	1	*	1	4	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*	*	*
10	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	*	*	*	*
11	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	2	*	*	*
12	1	*	2	4	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*
13	1	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	10	*
14	1	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15	*
15	1	*	2	5	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	2	*	4	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	*	*	*	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Combined with Wall Material A2 or A7

R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	3	6	*	*	*	*	*	*	*	6	*	*	*	*	*	*	3	11	*	*	*	*	*	*	*
2	3	10	*	*	*	*	*	5	10	10	*	*	*	*	17	24	5	11	*	*	*	*	*	*	*
3	4	10	5	*	*	5	*	5	10	11	*	*	10	*	17	25	5	16	*	*	*	*	*	*	*
4	*	11	5	*	*	10	5	5	11	11	15	10	10	17	18	26	5	17	*	*	*	*	10	*	*
5	*	11	5	10	*	10	5	5	11	11	16	10	16	23	18	26	5	17	*	*	*	*	10	*	*
6	*	11	*	11	*	10	5	5	16	11	17	10	16	24	18	33	5	17	*	*	*	*	16	*	23
7	*	11	*	11	*	10	5	10	16	16	17	10	16	25	25	33	5	17	5	*	*	*	16	*	23
8	*	16	*	*	22	10	9	10	16	11	17	11	16	25	25	34	10	18	9	*	*	*	17	*	24
9	*	16	*	*	23	11	9	10	16	16	24	16	16	26	25	34	10	18	10	15	*	*	17	*	25
10	*	16	*	*	*	15	9	10	16	17	24	15	16	26	26	34	10	18	10	15	22	*	17	*	25
11	*	16	*	*	*	15	10	10	17	16	24	16	17	33	26	35	10	18	10	16	23	10	23	*	25
12	*	16	*	*	*	16	10	10	17	17	24	16	17	33	26	35	10	18	10	16	23	15	23	*	32
13	*	16	*	*	*	16	10	10	17	16	25	17	17	33	26	35	10	24	15	23	24	15	24	23	32
14	*	17	*	*	*	16	10	15	23	17	31	23	24	33	26	40	10	24	15	23	31	16	23	30	32
15	*	17	*	*	*	16	15	15	23	23	31	23	24	38	33	40	10	24	15	24	31	16	23	30	32
16	*	23	*	*	*	22	15	16	24	24	32	23	24	38	33	41	15	25	15	23	32	22	23	31	32
17	*	*	*	*	*	*	15	*	*	*	32	23	*	39	*	*	*	*	22	30	32	23	24	32	38

R-Value Ranges, h·ft^2·°F/Btu

R	Range
1	0.0 - 2.0
2	2.0 - 2.5
3	2.5 - 3.0
4	3.0 - 3.5
5	3.5 - 4.0
6	4.0 - 4.75
7	4.75 - 5.5
8	5.5 - 6.5
9	6.5 - 7.75
10	7.75 - 9.0
11	9.0 - 10.75
12	10.75 - 12.75
13	12.75 - 15.0
14	15.0 - 17.5
15	17.5 - 20.0
16	20.0 - 23.0
17	23.0 - 27.0

Wall Materials Layers (Table 11)

No.	Layers
1	A1,A3,A6, or E1
2	A2 or A7
3	B7
4	B10
5	B9
6	C1
7	C2
8	C3
9	C4
10	C5
11	C6
12	C7
13	C8
14	C9
15	C10
16	C11
17	C12
18	C13
19	C14
20	C15
21	C16
22	C17
23	C18
24	C19
25	C20

*Denotes a wall not possible with chosen combination of parameters.

Table 17 Walls for Mass-Out Case—Dominant Wall Material

R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Combined with Wall Material A1, E1, or Both																									
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*
2	*	3	*	*	*	*	*	2	3	5	*	*	*	*	6	*	1	5	*	*	*	*	*	*	*
3	*	3	*	*	*	2	*	2	4	5	*	*	5	*	11	18	2	5	*	*	*	*	*	*	*
4	*	3	*	*	*	2	2	2	5	5	*	*	5	16	11	18	2	5	*	*	*	*	*	*	*
5	*	3	*	*	*	2	2	2	5	5	10	4	6	17	11	19	2	6	*	*	*	*	5	*	*
6	*	4	*	*	*	4	2	2	5	5	10	4	6	17	11	19	2	6	*	*	*	*	9	*	16
7	*	4	*	*	*	4	2	2	5	6	11	5	10	17	12	19	2	6	2	*	*	*	10	*	16
8	*	5	*	*	*	4	2	2	5	6	11	5	10	18	11	20	2	6	4	*	*	*	10	*	16
9	*	5	*	*	*	4	2	2	5	6	11	5	10	18	11	26	2	6	4	9	*	*	10	*	17
10	*	5	*	*	*	5	2	4	5	6	16	10	10	18	12	26	2	6	4	9	15	*	10	*	17
11	*	5	*	*	*	5	4	4	5	6	16	10	10	18	12	26	2	6	4	10	15	4	11	*	18
12	*	5	*	*	*	5	4	4	10	6	16	10	10	18	12	26	2	10	5	10	16	9	11	*	18
13	*	5	*	*	*	5	4	4	10	10	17	10	11	18	12	26	2	10	5	11	17	9	11	15	24
14	*	5	*	*	*	5	4	4	10	10	17	10	11	24	18	26	2	10	9	15	23	10	16	16	24
15	*	5	*	*	*	9	4	4	10	10	17	10	15	25	18	26	2	10	9	15	23	10	16	22	24
16	*	9	*	*	*	9	9	9	15	10	17	10	15	25	18	33	4	11	9	16	24	15	16	23	24
17	*	*	*	*	*	*	*	*	*	*	23	15	*	*	*	*	*	*	9	22	24	15	16	24	25
Combined with Wall Material A3 or A6																									
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*
2	*	3	*	*	*	*	*	2	3	2	*	*	*	*	6	*	1	5	*	*	*	*	*	*	*
3	*	3	*	*	*	2	*	2	3	2	*	*	*	*	10	17	1	5	*	*	*	*	*	*	*
4	*	3	*	*	*	2	1	2	4	3	*	*	4	11	11	17	1	5	*	*	*	*	*	*	*
5	*	3	*	*	*	2	2	2	4	3	5	2	5	11	11	18	1	6	*	*	*	*	4	*	*
6	*	3	*	*	*	2	2	2	4	3	10	3	5	12	11	18	2	6	*	*	*	*	5	*	10
7	*	3	*	*	*	2	2	2	5	3	10	4	5	12	11	18	2	6	2	*	*	*	5	*	11
8	*	4	*	*	*	2	2	2	5	3	10	4	5	12	11	18	2	6	2	*	*	*	5	*	12
9	*	4	*	*	*	2	2	2	5	4	11	5	5	17	11	18	2	6	2	5	*	*	6	*	16
10	*	5	*	*	*	2	2	2	5	4	11	5	5	17	11	19	2	6	2	5	10	*	6	*	17
11	*	5	*	*	*	2	2	2	5	4	11	5	5	17	12	19	2	6	4	5	11	4	10	*	17
12	*	5	*	*	*	4	2	2	5	5	11	5	5	17	12	19	2	6	4	10	15	4	10	*	17
13	*	5	*	*	*	4	2	2	5	5	11	5	10	18	12	19	2	10	4	10	16	5	10	10	17
14	*	5	*	*	*	4	2	4	5	5	16	9	10	18	12	25	2	10	4	10	17	9	10	16	17
15	*	5	*	*	*	4	4	4	9	5	16	9	10	18	16	25	2	10	5	11	17	10	10	16	18
16	*	9	*	*	*	4	4	4	9	9	16	10	10	24	17	25	4	10	5	11	17	10	11	17	18
17	*	*	*	*	*	*	*	*	*	*	16	10	*	*	*	*	*	*	9	16	23	10	15	23	24
Combined with Wall Material A2 or A7																									
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	3	*	*	*	*	*	*	*	*	11	*	*	*	*	*	*	5	*	*	*	*	*	*	*	*
3	3	10	*	*	*	*	*	5	10	11	*	*	*	*	17	*	5	12	*	*	*	*	*	*	*
4	3	11	5	*	*	10	*	5	11	11	*	*	11	*	18	26	6	12	*	*	*	*	*	*	*
5	3	11	5	*	*	10	5	6	11	11	*	*	11	24	18	26	6	13	*	*	*	*	*	*	*
6	3	11	5	10	*	10	5	10	11	11	17	10	11	24	18	26	6	13	*	*	*	*	16	*	23
7	3	12	5	10	*	10	9	10	11	12	17	11	16	25	19	27	6	17	9	*	*	*	16	*	23
8	4	12	5	10	*	10	10	10	12	12	17	15	16	25	19	27	6	17	10	*	*	*	16	*	24
9	4	12	5	10	23	11	10	10	12	12	23	16	17	26	19	27	10	18	10	15	*	*	16	*	25
10	5	12	5	15	24	11	10	10	16	12	24	16	17	26	19	34	10	18	10	16	22	*	17	*	25
11	5	12	9	15	30	11	10	10	16	12	24	16	17	26	19	34	10	18	10	16	23	15	17	*	25
12	5	12	10	15	31	11	10	10	17	12	24	16	17	26	25	34	10	18	10	22	24	15	17	*	32
13	5	17	10	16	32	11	10	11	17	17	24	16	17	26	25	34	11	18	15	23	30	15	23	23	32
14	5	17	10	16	32	15	10	11	17	17	25	16	17	33	25	34	11	18	15	23	31	22	23	30	32
15	5	17	10	16	32	16	15	15	17	17	25	22	23	33	26	35	11	18	15	23	31	22	23	30	32
16	9	17	15	16	32	16	15	15	23	17	31	22	23	33	26	40	15	24	15	23	32	23	24	31	32
17	*	*	*	22	38	*	15	*	*	*	31	23	*	33	*	*	*	*	22	30	37	23	24	37	38

R	R-Value Ranges, h·ft²·°F/Btu
1	0.0 - 2.0
2	2.0 - 2.5
3	2.5 - 3.0
4	3.0 - 3.5
5	3.5 - 4.0
6	4.0 - 4.75
7	4.75 - 5.5
8	5.5 - 6.5
9	6.5 - 7.75
10	7.75 - 9.0
11	9.0 - 10.75
12	10.75 - 12.75
13	12.75 - 15.0
14	15.0 - 17.5
15	17.5 - 20.0
16	20.0 - 23.0
17	23.0 - 27.0

	Wall Materials Layers (Table 11)
1	A1,A3,A6, or E1
2	A2 or A7
3	B7
4	B10
5	B9
6	C1
7	C2
8	C3
9	C4
10	C5
11	C6
12	C7
13	C8
14	C9
15	C10
16	C11
17	C12
18	C13
19	C14
20	C15
21	C16
22	C17
23	C18
24	C19
25	C20

*Denotes a wall not possible with chosen combination of parameters.

Table 18 Wall Conduction Transfer Function Coefficients (*b* and *d* Factors)

Wall Group	(Layer Sequence Left to Right = Inside to Outside)		*n* =0	*n* =1	*n* =2	*n* =3	*n* =4	*n* =5	*n* =6
1	Layers E0 A3 B1 B13 A3 A0	b_n	0.00768	0.03498	0.00719	0.00006	0.00000	0.00000	0.00000
	Steel siding with 4 in. insulation	d_n	1.00000	–0.24072	0.00168	0.00000	0.00000	0.00000	0.00000
2	Layers E0 E1 B14 A1 A0 A0	b_n	0.00016	0.00545	0.00961	0.00215	0.00005	0.00000	0.00000
	Frame wall with 5 in. insulation	d_n	1.00000	–0.93389	0.27396	–0.02561	0.00014	0.00000	0.00000
3	Layers E0 C3 B5 A6 A0 A0	b_n	0.00411	0.03230	0.01474	0.00047	0.00000	0.00000	0.00000
	4 in. h.w. concrete block with 1 in. insulation	d_n	1.00000	–0.76963	0.04014	–0.00042	0.00000	0.00000	0.00000
4	Layers E0 E1 B6 C12 A0 A0	b_n	0.00001	0.00108	0.00384	0.00187	0.00013	0.00000	0.00000
	2 in. insulation with 2 in. h.w. concrete	d_n	1.00000	–1.37579	0.61544	–0.09389	0.00221	0.00000	0.00000
5	Layers E0 A6 B21 C7 A0 A0	b_n	0.00008	0.00444	0.01018	0.00296	0.00010	0.00000	0.00000
	1.36 in. insulation with 8 in. l.w. concrete block	d_n	1.00000	–1.16043	0.32547	–0.02746	0.00021	0.00000	0.00000
6	Layers E0 E1 B2 C5 A1 A0	b_n	0.00051	0.00938	0.01057	0.00127	0.00001	0.00000	0.00000
	1 in. insulation with 4 in. h.w. concrete	d_n	1.00000	–1.17580	0.30071	–0.01561	0.00001	0.00000	0.00000
7	Layers E0 A6 C5 B3 A3 A0	b_n	0.00099	0.00836	0.00361	0.00007	0.00000	0.00000	0.00000
	4 in. h.w. concrete with 2 in. insulation	d_n	1.00000	–0.93970	0.04664	0.00000	0.00000	0.00000	0.00000
8	Layers E0 A2 C12 B5 A6 A0	b_n	0.00014	0.00460	0.00733	0.00135	0.00002	0.00000	0.00000
	Face brick and 2 in. h.w. concrete with 1 in. insul.	d_n	1.00000	–1.20012	0.27937	–0.01039	0.00005	0.00000	0.00000
9	Layers E0 A6 B15 B10 A0 A0	b_n	0.00000	0.00006	0.00086	0.00146	0.00051	0.00004	0.00000
	6 in. insulation with 2 in. wood	d_n	1.00000	–1.63352	0.86971	–0.18121	0.01445	–0.00031	0.00000
10	Layers E0 E1 C2 B5 A2 A0	b_n	0.00001	0.00102	0.00441	0.00260	0.00024	0.00000	0.00000
	4 in. l.w. conc. block w/1 in. insul. and face brick	d_n	1.00000	–1.66358	0.82440	–0.11098	0.00351	0.00000	0.00000
11	Layers E0 E1 C8 B6 A1 A0	b_n	0.00000	0.00061	0.00289	0.00183	0.00018	0.00000	0.00000
	8 in. h.w. concrete block with 2 in. insulation	d_n	1.00000	–1.52480	0.67146	–0.09844	0.00239	0.00000	0.00000
12	Layers E0 E1 B1 C10 A1 A0	b_n	0.00002	0.00198	0.00816	0.00467	0.00044	0.00001	0.00000
	8 in. h.w. concrete	d_n	1.00000	–1.51658	0.64261	–0.08382	0.00289	–0.00001	0.00000
13	Layers E0 A2 C5 B19 A6 A0	b_n	0.00003	0.00203	0.00601	0.00233	0.00013	0.00000	0.00000
	Face brick and 4 in. h.w. concrete with 0.61 in. ins.	d_n	1.00000	–1.41349	0.48697	–0.03218	0.00057	0.00000	0.00000
14	Layers E0 A2 A2 B6 A6 A0	b_n	0.00000	0.00030	0.00167	0.00123	0.00016	0.00000	0.00000
	Face brick and face brick with 2 in. insulation	d_n	1.00000	–1.52986	0.62059	–0.06329	0.00196	–0.00001	0.00000
15	Layers E0 A6 C17 B1 A7 A0	b_n	0.00000	0.00003	0.00060	0.00145	0.00074	0.00009	0.00000
	8 in. l.w. concrete block (filled) and face brick	d_n	1.00000	–1.99996	1.36804	–0.37388	0.03885	–0.00140	0.00002
16	Layers E0 A6 C18 B1 A7 A0	b_n	0.00000	0.00014	0.00169	0.00270	0.00086	0.00006	0.00000
	8 in. h.w. concrete block (filled) and face brick	d_n	1.00000	–2.00258	1.32887	–0.32486	0.02361	–0.00052	0.00000
17	Layers E0 A2 C2 B15 A0 A0	b_n	0.00000	0.00000	0.00013	0.00044	0.00030	0.00005	0.00000
	Face brick and 4 in. l.w. conc. block with 6 in. ins.	d_n	1.00000	–2.00875	1.37120	–0.37897	0.03962	–0.00165	0.00002
18	Layers E0 A6 B25 C9 A0 A0	b_n	0.00000	0.00001	0.00026	0.00071	0.00040	0.00005	0.00000
	3.33 in. insulation with 8 in. common brick	d_n	1.00000	–1.92906	1.24412	–0.33029	0.03663	–0.00147	0.00002
19	Layers E0 C9 B6 A6 A0 A0	b_n	0.00000	0.00005	0.00064	0.00099	0.00030	0.00002	0.00000
	8 in. common brick with 2 in. insulation	d_n	1.00000	–1.78165	0.96017	–0.16904	0.00958	–0.00016	0.00000
20	Layers E0 C11 B19 A6 A0 A0	b_n	0.00000	0.00012	0.00119	0.00154	0.00038	0.00002	0.00000
	12 in. h.w. concrete with 0.61 in. insulation	d_n	1.00000	–1.86032	1.05927	–0.19508	0.01002	–0.00016	0.00000
21	Layers E0 C11 B6 A1 A0 A0	b_n	0.00000	0.00001	0.00019	0.00045	0.00022	0.00002	0.00000
	12 in. h.w. concrete with 2 in. insulation	d_n	1.00000	–2.12812	1.53974	–0.45512	0.05298	–0.00158	0.00002
22	Layers E0 C14 B15 A2 A0 A0	b_n	0.00000	0.00000	0.00006	0.00026	0.00025	0.00006	0.00000
	4 in. l.w. concrete with 6 in. insul. and face brick	d_n	1.00000	–2.28714	1.85457	–0.63564	0.08859	–0.00463	0.00009
23	Layers E0 E1 B15 C7 A2 A0	b_n	0.00000	0.00000	0.00002	0.00012	0.00019	0.00008	0.00001
	6 in. insulation with 8 in. l.w. concrete block	d_n	1.00000	–2.54231	2.43767	–1.10744	0.24599	–0.02510	0.00101
24	Layers E0 A6 C20 B1 A7 A0	b_n	0.00000	0.00000	0.00015	0.00066	0.00062	0.00015	0.00001
	12 in. h.w. concrete block (filled) and face brick	d_n	1.00000	–2.47997	2.22597	–0.87231	0.14275	–0.00850	0.00018
25	Layers E0 A2 C15 B12 A6 A0	b_n	0.00000	0.00000	0.00004	0.00019	0.00021	0.00006	0.00001
	Face brick and 6 in. l.w. conc. blk. w/3 in. insul.	d_n	1.00000	–2.28573	1.80756	–0.58999	0.08155	–0.00500	0.00013
26	Layers E0 A2 C6 B6 A6 A0	b_n	0.00000	0.00000	0.00010	0.00036	0.00027	0.00005	0.00000
	Face brick and 8 in. clay tile with 2 in. insulation	d_n	1.00000	–2.18780	1.60930	–0.46185	0.05051	–0.00218	0.00003
27	Layers E0 E1 B14 C11 A1 A0	b_n	0.00000	0.00000	0.00001	0.00006	0.00011	0.00005	0.00001
	5 in. insulation with 12 in. h.w. concrete	d_n	1.00000	–2.55944	2.45942	–1.12551	0.25621	–0.02721	0.00107
28	Layers E0 E1 C11 B13 A1 A0	b_n	0.00000	0.00000	0.00002	0.00010	0.00012	0.00004	0.00000
	12 in. h.w. concrete with 4 in. insulation	d_n	1.00000	–2.37671	2.04312	–0.79860	0.14868	–0.01231	0.00037
29	Layers E0 A2 C11 B5 A6 A0	b_n	0.00000	0.00000	0.00004	0.00021	0.00021	0.00006	0.00000
	Face brick and 12 in. h.w. concrete with 1 in. insul.	d_n	1.00000	–2.42903	2.08179	–0.75768	0.11461	–0.00674	0.00015
30	Layers E0 E1 B19 C19 A2 A0	b_n	0.00000	0.00000	0.00001	0.00006	0.00015	0.00010	0.00002
	0.61 in. ins. w/12 in. l.w. blk. (fld.) and face brick	d_n	1.00000	–2.83632	3.10377	–1.65731	0.45360	–0.06212	0.00393
31	Layers E0 E1 B15 C15 A2 A0	b_n	0.00000	0.00000	0.00000	0.00002	0.00007	0.00006	0.00002
	6 in. insul. with 6 in. l.w. conc. and face brick	d_n	1.00000	–2.90291	3.28970	–1.85454	0.55033	–0.08384	0.00599
32	Layers E0 E1 B23 B9 A2 A0	b_n	0.00000	0.00000	0.00000	0.00005	0.00011	0.00007	0.00001
	2.42 in. insulation with face brick	d_n	1.00000	–2.82266	3.04536	–1.58410	0.41423	–0.05186	0.00273
33	Layers E0 A2 C6 B15 A6 A0	b_n	0.00000	0.00000	0.00000	0.00002	0.00006	0.00005	0.00001
	Face brick and 8 in. clay tile with 6 in. insulation	d_n	1.00000	–2.68945	2.71279	–1.28873	0.30051	–0.03338	0.00175

Table 18 Wall Conduction Transfer Function Coefficients (*b* and *d* Factors) (*Concluded*)

Wall Group	(Layer Sequence Left to Right = Inside to Outside)		*n* =0	*n* =1	*n* =2	*n* =3	*n* =4	*n* =5	*n* =6
34	Layers E0 C11 B21 A2 A0 A0	b_n	0.00000	0.00000	0.00003	0.00015	0.00014	0.00003	0.00000
	12 in. h.w. conc. with 1.36 in. insul. and face brick	d_n	1.00000	–2.67076	2.58089	–1.07967	0.18237	–0.01057	0.00021
35	Layers E0 E1 B14 C11 A2 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00003	0.00003	0.00001
	5 in. insul. with 12 in. h.w. conc. and face brick	d_n	1.00000	–2.96850	3.45612	–2.02882	0.64302	–0.10884	0.00906
36	Layers E0 A2 C11 B25 A6 A0	b_n	0.00000	0.00000	0.00000	0.00004	0.00007	0.00004	0.00001
	Face brick and 12 in. h.w. conc. with 3.33 in. insul.	d_n	1.00000	–2.55127	2.36600	–0.99023	0.19505	–0.01814	0.00075
37	Layers E0 E1 B25 C19 A2 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00003	0.00003	0.00002
	3.33 in. ins. w/12 in. l.w. blk. (fld.) and face brick	d_n	1.00000	–3.17762	4.00458	–2.56328	0.89048	–0.16764	0.01638
38	Layers E0 E1 B15 C20 A2 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00002	0.00003	0.00001
	6 in. ins. w/12 in. h.w. block (fld.) and face brick	d_n	1.00000	–3.14989	3.95116	–2.53790	0.89438	–0.17209	0.01706
39	Layers E0 A2 C16 B14 A6 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00002	0.00003	0.00001
	Face brick and 8 in. l.w. concrete with 5 in. insul.	d_n	1.00000	–2.99386	3.45884	–1.95834	0.57704	–0.08844	0.00687
40	Layers E0 A2 C20 B15 A6 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00002	0.00003	0.00001
	Face brick, 12 in. h.w. block (fld.), 6 in. insul.	d_n	1.00000	–2.97582	3.42244	–1.93318	0.56765	–0.08568	0.00652
41	Layers E0 E1 C11 B14 A2 A0	b_n	0.00000	0.00000	0.00000	0.00001	0.00002	0.00002	0.00001
	12 in. h.w. conc. with 5 in. insul. and face brick	d_n	1.00000	–3.08296	3.66615	–2.11991	0.62142	–0.08917	0.00561

Table 19 Wall Conduction Transfer Function Coefficients Σc_n, Time Lag, U-Factors, and Decrement Factors

Wall Group		Σc_n	TL, h	*U*	DF
1	Layers E0 A3 B1 B13 A3 A0	0.04990	1.30	0.066	0.98
2	Layers E0 E1 B14 A1 A0 A0	0.01743	3.21	0.055	0.91
3	Layers E0 C3 B5 A6 A0 A0	0.05162	3.33	0.191	0.78
4	Layers E0 E1 B6 C12 A0 A0	0.00694	4.76	0.047	0.81
5	Layers E0 A6 B21 C7 A0 A0	0.01776	5.11	0.129	0.64
6	Layers E0 E1 B2 C5 A1 A0	0.02174	5.28	0.199	0.54
7	Layers E0 A6 C5 B3 A3 A0	0.01303	5.14	0.122	0.41
8	Layers E0 A2 C12 B5 A6 A0	0.01345	6.21	0.195	0.35
9	Layers E0 A6 B15 B10 A0 A0	0.00293	7.02	0.042	0.58
10	Layers E0 E1 C2 B5 A2 A0	0.00828	7.05	0.155	0.53
11	Layers E0 E1 C8 B6 A1 A0	0.00552	7.11	0.109	0.37
12	Layers E0 E1 B1 C10 A1 A0	0.01528	7.25	0.339	0.33
13	Layers E0 A2 C5 B19 A6 A0	0.01053	7.17	0.251	0.28
14	Layers E0 A2 A2 B6 A6 A0	0.00337	7.90	0.114	0.22
15	Layers E0 A6 C17 B1 A7 A0	0.00291	8.64	0.092	0.47
16	Layers E0 A6 C18 B1 A7 A0	0.00545	8.91	0.222	0.38
17	Layers E0 A2 C2 B15 A0 A0	0.00093	9.36	0.043	0.30
18	Layers E0 A6 B25 C9 A0 A0	0.00144	9.23	0.072	0.24
19	Layers E0 C9 B6 A6 A0 A0	0.00200	8.97	0.106	0.20
20	Layers E0 C11 B19 A6 A0 A0	0.00326	9.27	0.237	0.16
21	Layers E0 C11 B6 A1 A0 A0	0.00089	10.20	0.112	0.13
22	Layers E0 C14 B15 A2 A0 A0	0.00064	10.36	0.040	0.36
23	Layers E0 E1 B15 C7 A2 A0	0.00042	11.17	0.042	0.28
24	Layers E0 A6 C20 B1 A7 A0	0.00159	11.29	0.196	0.23
25	Layers E0 A2 C15 B12 A6 A0	0.00051	11.44	0.060	0.19
26	Layers E0 A2 C6 B6 A6 A0	0.00078	10.99	0.097	0.15
27	Layers E0 E1 B14 C11 A1 A0	0.00024	11.82	0.052	0.12
28	Layers E0 E1 C11 B13 A1 A0	0.00029	11.40	0.064	0.10
29	Layers E0 A2 C11 B5 A6 A0	0.00052	12.06	0.168	0.08
30	Layers E0 E1 B19 C19 A2 A0	0.00034	12.65	0.062	0.24
31	Layers E0 E1 B15 C15 A2 A0	0.00017	12.97	0.038	0.21
32	Layers E0 E1 B23 B9 A2 A0	0.00025	13.05	0.069	0.16
33	Layers E0 A2 C6 B15 A6 A0	0.00015	12.96	0.042	0.12
34	Layers E0 C11 B21 A2 A0 A0	0.00035	12.85	0.143	0.09
35	Layers E0 E1 B14 C11 A2 A0	0.00009	13.69	0.052	0.08
36	Layers E0 A2 C11 B25 A6 A0	0.00016	12.82	0.073	0.06
37	Layers E0 E1 B25 C19 A2 A0	0.00008	14.70	0.040	0.14
38	Layers E0 E1 B15 C20 A2 A0	0.00008	14.39	0.041	0.12
39	Layers E0 A2 C16 B14 A6 A0	0.00007	14.64	0.040	0.10
40	Layers E0 A2 C20 B15 A6 A0	0.00007	14.38	0.041	0.08
41	Layers E0 E1 C11 B14 A2 A0	0.00005	14.87	0.052	0.06

CTF Coefficients (Tables 11 and 15 through 19)

Outside surface resistance = A0
4 in. high density concrete = C5
2 in. insulation = B3
Air space resistance = B1
3/4 in. plaster = E1
Inside surface resistance = E0

The appropriate arrangement of layers in the wall can be found in Table 17. The dominant wall layer C5 is at the outside surface ("mass out"), and has a Wall Material column number of 10; combined with an E1 layer, this dictates use of the upper array of code numbers for wall assembly groups. Entering this array with an R-value range of 9 (R = 6.667), column 10 indicates that Wall Group 6 most nearly represents the wall under consideration.

The CTF coefficients of Wall Group 6 as listed in Table 18 are:

b_0 =0.00051	d_0 = 1.0000
b_1 =0.00938	d_1 =−1.17580
b_2 =0.01057	d_2 = 0.30071
b_3 =0.00127	d_3 =−0.01561
b_4 =0.00001	d_4 = 0.00001
b_5 =0.00000	d_5 = 0.00000
b_6 =0.00000	d_6 = 0.00000

From Table 19, the U-factor of the wall is 0.199 and $\sum_{n=0} c_n = 0.02174$.

Heat Flow Calculations. The following format of Equation (25) demonstrates heat flow calculations through the wall:

$$q_{e,\theta}/A = \begin{bmatrix} b_0(t_{e,\theta}) \\ +b_1(t_{e,\theta-\delta}) \\ +b_2(t_{e,\theta-2\delta}) \\ . \\ . \\ . \end{bmatrix} - \begin{bmatrix} d_1[(q_{e,\theta-\delta})/A] \\ +d_2[(q_{e,\theta-2\delta})/A] \\ . \\ . \\ . \\ . \end{bmatrix} - \left[t_{rc}\sum_{n=0} c_n\right]$$

This arrangement indicates that the heat gain through the wall is the sum of three parts:

1. Sum of the products of b coefficients and sol-air temperature values. The current value of this temperature is multiplied by b_0, the sol-air temperature of one step in time earlier is multiplied by b_1, etc.
2. Sum of the products of d coefficients and the previous values of heat gain. Note that the first d used is d_1. Again, the order of values is the same as in the first term, i.e., d_1 is multiplied by the heat gain value that was calculated for the previous step in time, d_2 is multiplied by the value calculated for two steps back in time, etc.
3. A constant, since room air temperature is constant and needs to be calculated only once.

The sequence of calculation using numerical values of this example are then as follows (starting at time θ = 1, expressing heat flux in Btu/(h·ft²), setting A = 1.0, and dropping b and d coefficients 4 through 6 as insignificant):

$$q_{e,1} = \begin{bmatrix} +0.00051(76) \\ +0.00938(77) \\ +0.01057(79) \\ +0.00127(81) \end{bmatrix} - \begin{bmatrix} -1.17580(0) \\ +0.30071(0) \\ -0.01561(0) \end{bmatrix} - [0.02174(75)]$$

$$= 0.068$$

$$q_{e,2} = \begin{bmatrix} +0.00051(76) \\ +0.00938(76) \\ +0.01057(77) \\ +0.00127(79) \end{bmatrix} - \begin{bmatrix} -1.17580(0.068) \\ +0.30071(0) \\ -0.01561(0) \end{bmatrix} - [+1.6305]$$

$$= 0.117$$

The values for q_e for this example are given in the summary table.

The convergence of the heat gain values to a periodic steady-state condition is indicated by comparing the average of the last 24 values with the average heat flow. The latter is given by the product of the U-factor and the difference between the average sol-air and room temperature. Thus

$$q_{avg} = 0.199(91.54 - 75.00) = 3.291\ \text{Btu}/(\text{h}\cdot\text{ft}^2)$$

The average of the last 24 values of heat gain tabulated in the summary table is given by:

$$q_{e,avg} = \left(\sum_{i=73}^{96} q_{e,i}\right)/24 = \frac{78.954}{24} = 3.29\text{Btu/h}\cdot\text{ft}^2$$

Summary of Calculations for Example 3

n	$q_{e,n}$	n	$q_{e,n}$	n	$q_{e,n}$	n	$q_{e,n}$
1	0.068	25	3.688	49	3.744	73	3.745
2	0.117	26	3.174	50	3.221	74	3.221
3	0.139	27	2.712	51	2.751	75	2.751
4	0.141	28	2.303	52	2.335	76	2.336
5	0.117	29	1.933	53	1.961	77	1.961
6	0.077	30	1.603	54	1.626	78	1.626
7	0.048	31	1.329	55	1.348	79	1.349
8	0.065	32	1.141	56	1.157	80	1.157
9	0.156	33	1.060	57	1.073	81	1.073
10	0.333	34	1.092	58	1.103	82	1.103
11	0.599	35	1.237	59	1.246	83	1.246
12	0.948	36	1.483	60	1.491	84	1.491
13	1.372	37	1.821	61	1.828	85	1.828
14	1.945	38	2.322	62	2.328	86	2.328
15	2.746	39	3.063	63	3.068	87	3.068
16	3.731	40	3.997	64	4.002	88	4.002
17	4.773	41	4.997	65	5.000	89	5.000
18	5.702	42	5.890	66	5.892	90	5.892
19	6.320	43	6.478	67	6.480	91	6.480
20	6.388	44	6.520	68	6.522	92	6.522
21	5.974	45	6.085	69	6.087	93	6.087
22	5.401	46	5.495	70	5.496	94	5.496
23	4.810	47	4.888	71	4.889	95	4.889
24	4.236	48	4.302	72	4.303	96	4.303

Note: n is in hours and $q_{e,n}$ is in Btu/(h·ft²).

Heat Gain through Interior Partitions, Floors, and Ceilings

Whenever a conditioned space is adjacent to other spaces at different temperatures, the transfer of heat through the partition can be calculated by:

$$q_{e,\theta}/A = \sum_{n=0} b_n(t_{e,\theta-n\delta}) - \sum_{n=1} \frac{d_n(q_{e,\theta-n\delta})}{A} - t_{rc}\sum_{n=0} c_n \tag{26}$$

where

A = area, ft²
t_b = air temperature of adjacent space, °F
b, c, d = CTF coefficients derived from Tables 11 through 19, considering partitions as walls and floors or ceilings as roofs

Heat Gain from Adjacent Spaces. When t_b is constant or at least the variations of t_b are small compared to the difference ($t_b - t_{rc}$), $q_{p,\theta}$ is given by the simple steady-state expression

$$q_{p,\theta} = UA(t_b - t_{rc}) \tag{27}$$

where U = coefficient of overall heat transfer between the adjacent and the conditioned spaces (see Tables 14 or 19 or Chapter 24).

The same expression gives the mean values for $q_{p,\theta}$, when a mean value of t_b is used even though t_b varies. When $q_{p,\theta}$, is relatively small compared to the other room heat gain components, it may be considered constant at its mean value. If this component of heat gain is large, the temperature in the adjacent space should be calculated.

Note the common values $q_{p,\theta}$, A, t_b, and t_{rc} in Equations (26) and (30), illustrating the general functional equivalency of CTF coefficients b, c, and d in dynamic heat transfer over time to the steady-state heat transfer coefficient U, thus setting the rationale for adjustment of tabular CTF values by ratio of U_{actual}/U_{table}.

Conversion of Cooling Load from Heat Gain

The cooling load of a space depends on the magnitude and the nature of the sensible heat gain (i.e., heat conduction through walls, direct and diffuse solar radiation, energy input to lights, etc.) and on the location and mass of room objects that absorb the radiant heat. For example, the cooling load profile resulting from a unit pulse of solar radiation absorbed by window glass is quite different from that absorbed by a floor surface. Thus, each component of the room heat gain gives rise to a distinct component of cooling load, and the sum of these various components at any time is the total cooling load at that time.

Unlike other components, the latent heat gain component of the cooling load may or may not be part of room load depending on the type of air-conditioning system, i.e., ventilation air may be dehumidified at a central location rather than in each room.

Cooling Load by Room Transfer Function. Stephenson and Mitalas (1967), Mitalas and Stephenson (1967), and Kimura and Stephenson (1968) related heat gain to the corresponding cooling load by a room transfer function (RTF), which depends on the nature of the heat gain and on the heat storage characteristics of the space (i.e., of the walls, floor, etc., that enclose the space, and of the contents of that space). Where the heat gain q_θ is given at equal time intervals, the corresponding cooling load Q_θ at time θ can be related to the current value of q_θ and the preceding values of cooling load and heat gain by:

$$Q_\theta = \sum_{i=1} (v_o q_\theta + v_1 q_{\theta-d} + v_2 q_{\theta-2\delta} + \dots) - (w_1 Q_{\theta-\delta} + w_2 Q_{\theta-2\delta} + \dots) \quad (28)$$

where i is taken from 1 to the number of heat gain components and δ = time interval. The terms v_0, v_1 ..., w_1, w_2 ... are the coefficients of the RTF

$$K_{(z)} = \frac{v_0 + v_1 z^{-1} + v_2 z^{-2} + \dots}{1 + w_1 z^{-1} + w_2 z^{-2} + \dots} \quad (29)$$

which relates the transform of the corresponding parts of the cooling load and of the heat gain. These coefficients depend on (1) the size of the time interval δ between successive values of heat gain and cooling load, (2) the nature of the heat gain (how much is in the form of radiation and where it is absorbed), and (3) on the heat storage capacity of the room and its contents. Therefore, different RTFs are used to convert each distinct heat gain component to cooling load.

While the basic form of Equation (31) anticipates a series of v_n and w_n coefficients, the effect of past v_1 and w_1 is negligible, and data tabulated may generally be used with confidence. A slight inaccuracy does occur in the calculation for the first hour that internal loads begin; up through the second before the hour for which the calculation is made, such load does not exist, and the value generated by the transfer functions is not reached until the end of that hour. The convective component of such load is instantaneous, and the growth of the radiant component (combined with the convective element by the transfer coefficients) as it is absorbed and released by the building mass and contents is realistic throughout the rest of the load period.

Sensitivity of Parameters—Nontypical Applications

The concept of evaluating the thermal storage performance of a given space by means of RTF coefficients is based on the essential similarity of enclosing surfaces, spacial geometry, and related characteristics of that space to corresponding parameters of the space for which the data were calculated. ASHRAE research projects 359-RP [(Chiles and Sowell 1984), (Sowell and Chiles 1984a), (Sowell and Chiles 1984b)], 472-RP [(Harris and McQuiston 1988), (Sowell 1988a), (Sowell 1988b), (Sowell 1988c)], and 626-RP [(Falconer et al. 1993), (Spitler and McQuiston 1993), (Spitler et al. 1993)] investigated the unexpected sensitivity of such attributes and other counterintuitive phenomena regarding apparent responsiveness of relative masses in the storage and rejection of heat, and identified 14 discrete screening parameters with two to five levels of characterization each (Tables 20 through 23) by which to select representative data and to modify factors

Table 20 Zone Parametric Level Definitions

No.	Parameter	Meaning	Levels (in normal order)
1	ZG	Zone geometry	100 ft × 20 ft, 15 ft × 15 ft, 100 ft × 100 ft
2	ZH	Zone height	8 ft, 10 ft, 20 ft
3	NW	No. exterior walls	1, 2, 3, 4, 0
4	IS	Interior shade	100, 50, 0%
5	FN	Furniture	With, Without
6	EC	Exterior wall construction	1, 2, 3, 4 (Table 21)
7	PT	Partition type	5/8 in. gypsum board-air space 5/8 in. gypsum board, 8 in. concrete block
8	ZL	Zone location	Single-story, top floor, bottom floor, mid-floor
9	MF	Mid-floor type	8 in. concrete, 2.5 in. concrete, 1 in. wood
10	ST	Slab type	Mid-floor type, 4 in. slab on 12 in. soil
11	CT	Ceiling type	3/4 in. acoustic tile and air space, w/o ceiling
12	RT	Roof type	1, 2, 3, 4 (Table 23)
13	FC	Floor covering	Carpet with rubber pad, vinyl tile
14	GL	Glass percent	10, 50, 90

Table 21 Exterior Wall Construction Types

Type	Description
1	Outside surface resistance, 1 in. stucco, 1 in. insulation, 3/4 in. plaster or gypsum, inside surface resistance (A0, A1, B1, E1, E0)*
2	Outside surface resistance, 1 in. stucco, 8 in. HW concrete, 3/4 in. plaster or gypsum, inside surface resistance (A0, A1, C10, E1, E0)
3	Outside surface resistance, steel siding, 3 in. insulation, steel siding, inside surface (A0, A3, B12, A3, E0)*
4	Outside surface resistance, 4 in. face brick, 2 in. insulation. 12 in. HW concrete, 3/4 in. plaster or gypsum, inside surface resistance (A0, A2, B3, C11, E1, E0)*

Note: Code letters are defined in Table 11.

Table 22 Floor and Ceiling Types Specified by Zone Location Parameter

Zone Location	Floor	Ceiling
Single story	Slab-on-grade	Roof
Top floor	Mid-floor	Roof
Bottom floor	Slab-on-grade	Mid-floor
Mid-floor	Mid-floor	Mid-floor

Table 23 Roof Construction Types

Type	Description
1	Outside surface resistance, 1/2 in. slag or stone, 3/8 in. felt membrane, 1 in. insulation, steel siding, inside surface resistance (A0, E2, E3, B4, A3, E0)*
2	Outside surface resistance, 1/2 in. slag or stone, 3/8 in. felt membrane, 6 in. LW concrete, inside surface resistance (A0, E2, E3, C15, E0)*
3	Outside surface resistance, 1/2 in. slag or stone, 3/8 in. felt membrane, 2 in. insulation, steel siding, ceiling air space, acoustic tile, inside surface resistance (A0, E2, E3, B6, A3, E4, E5, E0)*
4	Outside surface resistance, 1/2 in. slag or stone, 3/8 in. felt membrane, 8 in. LW concrete, ceiling air space, acoustic tile, inside surface resistance (A0, E2, E3, C16, E4, E5, E0)*

Note: Code letters are defined in Table 11.

Table 24 Room Transfer Functions: Coefficient

Room Air Circulation[a] and S/R Type	Room Envelope Construction[b]				
	2-in. Wood Floor	3-in. Concrete Floor	6-in. Concrete Floor	8-in. Concrete Floor	12-in. Concrete Floor
	Specific Mass per Unit Floor Area, lb/ft^2				
	10	40	75	120	160
Low	–0.88	–0.92	–0.95	–0.97	–0.98
Medium	–0.84	–0.90	–0.94	–0.96	–0.97
High	–0.81	–0.88	–0.93	–0.95	–0.97
Very High	–0.77	–0.85	–0.92	–0.95	–0.97
	–0.73	–0.83	–0.91	–0.94	–0.96

[a]Circulation rate—

Low: Minimum required to cope with cooling load from lights and occupants in interior zone. Supply through floor, wall, or ceiling diffuser. Ceiling space not used for return air, and h = 0.4 Btu/h·ft^2·°F (where h = inside surface convection coefficient used in calculation of w_1 value).

Medium: Supply through floor, wall, or ceiling diffuser. Ceiling space not used for return air, and 0.6 Btu/h·ft^2·°F.

High: Room air circulation induced by primary air of induction unit or by room fan and coil unit. Ceiling space used for return air, and 0.8 Btu/h·ft^2·°F.

Very high: High room circulation used to minimize temperature gradients in a room. Ceiling space used for return air, and 0.8 Btu/h·ft^2·°F.

[b]Floor covered with carpet and rubber pad; for a bare floor or if covered with floor tile, take next w_1 value down the column.

appropriately for specific applications. While these selection parameters are arranged so that errors due to deviations are minimal and conservative, careful use is required in situations differing significantly from one or more specific parameters.

Peak Heat Gain Versus Peak Cooling Load. The RTF procedure distributes all heat gained during a 24-h period throughout that period in the conversion to cooling load. Thus, individual heat gain components rarely appear at full value as part of the cooling load unless representing a constant 24-h input (such as a continuously burning light fixture), or in very low mass construction that releases stored radiant heat relatively quickly. This concept is further complicated by the premise of "constant interior space temperature" (i.e., operation of an HVAC system 24 h a day, seven days a week with fixed control settings), which practice is far less prevalent today than in the past. The effect of intermittent system operation is seen primarily during the first hours of operation for a subsequent day, as discussed in the section Heat Extraction Rate, and can impact equipment size selection significantly.

Superposition of Load Components. Finally, a presupposition of the TFM is that total cooling load for a space can be calculated by simple addition of the individual components. For example, radiation heat transfer from individual walls or roofs is assumed to be independent of the other surfaces, which is slightly incorrect in a theoretical sense. However, means for compensation for these

Table 25 Room Transfer Functions: v_0 and v_1 Coefficients

Heat Gain Component	Room Envelope Construction[b]	v_0	v_1
		Dimensionless	
Solar heat gain through glass[c] with no interior shade; radiant heat from equipment and people	Light	0.224	$1 + w_1 - v_0$
	Medium	0.197	$1 + w_1 - v_0$
	Heavy	0.187	$1 + w_1 - v_0$
Conduction heat gain through exterior walls, roofs, partitions, doors, windows with blinds or drapes	Light	0.703	$1 + w_1 - v_0$
	Medium	0.681	$1 + w_1 - v_0$
	Heavy	0.676	$1 + w_1 - v_0$
Convective heat generated by equipment and people, and from ventilation and infiltration air	Light	1.000	0.0
	Medium	1.000	0.0
	Heavy	1.000	0.0

Heat Gain from Lights[d]

Furnishings	Air Supply and Return	Type of Light Fixture	v_0	v_1
Heavyweight simple furnishings, no carpet	Low rate; supply and return below ceiling ($V \le 0.5$)[e]	Recessed, not vented	0.450	$1 + w_1 - v_0$
Ordinary furnishings, no carpet	Medium to high rate, supply and return below or through ceiling ($V \ge 0.5$)[e]	Recessed, not vented	0.550	$1 + w_1 - v_0$
Ordinary furnishings, with or without carpet on floor	Medium to high rate, or induction unit or fan and coil, supply and return below, or through ceiling, return air plenum ($V \ge 0.5$)[e]	Vented	0.650	$1 + w_1 - v_0$
Any type of furniture, with or without carpet	Ducted returns through light fixtures	Vented or free-hanging in air-stream with ducted returns	0.750	$1 + w_1 - v_0$

[a]The transfer functions in this table were calculated by procedures outlined in Mitalas and Stephenson (1967) and are acceptable for cases where all heat gain energy eventually appears as cooling load. The computer program used was developed at the National Research Council of Canada, Division of Building Research.

[b]The construction designations denote the following:

Light construction: such as frame exterior wall, 2-in. concrete floor slab, approximately 30 lb of material per square foot of floor area.

Medium construction: such as 4-in. concrete exterior wall, 4-in. concrete floor slab, approximately 70 lb of building material per square foot of floor area.

Heavy construction: such as 6-in. concrete exterior wall, 6-in. concrete floor slab, approximately 130 lb of building material per square foot of floor area.

[c]The coefficients of the transfer function that relate room cooling load to solar heat gain through glass depend on where the solar energy is absorbed. If the window is shaded by an inside blind or curtain, most of the solar energy is absorbed by the shade, and is transferred to the room by convection and long-wave radiation in about the same proportion as the heat gain through walls and roofs; thus the same transfer coefficients apply.

[d]If room supply air is exhausted through the space above the ceiling and lights are recessed, such air removes some heat from the lights that would otherwise have entered the room. This removed light heat is still a load on the cooling plant if the air is recirculated, even though it is not a part of the room heat gain as such. The percent of heat gain appearing in the room depends on the type of lighting fixture, its mounting, and the exhaust airflow.

[e]V is room air supply rate in cfm/ft^2 of floor area.

limitations fall within the range of acceptable error that must be expected in any estimate of cooling load.

The previously mentioned research calculated RTF values for all possible combinations of screening parameter levels for a total of 200,640 individual cases. Access to these data is available electronically by techniques outlined in the *Cooling and Heating Load Calculation Manual* (McQuiston and Spitler 1992). A simplified method of RTF selection is presented in this chapter with RTF coefficients for various types and configurations of room construction and room air circulation rates given in Tables 24 and 25.

Use of Room Transfer Functions

To obtain appropriate room transfer function data for use in Equation (28), (1) select the value of w_1 from Table 24 for the approximate space envelope construction and range of air circulation, and (2) select and/or calculate the values of v_0 and v_1 from Table 25 for the appropriate heat gain component and range of space construction mass.

Example 4. Cooling load due to solar radiation through glass. Consider a room having a 1/2 in. air space double-glazed window (shading coefficient = 0.83) in a multistory office building of heavyweight construction (approximately 120 lb/ft^2 floor area). The building is located at 40°N latitude, the date is June 21, and the window orientation is NW. The U-factor for the window is 0.56 Btu/(h·ft^2·°F). Assume the floor to be carpeted, the air circulation rate "medium" (h_i = 0.6 Btu/(h·ft^2·°F), and the ceiling space not ventilated. Calculate the cooling load due to solar radiation through glass. Solar heat gain (SHG) to the room through the window is given as SHG = SHGF × Shading Coefficient = SHGF × 0.83.

Time, h	SHGF	SHG	Time, h	SHGF	SHG
0100	0	0	1300	40	33
0200	0	0	1400	63	52
0300	0	0	1500	114	95
0400	0	0	1600	156	129
0500	1	1	1700	172	143
0600	13	11	1800	143	119
0700	21	17	1900	21	17
0800	27	22	2000	0	0
0900	32	27	2100	0	0
1000	35	29	2200	0	0
1100	38	32	2300	0	0
1200	38	32	2400	0	0
Daily total				917	753

Note: SHGF from Table 18, Chapter 29. Units are Btu/h·ft^2

Solution: The room transfer function coefficients for 120 lb/ft^2 construction, solar radiation input, medium air circulation rate, and the condition of "no heat loss for the room" are (see Tables 24 and 25):

$$v_0 = 0.187 \qquad w_0 = 1.000 \text{ (in all cases)}$$
$$v_1 = -0.147 \qquad w_1 = -0.960$$

The cooling load component due to solar radiation through glass at any time θ is given by Equation (28). The calculations can be set up as follows:

$$Q_\theta = \begin{bmatrix} v_0(\mathrm{SHG}_\theta) \\ +\,v_1(\mathrm{SHG}_{\theta-\delta}) \\ -\,w_1(Q_{\theta-\delta}) \end{bmatrix}$$

As in the earlier heat gain calculation example, the calculation is started by assuming that the previous *Q*s are zero. Furthermore, in this example, SHG = 0 for θ = 1, 2, 3, and 4; therefore, *Q*s in Btu/(h·ft^2) are:

Q_5	*v, w*	Hour	SHG	Prev. *Q*s	Factor
	0.187	5	1		0.187
	−0.147	4	0		0.000
	0.96	4		0	0.000
				Q_5 =	0.187
Q_6	***v, w***	**Hour**	**SHG**	**Prev. *Q*s**	**Factor**
	0.187	6	11		0.187
	−0.147	5	1		−0.147
	0.96	5		0.187	0.180
				Q_6 =	2.090

Values of Q_θ for the remainder of the calculations are listed in the following table. The calculations of Q_θ are terminated at θ = 96 h, because by that time, the effect of the assumed zero initial conditions has decreased to negligible proportions.

Values of Q_θ for Example 4

θ	Q_θ	θ	Q_θ	θ	Q_θ	θ	Q_θ
1 =	0.000	25 =	17.041	49 =	23.440	73 =	25.842
2 =	0.000	26 =	16.359	50 =	22.502	74 =	24.808
3 =	0.000	27 =	15.705	51 =	21.602	75 =	23.816
4 =	0.000	28 =	15.077	52 =	20.738	76 =	22.863
5 =	0.187	29 =	14.661	53 =	20.095	77 =	22.135
6 =	2.090	30 =	15.985	54 =	21.201	78 =	23.160
7 =	3.568	31 =	16.908	55 =	21.915	79 =	23.796
8 =	5.040	32 =	17.847	56 =	22.653	80 =	24.459
9 =	6.653	33 =	18.948	57 =	23.562	81 =	25.296
10 =	7.841	34 =	19.644	58 =	24.074	82 =	25.738
11 =	9.248	35 =	20.579	59 =	24.832	83 =	26.429
12 =	10.158	36 =	21.036	60 =	25.119	84 =	26.652
13 =	11.219	37 =	21.662	61 =	25.581	85 =	27.053
14 =	15.643	38 =	25.669	62 =	29.431	86 =	30.844
15 =	25.138	39 =	34.763	63 =	38.375	87 =	39.731
16 =	34.290	40 =	43.530	64 =	46.998	88 =	48.300
17 =	40.696	41 =	49.567	65 =	52.896	89 =	54.146
18 =	40.300	42 =	48.816	66 =	52.012	90 =	53.212
19 =	24.374	43 =	32.549	67 =	35.618	91 =	36.770
20 =	20.900	44 =	28.748	68 =	31.694	92 =	32.800
21 =	20.064	45 =	27.598	69 =	30.426	93 =	31.488
22 =	19.261	46 =	26.494	70 =	29.209	94 =	30.228
23 =	18.491	47 =	25.434	71 =	28.041	95 =	29.019
24 =	17.751	48 =	24.417	72 =	26.919	96 =	27.858

Note: Values carried to 3 decimals to illustrate degree of convergence.

Cooling Load from Nonradiant Heat Gain

Sensible cooling load from strictly convective heat gain elements is instantaneous, added directly to the results of those gains processed by CTF and RTF coefficients, per the following equation.

$$Q_{sc} = \sum_{j=1} (q_{c,j}) \tag{30}$$

where

Q_{sc} = sensible cooling load from heat gain elements having only convective components
q_c = each of *j* heat gain elements having only such convective component

Heat Extraction Rate and Room Temperature

Discussion to this point has concentrated on estimating design cooling load for a conditioned space, assuming the maintenance of a constant interior temperature and the hourly total removal of all cooling load entering the space; and allowing the delaying action of building mass and contents to run its course. Certain minor factors have been ignored, such as the relatively indeterminate radiant heat loss to the outside of the building.

The basic principles of the TFM are also useful in estimating dynamic cooling load requirements over an extended period (see Chapter 30). In such cases, however, the goal is no longer to seek the peak load for equipment selection purposes, and the ebb and flow of heat into and out of the building assume much greater importance; thus, any loss back to the environment must be considered. This concept is also critical in predicting temperature swings in the space and the ability of cooling equipment to extract heat when operated in a building with extended off cycles (nights and weekends).

The cooling loads determined by the TFM serve as input data for estimating the resultant room air temperature and the heat extraction rate with a particular type and size of cooling unit, or set of operating conditions, or both. In addition, the characteristics of the cooling unit (i.e., heat extraction rate versus room air temperature), the schedule of operation, and a space air transfer function (SATF) for the room that relates room air temperature and heat extraction rate must also be included to run these calculations.

The heat extraction characteristics of the cooling unit can be approximated by a linear expression of the form

$$ER_\theta = W_\theta + St_{r\theta} \tag{31}$$

where

ER_θ = rate of heat removal from space at time θ
$t_{r\theta}$ = the air temperature in space at time θ
W, S = parameters characterizing performance of specific types of cooling equipment

This linear relationship only holds when $t_{r\theta}$ is within the throttling range of the control system. When $t_{r\theta}$ lies outside of this range, ER_θ has the value of either ER_{max} or ER_{min}, depending on whether the temperature $t_{r\theta}$ is above or below the throttling range. The value of S is the difference $ER_{max} - ER_{min}$ divided by the width of the throttling range, and W_θ is the value ER_θ would have if the straight-line relationship between it and $t_{r\theta}$ held at t_{r1} equals zero. This intercept depends on the set point temperature of the control system, which may be taken as the temperature at the middle of the throttling range. Thus,

$$W_\theta = \frac{ER_{max} + ER_{min}}{2} - St^*_{r\theta} \tag{32}$$

where $St^*_{r\theta}$ is the thermostat set point temperature at time θ.

Space Air Transfer Function

The heat extraction rate and the room air temperature are related by the space air transfer function (SATF):

$$\sum_{i=0}^{1} p_i(ER_{\theta-\delta} - Q_{\theta-i\delta}) = \sum_{i=0}^{2} g_i(t_{rc} - t_{r,\theta-i\delta}) \tag{33}$$

where g_1 and p_1 are the SATF coefficients, and Q is the calculated cooling load for the room at time θ, based on an assumed constant room temperature of t_{rc}. Normalized values of g and p are given in Table 26 for light, medium, and heavy construction.

Thermal Conductance to Surroundings. In calculating the design cooling load components previously described, it was assumed that all energy transferred into the space eventually appears as space cooling load. However, this is not quite true over an extended period, because a fraction of the input energy can instead be lost back to the surroundings. This fraction F_c depends on the thermal conductance between the space air and the surroundings and can be estimated as

$$F_c = 1 - 0.02K_\theta \tag{34}$$

Table 26 Normalized Coefficients of Space Air Transfer Functions[a]

Room Envelope Construction	g_0^*	g_1^*	g_2^*	p_0	p_1
	Btu/h·ft·°F			Dimensionless	
Light	1.68	−1.73	0.05	1.0	−0.82
Medium	1.81	−1.89	0.08	1.0	−0.87
Heavy	1.85	−1.95	0.10	1.0	−0.93

[a]For simplified procedure for calculating space air transfer function coefficients, see ASHRAE (1975).
[b]The designations Light, Medium, and Heavy denote the same meanings as those footnoted for Table 25.

where K_θ is the unit length conductance between the space air and surroundings given by

$$K_\theta = (1/L_F)(U_R A_R + U_W A_W + U_{OW} A_{OW} + U_P A_P) \tag{35}$$

where

L_F = length of space exterior wall, ft
U = U-factor of space enclosure element (subscript R for roof, W for window, OW for outside wall, and P for partition, should such be adjacent to an unconditioned area), Btu/(h·ft²·°F)
A = area of space enclosure element, ft²

The units of K_θ are Btu/(h·ft·°F). Therefore, if F_c is to be dimensionless, the multiplier is 0.02 h·ft·°F/Btu.

Adjustment of Load Components. To adjust the space cooling loads calculated in the previous sections, multiply the value of the following components by the factor F_c from Equation (34):

- Sensible cooling load from heat gain by conduction through exterior roofs and walls
- Sensible cooling load from conduction and solar heat gain through fenestration areas
- Sensible cooling load from heat gain through interior partitions, ceilings, and floors
- Sensible cooling load from radiant portion of heat gain from lights, people, and equipment

Adjustments to g^* Coefficients. To obtain the SATF coefficients for Equation (36), first select the values of p_0, p_1, g_0*, g_1*, and g_2* from Table 26 for the appropriate space envelope construction. Since the * coefficients in Table 26 are for a space with zero heat conductance to surrounding spaces and are normalized to a unit floor area, it is necessary to adjust the 0 and 1 values. To get the g_0 and g_1 coefficients for a space with a floor area A, total conductance K_θ [by Equation (35)] between space air surroundings, ventilation rate, and infiltration rate, the relationships are:

$$g_{0,\theta} = g_0^* A + p_0[K_\theta + 1.10(V_\theta + VI_\theta)] \tag{36}$$

$$g_{1\theta} = g_1^* A + p_1[K_\theta + 1.10(V_{\theta-1\delta} + VI_{\theta-1\delta})] \tag{37}$$

Note that Equation (37) has no second term when calculating $g_{2,\theta}$, since p_2 has no value.

Heat Extraction Rate. For either condition (heat loss to surroundings or not, and using the appropriate values of g), Equations (31) and (32) can be solved simultaneously for ER_θ

$$ER_\theta = \frac{W_\theta g_0}{S + g_0} + \frac{I_\theta S}{S + g_0} \tag{38}$$

where

$$I_\theta = t_{rc}\sum_{i=0}^{2} g_{i,\theta} - \sum_{i=1}^{2} g_{i,\theta}(t_{r,\theta-i\delta}) + \sum_{i=0}^{1} p_i(Q_{\theta-i\delta}) - \sum_{i=1}^{1} p_i(ER_{\theta-i\delta}) \tag{39}$$

If the value of ER_θ calculated by Equation (38) is greater than ER_{max}, it is made equal to ER_{max}; if it is less than ER_{min}, it is made equal to ER_{min}. Then $t_{r\theta}$ is calculated from the expression

$$t_{r\theta} = (1/g_{0,\theta})(I_\theta - ER_\theta) \tag{40}$$

Example 5. Calculation of room air temperature and heat extraction rate. A room is of heavy construction with a floor area of 400 ft^2. The total room cooling load calculated on the basis of t_{rc} = 70°F is given as:

θ, h	Q_θ, Btu/h	θ, h	Q_θ, Btu/h	θ, h	Q_θ, Btu/h
1	2200	9	2180	17	7630
2	2030	10	2330	18	6880
3	1850	11	2650	19	5530
4	1730	12	3580	20	4380
5	1680	13	4880	21	3630
6	1750	14	6180	22	3130
7	1880	15	7150	23	2730
8	2030	16	7680	24	2450

The cooling unit has a maximum heat extraction capability of 7500 Btu/h and a minimum of zero. The throttling range is 3°F wide. Assume no ventilation and no infiltration, and heat loss to the exterior surroundings at the rate of 100 Btu/(h · °F). Calculate room air temperature and heat extraction rate for:

Schedule A. The control thermostat is set at 77°F from 0700 to 1800 h; during the rest of the time, it is set up to 85°F.

Schedule B. The control thermostat is set at 77°F all the time.

Solution:

(a) Space Air Transfer Functions.

The SATF coefficients for a 400 ft^2 room of heavy construction are [from Table 26 and Equations (36) and (37) with *V* and V_1 dropping out]:

$$g_{0,\theta} \quad 400(+1.85) + 100(+1.0) = 840.00$$
$$g_{1,\theta} \quad 400(-1.95) + 100(-0.93) = -873.00$$
$$g_{2,\theta} \quad 400(+0.10) = 40.00$$
$$\sum_{i=0}^{2} g_i = 7.00$$

(b) Cooling Unit Characteristics.

$$ER_{max} = 7500 \text{ Btu/h}$$
$$ER_{min} = 0$$
$$t_{tr} = 3°\text{F throttling range}$$
$$S = (7500 - 0)/3 = 2500 \text{ Btu/(h} \cdot °\text{F)}$$

when $t^*_{r\theta}$ = 77.0°F,

$$W_\theta = [(7500 - 0)/2] - 2500(77.0) = -188{,}750 \text{ Btu/h}$$

and when $t^*_{r\theta}$ = 85.0°F,

$$W_\theta = [(7500 - 0)/2] - 2500(85.0) = -208{,}750 \text{ Btu/h}$$

(c) Calculation of ER_θ and $t_{r\theta}$.

Some prior values for ER_θ and $t_{r\theta}$ must be assumed to begin the computation process. The computation is repeated until the results for successive days are the same. At that time, the results are independent of the values assumed initially.

To get the calculation started, assume all previous values of *ER* = 0 and t_r = 80°F. Thus:

$$I_1 = 70.0(7.0) - \begin{bmatrix} -873(80) \\ +40(80) \end{bmatrix} + \begin{bmatrix} +1.0(2200) \\ -0.93(2450) \end{bmatrix} - \begin{bmatrix} -0.93(0.0) \end{bmatrix}$$
$$= 67{,}052 \text{ Btu/h}$$
$$ER_1 = \frac{-208{,}750 \times 840}{2500 + 840} + \frac{67{,}052 \times 2500}{2500 + 840}$$
$$= -52{,}500 + 50{,}189 = -2311 \text{ Btu/h}$$

As this is less than ER_{min}, $ER_1 = ER_{min} = 0$ and t_{r1} = (1/840)(67,052 – 0.0) = 79.8°F

Table 27 Room Air Temperature and Heat Extraction Rates for Example 6

	Schedule A (Control thermostat set at 77°F from 0800 to 1800, and at 85°F at all other times)		Schedule B (Control thermostat set at 77°F at all times)	
Time, h	Room Air Temperature t_r, °F	Heat Extraction ER, Btu/h	Room Air Temperature t_r, °F	Heat Extraction ER, Btu/h
0100	82.0	0	76.3	1956
0200	81.9	0	76.2	1806
0300	81.8	0	76.2	1649
0400	81.7	0	76.1	1535
0500	81.7	0	76.1	1474
0600	81.8	0	76.1	1505
0700	82.0	0	76.1	1584
0800	77.2	4235	76.2	1680
0900	77.1	4051	76.2	1780
1000	77.1	4025	76.3	1881
1100	77.2	4138	76.3	2113
1200	77.4	4720	76.6	2807
1300	77.7	5602	77.0	3794
1400	78.1	6507	77.4	4799
1500	78.4	7184	77.7	5571
1600	78.6	7500	77.9	6019
1700	78.5	7477	77.9	6032
1800	78.3	6876	77.7	5513
1900	83.8	786	77.3	4528
2000	83.6	268	77.0	3669
2100	83.3	0	76.7	3099
2200	82.8	0	76.6	2710
2300	82.5	0	76.5	2393
2400	82.3	0	76.4	2164
	Totals	63369		72061

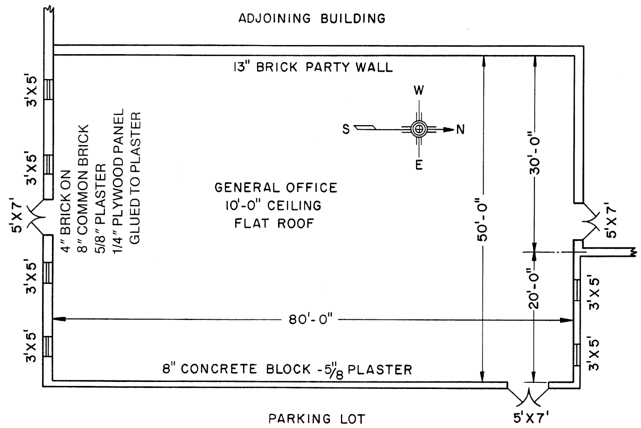
$$I_2 = 70.0(7.0) - \begin{bmatrix} -873(79.8) \\ +40(80) \end{bmatrix} + \begin{bmatrix} +1.0(2030) \\ -0.93(2200) \end{bmatrix} - \begin{bmatrix} -0.93(0.0) \end{bmatrix}$$
$$= 66{,}939 \text{ Btu/h}$$
$$ER_2 = \frac{-208{,}750 \times 840}{2500 + 840} + \frac{66{,}939 \times 2500}{2500 + 840}$$
$$= -52{,}500 + 50{,}104 = -2396 \text{ Btu/h}$$

As this also is less than ER_{min}, $Er_2 = ER_{min} = 0$ and t_{r2} = (1/840) (66,939 – 0) =79.7°F, and so on.

The effect of the assumed initial ER_θ and $t_{r\theta}$ values has decreased to negligible proportions by the time θ = 145, i.e., $t_{r145} = t_{r169}$ = 82.6°F. The complete set of results for operating schedules A and B is given in Table 27.

EXAMPLE COOLING LOAD CALCULATION

Example 6. Cooling load calculation of small office building. A one-story small commercial building (Figure 4) is located in the eastern United States near 40°N latitude. The adjoining buildings on the north and west are not conditioned, and the air temperature within them is approximately equal to the outdoor air temperature at any time of day.



Note: The small commercial building shown in this figure has been in the ASHRAE literature for several decades to illustrate cooling load procedures. In this example, some materials have been updated to reflect currently available products and associated U-factors; the calculation month has been changed to July for better comparison with newer data. Otherwise, all other characteristics of this example remain unchanged.

Fig. 4 Plan of One-Story Office Building

Building Data:

South wall construction. 4-in. light-colored face brick, 8-in. common brick, 0.625-in. plaster, 0.25-in. plywood panel glued on plaster (Summer U = 0.24 Btu/h·ft²·°F, or R = 4.14).

East wall and outside north wall construction. 8-in. light-colored heavy concrete block, 5/8-in. plaster on walls (Summer U = 0.48 Btu/h·ft²·°F, or R = 2.083).

West wall and adjoining north party wall construction. 13-in. solid brick (color n/a), no plaster: with U for a 12-in. brick interior wall = 0.26, R for that wall = 1/0.26 = 3.84; subtracting two still air film coefficients with R_{fc} = 0.68 each leaves R_b = 2.486; thus for this wall:

$$R_w = 0.68 + (2.486 \times 13/12) + 0.68 = 4.053$$

and $$U_w = 1/4.053 = 0.247, \text{ say } U = 0.25\text{Btu}/(\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})$$

Roof construction. 4-1/2-in. (nominal) flat roof of 2-in. gypsum slab on metal roof deck, 2-in. rigid roof insulation, surfaced with two layers of mopped 15-lb felt vapor-seal built-up roofing having dark-colored gravel surface, and with no false ceiling below underside of roof deck; (Summer U = 0.09 Btu/h·ft²·°F, or R = 11.11).

Floor construction. 4-in. concrete on ground.

Fenestration. 3 ft by 5 ftnonoperable windows of regular plate glass with light colored venetian blinds [Summer U = 0.81 Btu/h·ft²·°F].

Door construction. Light-colored 1.75-in. steel door with solid urethane core and thermal break (Summer U = 0.19 Btu/h·ft²·°F or R = 5.26 for exterior doors, and U = 0.18 Btu/h·ft²·°F or R = 5.56 for interior doors).

Front doors. Two 30 in. by 7 ft

Side doors. Two 30 in. by 7 ft

Rear doors. Two 30 in. by 7 ft (interior)

Note: U-factors for all exterior surfaces assume a summer wind velocity of 7.5 mph. Those for party walls and other interior surfaces assume still air.

Summer outdoor design conditions. Dry bulb = 94°F, daily range = 20°F, wet bulb = 77°F, W_o = 0.0161 lb (water)/lb (dry air)0.0159 kg (water)/kg (dry air), h_o = 40.3 Btu/lb (dry air)

Winter outdoor design conditions. Dry bulb = 10°F

Summer indoor design conditions. Dry bulb = 75°F, wet bulb = 62.5°F, W_i = 0.0092 lb (water)/lb (dry air), h_i = 28.07 Btu/lb (dry air)

Winter indoor design conditions. Dry bulb = 75°F

Occupancy. 85 office workers from 0800 to 1700 h

Lights. 17,500 W, fluorescent, operating from 0800 to 1700 hours daily; along with 4000 W, tungsten, operated continuously. Lighting fixtures are non-ventilated type.

Power equipment and appliances. For this example, none are assumed.

Ventilation. A ventilation rate of 15 cfm/person is selected as representative of a drugstore or hardware store. With 85 people, the total ventilation air quantity is thus 1275 cfm. Floor area of 4000 ft² with a 10 ft ceiling height gives a space volume of 40,000 ft³, corresponding to (1275 cfm × 60)/40,000 = 1.91 air changes per hour . In practice, ventilation air is normally conditioned to some extent by the air conditioning equipment before being admitted to the conditioned space. However, the variety of such arrangements and the varying impact felt by the load calculation process are not covered by this chapter and should be evaluated as part of a system analysis procedure. For this example, assume the ventilation air is introduced directly into the space and included as part of the space cooling load, but only during scheduled operating hours of the cooling equipment.

Infiltration. Window infiltration is considered zero, since the windows are sealed. Infiltration through wall surfaces is also neglected as insignificant, particularly with plastered interior surfaces. Calculation of door infiltration however, requires some judgement. The pressure of 1.91 air changes/h in the form of positive ventilation could be sufficient to prevent door infiltration, depending on the degree of simultaneous door openings and the wind direction and velocity. For this example, assume that outside and inside doors are frequently opened simultaneously, and that door infiltration should be included as part of the cooling load, estimating 100 ft³ per person per door passage. Further estimating outside door use at 10 persons hour, and inside doors (to unconditioned space, previously estimated to be at ambient temperature and humidity) at 30 persons per hour, generates the following infiltration rate:

$$Q_{inf} = 40 \times 100/60 = 67 \text{ cfm}$$

Thermal responsiveness of building and contents. For this example, mass of building construction and contents is "medium."

Conditioning equipment location. Conditioning equipment is in an adjoining structure to the north, thus having no direct impact on heat gain.

Find:

1. Sensible cooling load.
2. Latent cooling load.
3. Total cooling load.
4. Capacity of system to maintain:
   (a) Fixed temperature: 75°F indoor temperature, 24-hour "on" period.
   (b) 2°F throttling range: Indoor temperature in the range 75 to 77°F, 24-hour "on" period.
   (c) 4°F throttling range: Indoor temperature in the range 75 to 79°F, 24-hour "on" period.
   (d) 2°F throttling range: Indoor temperature in the range 75 to 77°F, 10-hour "on" period, 0800 to 1700.
   (e) 4°F throttling range: Indoor temperature in the range 75 to 79°F, 12-hour "on" period, 0600 to 1700.

Solution by Transfer Function Method

1. Daily load cycle: Estimated thermal loads are calculated by the TFM once per hour for a 24-h daily cycle.
2. Hourly heat gain components: The methodology using CTF coefficients is used to calculate heat gain components through walls and roof.
3. Thermal storage: The heat storage effect of the building and contents is accounted for by RTF coefficients.
4. Room temperature and heat extraction: TFM approximates resultant room air temperature and heat extraction rates for a specified schedule of thermostat set-points and/or cooling unit operating periods, by applying SATF coefficients to sensible cooling loads, including consideration for heat loss to surroundings. This process can be used to predict the capability of a particular size and type of cooling equipment, its control, and its operating schedule to maintain room air temperature within a specified range.
5. Summary: The data and summary of results using TFM are tabulated in Table 28. The following describes the calculation procedure used to determine the values for this table:

1. **Sensible cooling load**

(a) *General*

Line 1, Time of day in hours: Various temperatures and heat flow rates were calculated for every hour on the hour, assuming that hourly values are sufficient to define the daily profile.

Line 2, Outside air temperatures: Hourly values derived by the abovementioned procedure, using the specified maximum dry bulb temperature of 94°F and daily range of 20°F.

(b) *Solar Heat Gain Factors*

Lines 3, 4, 5, and 6, Solar heat gain through opaque surfaces: SHGF values from Table 18, Chapter 29 for July 21 at 40°N latitude. These values are used to calculate sol-air temperatures of various outside surfaces, and solar heat gain through windows.

Values for June might have been used, since the solar irradiation of horizontal surface (e.g., a roof) is maximum at that time of year and since the heat gain through the roof appears to be the major component of exterior heat gain in this problem. The difference between June and August values is relatively small however, compared to the large percentage increase in solar heat gain through south glass in August versus June at this latitude, thus indicating that August might be the better choice. For this example, data for July were selected as reasonable, and to provide better comparison with the results from other techniques for which tabular data are limited. To determine the month when the maximum building load will occur, the relative loads of various surfaces should first be evaluated and compared for several months.

(c) *Sol-Air Temperatures*

Lines 7, 8, 9, and 10, Sol-air temperatures at opaque surfaces: Sol-air temperatures, calculated by Equation (6), of the various opaque surfaces. These values are used in calculations of heat gain through the roof and outside walls.

(d) *Instantaneous Sensible Heat Gain*

Line 11, Roof heat gain: Instantaneous heat gain through the roof, calculated by CTF coefficients.

From Table 11, the major element of the roof (that layer with the most mass) is the gypsum slab (code number C14). Other elements are the metal deck (A3), rigid insulation (B3), built-up roofing (E3), and gravel surface (E2). Entering Table 12 with these code values, the C14 roof slab designates column 7, and the R-value 11.11 calls for R = 3. From the "mass-in" part of the table and the condition of being "w/o ceiling," the table identifies Roof Group 5 as that whose CTF coefficients will best represent the roof in question.

The CTF coefficients (b, d, and $\sum_{n=0} c_n$) are then obtained from Tables 13 and 14, by selecting roof group 5 and adjusting the tabulated b_n and $\sum_{n=0} c_n$ by the $U_{example}/U_{table}$ = 0.09/0.055 = 1.636.

The adjusted b_n and $\sum_{n=0} c_n$ are:

b_0 = 0.00006 (1.636) = 0.00010
b_1 = 0.00256 (1.636) = 0.00419
b_2 = 0.00477 (1.636) = 0.00780
b_3 = 0.00100 (1.636) = 0.00164
b_4 = 0.00002 = n/a
b_5 = 0.00000 = n/a
b_6 = 0.00000 = n/a
$\sum_{n=0} c_n$ = 0.00841 (1.636) = 0.01376

The d values (used without modification) are:

d_0 = 1.00000
d_1 = −1.10395
d_2 = 0.26169
d_3 = −0.00475
d_4 = 0.00002
d_5 = 0.00000
d_6 = 0.00000

The heat gain through the roof is calculated by Equation (25), using the sol-air temperature cycle given in line 7 and t_{rc} = 75°F. The calculations are extended for five daily cycles at which time the daily periodic steady state is effectively reached. The last daily cycle is used as the heat gain through the roof. (*Note*: Three daily cycles are sufficiently accurate in this case, but since calculations do not converge for the more massive wall components before the 93rd hour, all calculations are run to hour 120.)

Lines 12, 13, 14, and 15, Wall heat gain. The instantaneous heat gains through the various walls are calculated by the same approach as that used for the roof. The CTF coefficients selected from Tables 11 and 15 to 19 are:

North and East Exterior Walls
- Dominant element C8, or col. 13 in Integral Mass table (Table 16);
- Interior finish E1;
- R-value indicating R of 2 in Table 16;
- Select Wall Group 5 in Tables 18 and 19 for representative factors.

South Wall
- Dominant element C9, or col. 14 in Table 16;
- Exterior layer A2 or A7;
- Interior layer E1 (plywood panel ignored as trivial);
- R-value indicating R of 6;
- Select Wall Group 24 for representative factors.

North and West Party Walls
- With no specific data for a 13 in. brick wall, use a layer of 8 in. common brick (C9) and a layer of 4 in. face brick (A2 or A7) as an approximation; thus:
- Dominant element C9, or column 14 in Table 16;
- Exterior layer A2 or A7;
- R-value indicating R of 6;
- Select Wall Group 24 in Table 16 for representative factors.

The b_n and $\sum_{n=0} c_n$ require multiplication by the U-factor ratio to account for the difference in U-factors. The heat gain is then calculated by Equation (25), using corresponding wall CTF coefficients and sol-air temperatures for south, east, and north walls, and the outside air temperature cycle for north and west party walls.

Lines 16, 17, and 18, Door heat gain: Heat storage of the doors could be assumed negligible, in which case the heat gain would be calculated by Equation (16) as

$$q_{D\theta} = U_D A_D (t_{D\theta} - t_i)$$

where

U_D = 0.19 Btu/h·ft²·°F, U-factor of doors (0.18 for interior doors)
A_D = 35 ft², area of a door
t_i = 75°F, inside temperature
$t_{D\theta}$ = outside temperature at door, at time θ

For the door in the north party wall, $t_{D\theta}$ equals outside air temperature. For the doors in east and south walls $t_{D\theta}$ equals the east and south wall sol-air temperatures, respectively.

The foregoing would be a reasonable approach for estimating the minor loads involved. For the purpose of this example however, the relatively brief storage effect of the solid core doors has been considered by use of Equation (25), in accordance with:

Dominant element B7, or column 3 in Table 16;
- Interior finish A6;
- R value indicating *R* of 8;
- Select Wall Group 1 for representative factors.

Lines 19, 20, and 21, Window heat gain: The air to air heat gain (line 19):

$$q_a = U_w A_w (t_{o\theta} - t_i)$$

where

U_w = 0.81, U-factor of window
A_w = 90ft², area of windows
$t_{o\theta}$ = outside air temperature at time θ

The solar radiation heat gain (lines 20 and 21) through south and north windows:

$$Q_r = A_w \times \mathrm{SC} \times \mathrm{SHGF}_\theta$$

where

SHGF_θ = Solar heat gain factors given in line 5 for south and line 4 for north.
SC = 0.55; shading coefficient for clear window with light colored curtain or blind

Table 28 Tabulation of Data for Example 6

Table 28 Tabulation of Data for Example 6

1 Time, hour	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
2 Outside air temperature, °F	76	75	74	74	74	74	75	77	79	82	86	89
3 SHGF, Btu/h·ft², Horizontal	0	0	0	0	0	32	88	145	194	231	254	262
4 North	0	0	0	0	1	37	30	28	32	35	37	38
5 South	0	0	0	0	0	11	21	30	52	81	102	109
6 East	0	0	0	0	2	137	204	216	193	146	81	41
7 Sol-air temperature, °F, Horizontal	69	68	67	67	67	77	94	114	130	144	155	161
8 North	76	75	74	74	74	80	80	81	84	87	92	95
9 South	76	75	74	74	74	76	78	82	87	94	101	105
10 East	76	75	74	74	74	95	106	109	108	104	98	95
Instantaneous Sensible Heat Gain, Btu/h												
11 Roof	5377	3844	2565	1495	599	−140	−555	−208	1218	3715	6989	10682
12 East wall	934	794	664	544	434	337	272	266	292	338	417	532
13 West wall	1466	1454	1424	1379	1321	1255	1181	1103	1024	947	879	824
14 South wall	4390	3723	3107	2542	2029	1579	1471	2235	3679	5277	6646	7551
15 North and east party wall	2498	2535	2534	2497	2429	2335	2218	2086	1943	1797	1656	1529
16 East door (to adjacent building)	19	12	6	1	−3	−5	−4	2	12	26	44	64
17 West door	20	13	6	1	−4	−4	6	20	43	76	118	159
18 South door	20	13	6	1	−4	11	98	176	212	218	200	167
19 Windows, air to air heat gain	117	44	−15	−58	−73	−44	29	160	350	569	816	1050
20 East windows, solar heat gain	0	0	0	0	17	611	495	462	528	578	611	627
21 West windows, solar heat gain	0	0	0	0	0	363	693	990	1716	2673	3366	3597
22 Lights, tungsten (always on)	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640
23 Lights, fluorescent (on-off)	0	0	0	0	0	0	0	71610	71610	71610	71610	71610
24 People	0	0	0	0	0	0	0	21250	21250	21250	21250	21250
25 Infiltration	0	0	0	0	0	0	0	162	354	575	825	1061
26 Ventilation	2244	841	−281	−1122	−1403	−841	561	3086	6732	10940	15708	20196
27 Total instant sensible heat gain	30725	26913	23656	20920	18982	19097	20105	117040	124603	134229	144775	154539
Latent Heat Gain/Cooling Load, Btu/h												
28 People	0	0	0	0	0	0	0	17000	17000	17000	17000	17000
29 Infiltration	0	0	0	0	0	0	0	2205	2205	2205	2205	2205
30 Ventilation	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963
31 Total latent heat gain/cooling load	41963	41963	41963	41963	41963	41963	41963	61168	61168	61168	61168	61168
32 Sum: sens. + latent heat gain, Btu/h	72688	68876	65619	62883	60945	61060	62068	178208	185771	195397	205943	215707
Sensible Cooling Load from Convective Heat Gain, Btu/h												
33 Windows, air to air heat gain	117	44	−15	−58	−73	−44	29	160	350	569	816	1050
34 Lights, tungsten (20% convective)	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728
35 Lights, fluorescent (50% conv.)	0	0	0	0	0	0	0	35805	35805	35805	35805	35805
36 People (67% convective)	0	0	0	0	0	0	0	14237	14237	14237	14237	14237
37 Infiltration (100% convective)	0	0	0	0	0	0	0	162	354	575	825	1061
38 Ventilation (100% convective)	2244	841	−281	−1122	−1403	−841	561	3086	6732	10940	15708	20196
Sensible Cooling Load from Radiant Heat Gain, Btu/h												
39 Lights, tungsten (80% radiant)	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912
40 Lights, fluorescent (50% radiant)	12120	11271	10482	9748	9066	8431	7841	10873	12618	14241	15751	17154
41 People (33% radiant)	2118	1970	1832	1704	1584	1473	1370	2656	2961	3245	3508	3754
Sensible Cooling Load from Convective and Radiant Heat Gain, Btu/h												
42 From SHG through east windows	85	79	73	68	75	476	406	390	440	480	509	527
43 From SHG through west windows	267	249	231	215	200	433	653	858	1362	2038	2555	2769
44 From roof heat gain	7577	6379	5331	4409	3594	2882	2387	2418	3205	4766	6922	9442
45 From east wall heat gain	963	866	773	683	599	521	464	446	452	472	516	587
46 From west wall heat gain	1362	1361	1347	1322	1287	1244	1194	1140	1084	1027	975	931
47 From south wall heat gain	4984	4488	4015	3567	3146	2761	2605	3046	3973	5040	5989	6651
48 From N. and E. party wall heat gain	2304	2343	2356	2343	2308	2252	2178	2091	1993	1890	1788	1692
49 From east door heat gain	32	26	21	16	13	10	10	13	19	28	40	54
50 From west door heat gain	43	36	30	24	20	18	23	32	46	69	98	127
51 From south door heat gain	46	39	33	27	22	30	89	142	169	176	167	147
52 Total sensible cooling load, Btu/h	47902	43632	39868	36586	34078	33286	33450	91195	99440	109238	119849	129824
53 Sum: sens. + lat. cooling load, Btu/h	89865	85595	81831	78549	76041	75249	75413	152363	160608	170406	181017	190992
Air Temperature, °F, and Heat Extraction, Btu/h												
54 Total sensible cooling load, Btu/h (LTS)	45482	41375	37758	34612	32232	31516	31749	89212	97208	106702	116999	126680
55 2 °F throttling range: temperature	74.0	74.0	74.0	74.0	74.0	74.0	74.0	75.0	75.0	75.0	75.0	75.0
56 Equipment run 1-24; heat extraction	49487	45493	41936	38803	36358	35399	35314	85674	93257	102010	111520	120541
57 4 °F throttling range: temperature	74.0	74.0	74.0	74.0	74.0	74.0	74.0	75.0	75.0	75.0	75.0	76.0
58 Equipment run 1-24; heat extraction	52695	48849	45392	42318	39866	38753	38445	83238	90364	98444	107245	115651
59 2 °F throttling range: temperature	90	90	91	91	91	91	91	80	79	79	80	80
60 Equipment run 8-17; heat extraction	0	0	0	0	0	0	0	146600	146600	146600	146600	146600
61 4 °F throttling range: temperature	88	88	88	88	88	75	75	76	76	76	76	77
62 Equipment run 6-17; heat extraction	0	0	0	0	0	106261	95365	133756	135291	138399	142778	146600

Table 28 Tabulation of Data for Example 6 (*Concluded*)

1	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	**24 h**	**Heat Loss,**
2	91	93	94	93	92	89	87	84	82	80	78	77	**Total**	**Btu/h**
3	254	231	194	145	88	32	0	0	0	0	0	0	2150	
4	37	35	32	28	30	37	1	0	0	0	0	0	438	
5	102	81	52	30	21	11	0	0	0	0	0	0	703	
6	37	35	31	26	20	11	0	0	0	0	0	0	1180	
7	160	155	145	130	111	92	80	77	75	73	71	70		
8	97	98	99	97	97	95	87	84	82	80	78	77		
9	106	105	102	98	95	91	87	84	82	80	78	77		
10	97	98	99	97	95	91	87	84	82	80	78	77		
Instantaneous Sensible Heat Gain, Btu/h														
11	14436	17882	20649	22467	23154	22592	20788	18036	14908	11963	9395	7212	239063	23400
12	685	862	1045	1214	1356	1461	1531	1549	1486	1368	1228	1081	20690	5304
13	789	780	801	851	927	1020	1120	1218	1306	1378	1429	1459	27335	6318
14	7939	8025	8075	8159	8246	8247	8099	7757	7214	6548	5829	5100	133467	23868
15	1427	1358	1331	1351	1417	1525	1667	1831	2001	2165	2308	2421	46859	17306
16	84	100	111	116	115	108	96	81	65	51	38	28	1167	410
17	189	203	200	183	162	139	117	91	70	54	40	29	1931	432
18	147	148	153	156	149	136	116	90	70	54	40	29	2406	432
19	1224	1341	1385	1341	1239	1079	889	700	540	393	277	189	13542	4739
20	611	578	528	462	495	611	17	0	0	0	0	0	7231	*
21	3366	2673	1716	990	693	363	0	0	0	0	0	0	23199	*
22	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	327360	-13640
23	71610	71610	71610	71610	71610	0	0	0	0	0	0	0	716100	-71610
24	21250	21250	21250	21250	21250	0	0	0	0	0	0	0	212500	-21250
25	1238	1356	1400	1356	1253	0	0	0	0	0	0	0	9580	4791
26	23562	25806	26648	25806	23843	20757	17111	13464	10379	7574	5330	3646	260587	91163
27	162197	167612	170542	170952	169549	71678	65191	58457	51679	45188	39554	34834	2043017	
Latent Heat Gain/Cooling Load, Btu/h														
28	17000	17000	17000	17000	17000	0	0	0	0	0	0	0	170000	
29	2205	2205	2205	2205	2205	0	0	0	0	0	0	0	22050	
30	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	1007112	
31	61168	61168	61168	61168	61168	41963	41963	41963	41963	41963	41963	41963	1199162	
32	223365	228780	231710	232120	230717	113641	107154	100420	93642	87151	81517	76797	3242179	
Sensible Cooling Load from Convective Heat Gain, Btu/h														
33	1224	1341	1385	1341	1239	1079	889	700	540	393	277	189	13542	
34	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	65472	
35	35805	35805	35805	35805	35805	0	0	0	0	0	0	0	358050	
36	14237	14237	14237	14237	14237	0	0	0	0	0	0	0	142370	
37	1238	1356	1400	1356	1253	0	0	0	0	0	0	0	9580	
38	23562	25806	26648	25806	23843	20757	17111	13464	10379	7574	5330	3646	260587	
Sensible Cooling Load from Radiant Heat Gain, Btu/h														
39	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	261888	
40	18460	19674	20803	21853	22830	20158	18747	17434	16214	15079	14024	13042	357914	
41	3982	4194	4391	4575	4746	3523	3276	3047	2834	2635	2451	2279	70108	
Sensible Cooling Load from Convective and Radiant Heat Gain, Btu/h														
42	523	507	478	437	461	542	143	122	114	106	98	91	7230	
43	2669	2246	1624	1136	924	683	413	384	357	332	309	288	23195	
44	12086	14596	16711	18225	18990	18898	17928	16254	14249	12289	10518	8953	239009	
45	687	808	937	1059	1167	1251	1314	1341	1313	1245	1158	1063	20685	
46	900	886	893	921	967	1028	1095	1164	1227	1282	1324	1351	27312	
47	6979	7104	7203	7321	7439	7496	7448	7261	6926	6492	6007	5498	133439	
48	1611	1551	1520	1520	1553	1617	1708	1816	1933	2049	2155	2243	46814	
49	68	80	89	94	95	92	85	75	65	55	46	38	1164	
50	150	162	163	154	141	128	113	96	81	70	59	50	1933	
51	134	136	140	143	140	131	118	100	86	74	63	54	2406	
52	137955	144129	148067	149623	149470	91023	84028	76898	69958	63315	57459	52425	2042698	178163
53	199123	205297	209235	210791	210638	132986	125991	118861	111921	105278	99422	94388	3241860	71663
Air Temperature, °F, and Heat Extraction, Btu/h														
54	134552	140509	144275	145693	145432	87215	80409	73476	66754	60326	54673	49830	1974669	
55	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	74.0	74.0	74.0		
56	128005	133792	137639	139386	139602	88759	82327	75937	69698	63689	58341	53696	1966663	
57	76.0	76.0	76.0	76.0	76.0	75.0	75.0	75.0	75.0	74.0	74.0	74.0		
58	122700	128264	132093	134030	134566	89480	83460	77573	71790	66186	61150	56731	1959283	
59	80	81	81	81	80	89	90	90	90	90	90	90		
60	146600	146600	146600	146600	146600	0	0	0	0	0	0	0	1466000	
61	77	77	78	78	78	86	87	87	87	87	88	88		
62	146600	146600	146600	146600	146600	0	0	0	0	0	0	0	1631450	

Lines 22 and 23, Heat gain from tungsten and fluorescent lights: For the gain from lighting, Equation (9) is used with a use factor of unity and special allowance factors of 1.20 for fluorescent lamps and of unity for tungsten lamps. Thus:

$$q_{el\ tung} = 4000 \times 1 \times 1 \times 3.41 = 13{,}640 \text{ Btu/h},$$

and

$$q_{el\ fluor} = 17{,}500 \times 1 \times 1.20 \times 3.41 = 71{,}610 \text{ Btu/h}$$

Line 24, Heat gain from people: Sensible heat gain from occupants, for moderately active office work (Table 3):

$$q_{sp} = (\text{number of people})(\text{sensible heat generated per person}) = 85 \times 250 = 21{,}250 \text{ Btu/h}$$

Lines 25 and 26, Sensible heat gain from infiltration and ventilation: As developed in Building Data, the value used for infiltration is 67 cfm, and that for ventilation, 1275 cfm.

Heat gain from infiltration air is part of the space load, while that from ventilation air normally is not. In this example however, since ventilation is delivered directly to the space rather than through the cooling equipment first, its gain is also included as a direct space load.

Note: Had the ventilation air instead been mixed with return air leaving the occupied space and before entering the cooling equipment, only (4) that portion which passed through the cooling coil untreated due to coil inefficiency (or "Bypass Factor," normally 3 to 5% for a chilled water coil of six or more rows and close fin spacing up to 15% or more for refrigerant coils in packaged air-conditioning units), and/or (5) that quantity deliberately bypassed around the coil in response to a "face and bypass" or "conventional multizone" space dry-bulb temperature control scheme, would become a part of the space heat gain as such rather than a part of the cooling coil load directly.

The sensible loads are determined from Equation (22). At 1600 hours for example, when $t_o = 94°F$ and $t_i = 75°F$, this generates:

$$q_{si} = 1.1(\text{Infiltration rate})(t_o - t_i) = 1.1 \times 67(94 - 75) = 1400 \text{ Btu/h},$$

and

$$q_{sv} = 1.1(\text{Ventilation rate})(t_o - t_i) = 1.1 \times 1275(94 - 75) = 26{,}600 \text{ Btu/h},$$

Line 27, Total instantaneous sensible heat gain: The sum of instantaneous heat gain values listed in lines 11 through 26. All such values take into account the delaying effects of insulation and mass of the elements enclosing the conditioned space on the heat that ultimately enters that space, but before considering the thermal inertia of the overall mass and configuration of the building and contents in delaying conversion of radiant heat gain to space cooling load.

(e) *Instantaneous Latent Heat Gain*

Line 28, People: The latent heat gain due to people, using Table 3 data:

$$q_{lp} = (\text{number of persons})(\text{latent heat generated per person}) = 85 \times 200 = 17{,}500 \text{ Btu/h during the occupied period.}$$

Lines 29 and 30, Latent heat gain from infiltration and ventilation: The latent loads are determined from Equation (23). At 1600 hours for example, when $W_o = 0.0161$ and $W_s = 0.0093$, this generates

$$q_{si} = 4840(\text{Infiltration rate})(W_o - W_i) = 4840 \times 67(0.01661 - 0.0093) = 2{,}205 \text{ Btu/h},$$

and

$$q_{sv} = 4840(\text{Ventilation rate})(W_o - W_i) = 4840 \times 1275(0.01661 - 0.0093) = 41{,}963 \text{ Btu/h},$$

Line 31, Total latent heat gain: The total latent heat gain, i.e., the sum of lines 28, 29, and 30.

Line 32, Sum of instantaneous sensible and latent heat gain: The sum of heat gain values from lines 27 and 31.

(f) *Cooling Load from Convective Sensible Heat Gain Component*s

Lines 33 through 38: Direct inclusion of the convective portions of instantaneous heat gain components listed in lines 19, 25, and 26, and 20%, 50%, and 67% of lines 22, 23, and 24 respectively. These room sensible heat gain components (i.e., loads due to air-to-air heat gain through windows, tungsten lights, fluorescent lights, infiltration, ventilation, and heat gain due to people by convection, all appear as cooling load without delay. Percentages of heat gain considered corrective are listed in Table 3 and Table 44 under the section describing TETD/TA procedures. Selection of 33% of sensible gain for people as radiant is an approximation for purposes of this example.

(g) *Cooling Load from Radiant Sensible Heat Gain Components*

Lines 39 through 41: Heat gain data from lights and people (lines 22 through 24) are processed by Equation (28) using RTF coefficients from Tables 24 and 25:

> From Table 24, assuming "medium" mass of building and contents, the 75 lb/ft^2 specific mass classification can be considered representative. Assuming a conventional supply diffuser and non-plenum return air arrangement with inside surface coefficient h = 0.6 Btu/(h·ft^2·°F), or "medium" type indicates a w_1 value of –0.94; except with an uncarpeted floor the next w_1 value down the column is used, or 0.93.
>
> From the lower part of Table 25, assuming ordinary furnishings, no carpet, medium air circulation, supply and return below ceiling, and unvented light fixtures, the v_0 value for lighting is 0.55 and v_1 = 1 + (–0.93) –0.55 = –0.48.
>
> For people, the upper part of Table 25 calls for a v_0 of 1.0 and v_1 of 0 to be applied to convective heat gain (instantaneous conversion to cooling load), and for radiant heat gain a v_0 of 0.197 and v_1 = 1 + (–0.93) – 0.197 = –0.127.
>
> Note that the TFM treatment of lighting heat gain is "generic," without individual regard to the differences in radiant/convective percentages of heat gain from incandescent, fluorescent, or other type lamps, and the RTF coefficients are applied to the combined sensible heat gain values. For the purposes of this example, to facilitate comparison with other calculation methods, the values in lines 39 and 40 represent the hourly results of Equation (28) less the amounts of instantaneous cooling load included and indicated on lines 34 and 35.

(h) *Cooling Load from Convective and Radiant Sensible Heat Gain Components*

Lines 42 through 51: Elements of instantaneous heat gain from solar radiation through windows, walls, doors and roof, i.e., sum of values listed in lines 11 to 21, delayed in being felt as cooling load by the space. Data listed in lines 42 through 51 are the results of applying Equation (28) and appropriate RTF coefficients to the heat gain values from lines 11 through 21, without separately considering radiant or convective components. RTF coefficients are taken from Tables 24 and 25 in the manner above described for lighting loads, producing:

> From Table 24, w = –0.93 in all cases.
>
> From the upper part of Table 25, all cases fall within the second category described, which for "medium" building and contents mass indicates v_0 = 0.681 and v_1 = 1 + (–0.93) – 0.681 = –0.611.
>
> The heat gain by solar radiation transmitted through windows is included with heat gain through walls and roof because the venetian blind intercepts solar radiation and releases it to the room in a similar way as the heat gain through walls and roof.

Note: If the glass had no internal shading, the solar radiation through windows would have to be treated by a different set of RTF coefficients to account otherwise for thermal storage (see Tables 24 and 25). Translucent draperies fall somewhere between these limits, with assumed linear relationship in the absence of specific research on the subject (see Chapter 29).

Line 52, Total room sensible cooling load: Total sensible cooling load felt by the room, and the design sensible load used as the basis for sizing cooling equipment. This total load is the sum of the values listed in lines 33 through 51. The tiny difference between the 24 hour total of 2,042,698 Btu/h on line 52 and the sum of the 24 hour totals for lines 11 through 26 reflects rounding of values during intermediate computation.

2. **Latent Cooling Load**

Line 31—The sum of lines 28, 29, and 30: Total Latent Heat Gain is also the Total Latent Cooling Load, as all components occur instantaneously.

3. **Total Cooling Load**

Line 53—The sum of lines 52 and 31: Note that the Total Cooling Load for this example problem is the theoretical total for the conditions as defined, and may or may not represent the actual total cooling load imposed upon a system of cooling equipment. An appropriate psychrometric analysis should be performed of supply air, space air, return air, and mixed air (where ventilation air is mixed with return air en route back to the cooling equipment), considering the type of cooling equipment and characteristics of the preferred control scheme. Only an analysis of this type can verify that the design will meet the requirements, and determine whether the actual sensible, latent, and total cooling loads are greater or less than the theoretical values calculated.

4. **Capacity of System to Maintain Conditions**

(a) *Fixed temperature*: 75°F indoor temperature, 24 hour "on" period: The basic calculation procedure assumes a fixed indoor temperature, in this case 75°F; thus the results tabulated in lines 1 through 42 are for this condition.
(b) 2°F throttling range: Indoor temperature in the range 75 to 77°F, 24 hour "on" period.
(c) 4°F throttling range: Indoor temperature in the range 75 to 79°F, 24 hour "on" period.
(d) 2°F throttling range: Indoor temperature in the range 75 to 77°F, 10 hour "on" period, 0800 through 1700.
(e) 4°F throttling range: Indoor temperature in the range 75 to 79°F, 12 hour "on" period, 0600 through 1700.

Line 54, Sensible cooling load with loss to surroundings: To be consistent with the concept of heat extraction and resultant space temperatures, certain cooling load elements must be modified to account for heat loss to surroundings. The multiplier F_c = 0.94362 was calculated by the process noted for each of the envelope element areas times the respective U-factors, dividing the sum by the building perimeter to develop K_θ, and generating F_c by Equations (34) and (35); then using F_c to reduce the appropriate load elements. The sum of all modified and unmodified load elements is listed on line 53 as the basis for the various heat extraction/ space temperature evaluations.

Lines 55 through 62, Air temperatures and heat extraction rates: Heat extraction and indoor air temperatures are based on the normalized SATF coefficients for medium weight construction listed in Table 26 and calculated by use of Equations (36) through (40) in the procedure previously described. The SATF coefficients for this example are thus for hour θ (0800 – 1700):

$$\begin{aligned} g_{0\theta} &= g_0^*(\text{Floor area}) + p_0[K_\theta(\text{Perimeter length})] \\ &\quad + 1.1(\text{Ventilation and Infiltration}) \\ &= (1.81 \times 4000) + 1.0[(4.86 \times 260) + 1.1(1275 + 67)] \\ &= 7240 + (1263.4 + 1476.2) = 9980 \end{aligned}$$

$$\begin{aligned} g_{1\theta} &= g_1^*(\text{Floor area}) + p_1[K_\theta(\text{Perimeter length})] \\ &\quad + 1.1(\text{Ventilation and Infiltration}) \\ &= (-1.89 \times 4000)(-0.87)[(4.86 \times 260) + 1.1(1275 + 67)] \\ &= -7560 - 0.87(1263.4 + 1476.2) = -9944 \end{aligned}$$

$$\begin{aligned} g_{2\theta} &= g_2^*(\text{Floor area}) = 0.08 \times 4000 = 320 \\ p_0 &= 1.0000 \\ p_1 &= -0.87 \end{aligned}$$

The heat extraction rates and room air temperatures listed in lines 55 through 62 are calculated using these SATF coefficients, the modified total sensible cooling load values listed in line 54, and the specified throttling ranges and "on" and "off" periods.

The maximum sensible heat extraction capacity required to maintain the space temperature at a constant 75°F can be taken as the design peak value on line 52, or 149,470 Btu/h at 1600 hours.

The maximum sensible heat extraction capacity required to maintain interior temperature within a 75 to 77°F range is 145,693 Btu/h (hour 1600, line 54), and within a 75 to 79°F range is 139,602 Btu/h (hour 1700, line 56), assuming continuous operation of cooling equipment.

Comparable maintenance of space temperature ranges during equipment operation hours (limited to 10 hours and 12 hours respectively) requires heat extraction rates of 146,600 Btu/h (hours 0800 to 1700, line 60) and 146,600 Btu/h (hours 1200 to 1700, line 62) respectively. Here ER_{max} needs to be increased if the heat accumulated overnight is to be overcome; but the total daily heat extraction still will be significantly less than for continuous operation.

5. **Heating Load**

Lines 11 through 19, Heat loss by conduction: The heat loss column lists for each of the building envelope components a single value representing the product of exposed area, U-factor, and the temperature difference between inside design dry bulb and outside design dry bulb temperatures for winter conditions, in an adaptive use of Equation (8). Often, a lower inside design dry bulb temperature is selected for winter conditions than for summer, and, where appropriate, the U-factors are adjusted to reflect different average exterior wind velocities. For this example, the same inside temperatures and U-factors are used year-round.

These results are design heat loss values, which are used to establish a "design heating load" with which to design heating systems and to select properly sized equipment components. When the load calculation is used to analyze energy performance, hourly calculations of heat loss that reflect the profile of outside weather conditions must be run.

Lines 20 through 21, Solar heat gain: For *design* heating loss calculations, offsetting values of solar heat gain are routinely ignored at night or during periods of extended cloud cover, and thus not consistently available to assist the installed heating equipment. Designers must, however, consider the higher solar heat gain values that occur during winter months due to low solar angles that often cause peak cooling loads through large areas of exposed glass. Hourly calculations are required for energy use evaluation.

Lines 22, 23, and 24, Internal heat gains: Like solar heat gain, the heat from internal sources requires year-round cooling for completely interior spaces and contributes to unseasonable cooling requirements in conjunction with glass loads on sunny days. For conventional heating load purposes, however, these loads are normally ignored because of their uncertainty during all hours of need and since their full effect does not occur until some number of hours after occupancy begins during intermittent schedules. Heat gain values in this example are given as "negative heat loss" figures, and not routinely included in design heating load summaries.

Lines 25 and 26, Infiltration and ventilation: Values listed for these variables are calculated on the basis of a single "worst case" hour under winter design temperature conditions, adapting Equation (22) in a similar manner to that noted for conduction heat losses.

Humidification: For this example, the issue of maintaining interior humidity levels during winter months has been ignored. While this represents routine practice for most applications in latitudes 35°N and lower, humidity levels are of major concern in colder climates.

Line 52, Total sensible heat loss: The sum of heat loss values from lines 11 through 19, 25, and 26, and which conventionally represents the design heating load for the building. Internal heat gain figure from lines 22, 23, and 24 are not included in this total.

Line 53, Net sensible heat loss, considering internal heat gains: The heat loss summary value if internal heat gains were to be included in the total, illustrated here only to emphasize the potential significance of such elements and the importance of providing an appropriate means of temperature control for differently affected building areas.

CLTD/SCL/CLF CALCULATION PROCEDURE

To calculate a space cooling load using the CLTD/SCL/CLF convention, the same general procedures outlined for the TFM relative to data assembly and use of data apply. Similarly, the basic heat gain calculation concepts of solar radiation, total heat gain through exterior walls and roofs, heat gain through interior surfaces, and heat gain through infiltration and ventilation are handled in an identical manner.

The CLTD/SCL/CLF method is a one-step, hand calculation procedure, based on the transfer function method (TFM). It may be used to approximate the cooling load corresponding to the first three modes of heat gain (conductive heat gain through surfaces such as windows, walls, and roofs; solar heat gain through fenestrations; and internal heat gain from lights, people, and equipment) and the cooling load from infiltration and ventilation. The acronyms are defined as follows:

CLTD—Cooling Load Temperature Difference

SCL—Solar Cooling Load

CLF—Cooling Load Factor

The following sections give details of how the CLTD/SCL/CLF technique relates to and differs from the TFM. The sources of the space cooling load, forms of equations to use in the calculations, appropriate references, tables, are summarized in Table 29.

SYNTHESIS OF HEAT GAIN AND COOLING LOAD CONVERSION PROCEDURES

Exterior Roofs and Walls

This method was developed by using the TFM to compute one-dimensional transient heat flow through various sunlit roofs and walls. Heat gain was converted to cooling load using the room transfer functions for rooms with light, medium, and heavy thermal characteristics. Variations in the results due to such varying room constructions and other influencing parameters discussed in the TFM description are so large that only one set of factors is presented here for illustration. All calculations for data tabulated were based on the sol-air temperatures in Table 1. The inside air temperature was assumed to be constant at 78°F (cooling system in operation 24 h/day, seven days a week). The mass of building and contents was "light to medium." For application of CLTD/SCL/CLF techniques, refer to McQuiston and Spitler (1992).

Table 29 Procedure for Calculating Space Design Cooling Load by CLTD/SCL/CLF Method

External Cooling Load

Roofs, walls, and conduction through glass

$$q = UA(\text{CLTD}) \qquad (41)$$

U = design heat transfer coefficient for roof or wall from Chapter 24, Table 4; or for glass, Table 5, Chapter 29

A = area of roof, wall, or glass, calculated from building plans

CLTD = cooling load temperature difference, roof, wall, or glass

Solar load through glass

$$q = A(\text{SC})(\text{SCL}) \qquad (43)$$

SC = shading coefficient: Chapter 29

SCL = solar cooling load factor with no interior shade or with shade, Table 36.

Cooling load from partitions, ceilings, floors

$$q = UA(t_o - t_{rc}) \qquad (8)$$

U = design heat transfer coefficient for partition, ceiling, or floor, from Chapter 24, Table 4

A = area of partition, ceiling, or floor, calculated from building plans

t_b = temperature in adjacent space

t_{rc} = inside design temperature (constant) in conditioned space

Internal Cooling Load

People

$$q_{sensible} = N(\text{Sensible heat gain})\text{CLF} \qquad (44)$$

$$q_{latent} = N(\text{Latent heat gain}) \qquad (45)$$

N = number of people in space, from best available source. Sensible and latent heat gain from occupancy—Table 3, or Chapter 8; adjust as required

CLF = cooling load factor, by hour of occupancy, Table 37

Note: CLF 1.0 with high density or 24-h occupancy and/or if cooling off at night or during weekends.

Lights

$$q_{el} = 3.41 W F_{ul} F_{sa}(\text{CLF}) \qquad (9)(46)$$

W = watts input from electrical plans or lighting fixture data

F_{ul} = lighting use factor, as appropriate

F_{sa} = special allowance factor, as appropriate

CLF = cooling load factor, by hour of occupancy, Table 38

Note: CLF = 1.0 with 24-h light usage and/or if cooling off at night or during weekends.

Power

$$q_p = 2545\, PE_F\, \text{CLF} \qquad (15)(16)(17)(50)$$

P = horsepower rating from electrical plans or manufacturer's data

E_F = efficiency factors and arrangements to suit circumstances

CLF = cooling load factor, by hour of occupancy, Table 37

Note: CLF = 1.0 with 24-h power operation and/or if cooling off at night or during weekends.

Appliances

$$q_{sensible} = q_{input} F_U F_R(\text{CLF}) \qquad (18)(46)$$

or

$$q_{sensible} = q_{input} F_L(\text{CLF}) \qquad (19)(46)$$

q_{input} = rated energy input from appliances—Tables 5 through 9, or manufacturer's data

F_U, F_R, F_L = usage factors, radiation factors,and load factors from the General Principles section

CLF = cooling load factor, by scheduled hours and hooded or not; Tables 37 and 39

Note 1: CLF = 1.0 with 24-h appliance operation and/or if cooling off at night or during weekends.

Note 2: Set latent load = 0 if appliance under exhaust hood.

Ventilation and Infiltration Air

$$q_{sensible} = 1.10\, Q\, (t_o - t_i) \qquad (25)$$

$$q_{latent} = 4840\, Q\, (W_o - W_i) \qquad (23)$$

$$q_{total} = 4.5\, Q\, (h_o - h_i) \qquad (20)$$

Q = ventilation cfm from ASHRAE *Standard* 62; infiltration from Chapter 25

t_o, t_i = outside, inside air temperature, °F

W_o, W_i = outside, inside air humidity ratio, lb (water)/lb (dry air)

H_o, H_i = outside, inside air enthalpy, Btu/lb (dry air)

Basic CLTD cooling load for exterior surfaces. The results were generalized to some extent by dividing the cooling load by the U-factor for each roof or wall and are in units of total equivalent cooling load temperature difference (CLTD). This establishes the basic cooling load equation for exterior surfaces as:

$$q = UA(\text{CLTD}) \tag{41}$$

where

q = cooling load, Btu/h
U = coefficient of heat transfer, Btu/(h·ft²·°F)
A = area of surface, ft²
CLTD = cooling load temperature difference

In developing the method, it was assumed that the heat flow through a similar roof or wall (similar in thermal mass as well as U-factor) can be obtained by multiplying the total CLTDs listed in Tables 30 or 32 by the U-factor of the roof or wall at hand, respectively. The errors introduced by this approach depend on the extent of the differences between the construction in question (components, size, configuration, and general mass of building and contents) and the one used for calculating the CLTDs.

The sol-air temperature value depends on outdoor air temperature as well as the intensity of solar radiation. Consequently, a change in either outdoor air temperature or geographic location changes the sol-air temperature. The CLTD values in the tables were computed for an indoor air temperature of 78°F, an outdoor maximum temperature of 95°F, and an outdoor mean temperature of 85°F, with an outdoor daily range of 21°F and a solar radiation variation typical of 40°N latitude on July 21.

The notes associated with Tables 30 and 32 provide descriptions of the conditions under which the CLTD values were calculated. While variations in exterior color and/or outside and inside surface film resistances do have some effect, their impact on roofs or walls of contemporary construction is relatively minor and can be ignored with data that is already normalized for convenience. Variations in inside space temperature or the mean outdoor temperature are of much more significance, and the means of appropriate adjustment are thus outlined. Additional guidance for specific application may be found along with tables for a broad range of latitudes in McQuiston and Spitler (1992).

Space Cooling Load from Fenestration

The basic principles of calculating heat gain from conduction and solar radiation through fenestration are as previously discussed for the TFM.

CLTD Cooling load from conduction. For conduction heat gain, the overall heat transfer coefficient accounts for the heat transfer processes of (1) convection and long-wave radiation exchange outside and inside the conditioned space, and (2) conduction through the fenestration material. To calculate cooling load for this component, the conduction heat gain is treated in a manner similar to that through walls and roofs. The RTF coefficients used to convert the heat gain to cooling load are thus the same as those for walls and roofs. The resulting CLTDs are given in Table 34, again presenting only a single set of factors for all room construction types, neglecting the effects of mass and latitude due to the generally low density and the small magnitude of these components. The CLTDs from Table 34 can also be used for doors with reasonable accuracy. The cooling load from conduction and convection heat gain is calculated by:

$$q_{cond} = UA(\text{CLTD}) \tag{42}$$

where A is the net glass area of the fenestration in square feet. [Note that the equation is identical to Equation (41).]

Solar Heat Gain. The basic principles of evaluating heat gain from transmitted and absorbed solar energy through fenestration, including the primary terms SHGF and SC, are the same for the CLTD/CLF procedure as previously described for the TFM.

Previous ASHRAE Handbooks tabulated values of maximum solar heat gain factors for sunlit or externally shaded double-strength sheet glass, used as the heat gain input for calculating cooling load factors (CLFs), employing appropriate RTF coefficients as in the TFM discussion. This process, however, introduced new variables into the calculations: (1) the presence or absence of interior shading devices, which is pivotal, and (2) the construction, furnishings, floor coverings, and relative amounts of fenestration, which are critical when interior shading is absent. Results obtained with this method do not recognize the significant variation of solar cooling load profiles due to different latitudes, months, and other factors. A new term, solar cooling load (SCL), is introduced to more closely approximate cooling loads due to solar radiation transmitted through fenestration.

Cooling load caused by solar radiation through fenestration is calculated by:

$$q_{rad} = A(\text{SC})(\text{SCL}) \tag{43}$$

where

q_{rad} = cooling load caused by solar radiation, Btu/h
A = net glass area of fenestration, ft²
SC = shading coefficient, for combination of fenestration and shading device, obtained from Chapter 29
SCL = solar cooling load from Table 36, Btu/h·ft²

Total Cooling Load from Fenestration. The total cooling load due to fenestration is the sum of the conductive and radiant components q_{cond} and q_{rad}.

Zone Influencing Parameters. For purposes of estimating a cooling load, a zone is a particular combination of conditions defining the space under consideration, and which govern the absorption and release of radiant energy. The SCL for a particular zone depends on latitude, direction, nature, and quantity of enclosing surfaces, as well as various internal parameters that influence the SHGF for each glass exposure in that zone.

To determine the most appropriate SCL table for a zone, refer to Tables 35A and 35B, where zone types (A, B, C, or D) are given as functions of some of the more dominant of the 16 zone parameters defined in the TFM discussion. The SCLs for sunlit glass at 40°N latitude and one month, July, are tabulated in Table 36 for each zone type. SCLs for externally shaded glass may be taken from these tables as those for North exposure, although with some loss of accuracy at latitudes lower than 24°N. Interpolation between latitudes can be performed with some loss of accuracy. McQuiston and Spitler (1992) include additional data for multistory buildings and for other latitudes, months, and zone types.

Shading Coefficient

Interior Shading. The cooling load from solar radiation must be analyzed for one of two cases: (1) presence of interior shading or (2) absence of interior shading. Blinds (venetian or roller shades) or drapes absorb the solar energy before it can strike the floor or other interior surfaces of the space, which leads to a rapid response in the cooling load due to the low mass of the shading device.

When interior shading is absent, the solar energy is absorbed by the more massive elements of the space, which results in increased delay in such heat gain being converted to cooling load. Many variables, of which the more important are the presence or absence of carpet on the floor, mass of the floor and other surfaces, mass of the contents of the space, amount of glass in the exposed surfaces, presence or absence of a ceiling, the relative size of the space, etc., have influence on this phenomenon.

Table 30 July Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs at 40°North Latitude

Roof No.	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	–2	–4	–5	–6	–6	0	13	29	45	60	73	83	88	88	83	73	60	43	26	15	9	5	2
2	2	0	–2	–4	–5	–6	–4	4	17	32	48	62	74	82	86	85	80	70	56	39	25	15	9	5
3	12	8	5	2	0	–2	0	5	13	24	35	47	57	66	72	74	73	67	59	48	38	30	23	17
4	17	11	7	3	1	–1	–3	–3	0	7	17	29	42	54	65	73	77	78	74	67	56	45	34	24
5	21	16	12	8	5	3	1	2	6	12	21	31	41	51	60	66	69	69	65	59	51	42	34	27
8	28	24	21	17	14	12	10	10	12	16	21	28	35	42	48	53	56	57	56	52	48	43	38	33
9	32	26	21	16	13	9	6	4	4	7	12	19	27	36	45	53	59	63	64	63	58	52	45	38
10	37	32	27	23	19	15	12	10	9	10	12	17	23	30	37	44	50	55	57	58	56	52	47	42
13	34	31	28	25	22	20	18	16	16	17	20	24	28	33	38	42	46	48	49	48	46	44	40	37
14	35	32	30	27	25	23	21	20	19	20	22	24	28	32	36	39	42	44	45	45	44	42	40	37

Note: 1. Direct application of data
- Dark surface
- Indoor temperature of 78°F
- Outdoor maximum temperature of 95°F with mean temperature of 85°F and daily range of 21°F
- Solar radiation typical of clear day on 21st day of month
- Outside surface film resistance of 0.333 (h·ft^2·°F)/Btu
- With or without suspended ceiling but no ceiling plenum air return systems
- Inside surface resistance of 0.685 (h·ft^2·°F)/Btu

Note: 2. Adjustments to table data
- Design temperatures : Corr. CLTD = CLTD + (78 – t_r) + (t_m – 85)

  where

  t_r = inside temperature and t_m = mean outdoor temperature

  t_m = maximum outdoor temperature – (daily range)/2
- No adjustment recommended for color
- No adjustment recommended for ventilation of air space above a ceiling

Table 31 Roof Numbers Used in Table 30

Mass Location**	Suspended Ceiling	R-Value, h·ft^2·°F/Btu	B7, Wood 1 in.	C12, HW Concrete 2 in.	A3, Steel Deck	Attic-Ceiling Combination
Mass inside the insulation	Without	0 to 5	*	2	*	*
		5 to 10	*	2	*	*
		10 to 15	*	4	*	*
		15 to 20	*	4	*	*
		20 to 25	*	5	*	*
		25 to 30	*	*	*	*
	With	0 to 5	*	5	*	*
		5 to 10	*	8	*	*
		10 to 15	*	13	*	*
		15 to 20	*	13	*	*
		20 to 25	*	14	*	*
		25 to 30	*	*	*	*
Mass evenly placed	Without	0 to 5	1	2	1	1
		5 to 10	2	*	1	2
		10 to 15	2	*	1	2
		15 to 20	4	*	2	2
		20 to 25	4	*	2	4
		25 to 30	*	*	*	*
	With	0 to 5	*	3	1	*
		5 to 10	4	*	1	*
		10 to 15	5	*	2	*
		15 to 20	9	*	2	*
		20 to 25	10	*	4	*
		25 to 30	10	*	*	*
Mass outside the insulation	Without	0 to 5	*	2	*	*
		5 to 10	*	3	*	*
		10 to 15	*	4	*	*
		15 to 20	*	5	*	*
		20 to 25	*	5	*	*
		25 to 30	*	*	*	*
	With	0 to 5	*	3	*	*
		5 to 10	*	3	*	*
		10 to 15	*	4	*	*
		15 to 20	*	5	*	*
		20 to 25	*	*	*	*
		25 to 30	*	*	*	*

*Denotes a roof that is not possible with the chosen parameters.

**The 2 in. concrete is considered massive and the others nonmassive.

Table 32 July Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls 40°North Latitude

Wall Number 1

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	1	0	–1	–2	–3	–1	7	11	11	13	17	21	25	27	29	29	28	29	27	17	11	7	5	3
NE	1	0	–1	–2	–3	2	24	42	47	43	35	28	27	28	29	29	27	24	20	14	10	7	5	3
E	1	0	–1	–2	–2	2	28	51	62	64	59	48	36	31	30	30	28	25	20	14	10	7	5	3
SE	1	0	–1	–2	–3	0	15	32	46	55	58	56	49	39	33	31	28	25	20	14	10	7	5	3
S	1	0	–1	–2	–3	–2	0	4	11	21	33	43	50	52	50	44	34	27	20	14	10	7	5	3
SW	2	0	–1	–2	–2	–2	0	4	8	13	17	25	39	53	64	70	69	61	45	24	13	8	5	3
W	2	1	–1	–2	–2	–2	1	4	8	13	17	21	27	42	59	73	80	79	62	32	16	9	6	3
NW	2	0	–1	–2	–2	–2	0	4	8	13	17	21	25	29	38	50	61	64	55	29	15	9	5	3

Wall Number 2

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	5	3	2	0	–1	–2	–1	3	7	9	11	14	18	21	24	26	27	28	28	27	22	17	12	8
NE	5	3	2	0	–1	–2	2	13	26	36	39	37	33	31	29	29	29	28	26	23	18	14	10	7
E	5	3	2	0	–1	–1	2	15	32	47	55	57	52	44	38	34	32	30	27	23	19	14	11	8
SE	5	3	2	0	–1	–2	0	8	20	33	43	50	53	51	45	39	35	31	28	24	19	14	11	8
S	5	3	2	0	–1	–2	–2	–1	2	7	14	24	33	42	47	48	46	40	33	27	21	15	11	8
SW	7	4	2	1	0	–1	–2	0	2	5	9	13	20	30	41	53	61	65	62	53	39	27	17	11
W	8	5	3	1	0	–1	–2	0	2	5	9	13	17	23	33	46	59	69	73	66	50	34	22	14
NW	8	4	2	1	–1	–2	–2	–1	2	5	9	13	17	21	25	32	41	51	57	54	42	29	19	12

Wall Number 3

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	7	5	3	2	1	0	2	5	7	8	11	14	17	20	23	24	25	26	27	24	20	16	13	10
NE	7	5	3	2	0	0	7	17	26	31	33	31	30	29	29	29	29	28	25	22	18	15	12	9
E	7	5	4	2	1	1	8	21	33	42	47	47	44	40	37	35	33	31	28	24	20	16	13	10
SE	8	5	4	2	1	0	4	12	22	32	39	44	46	44	41	38	35	32	29	24	20	16	13	10
S	8	6	4	2	1	0	0	1	4	9	16	24	31	38	41	42	40	36	31	26	22	17	14	11
SW	12	9	6	4	2	1	1	2	4	6	9	14	21	30	40	49	55	57	54	45	36	28	21	16
W	14	10	7	5	3	1	1	2	4	6	9	13	17	24	34	45	56	63	63	54	43	33	25	19
NW	12	8	6	4	2	1	0	2	3	6	9	13	16	20	25	32	40	48	50	44	35	27	21	16

Wall Number 4

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	11	8	6	4	2	0	0	1	3	5	7	10	13	16	19	22	24	26	27	27	26	22	19	15
NE	10	7	5	3	2	0	0	4	12	21	29	32	33	32	31	30	30	29	28	26	23	20	16	13
E	10	8	5	4	2	1	1	5	15	27	38	45	49	47	44	40	37	34	32	29	25	21	17	14
SE	11	8	6	4	2	1	0	2	8	17	27	36	43	46	46	44	41	37	34	30	26	22	18	14
S	11	8	6	4	2	1	0	–1	0	2	6	13	20	28	35	41	43	42	39	35	30	24	19	15
SW	18	13	9	6	3	2	0	0	0	2	5	8	12	18	27	36	46	53	57	57	51	42	33	25
W	21	15	10	7	4	2	1	0	1	2	5	8	11	15	21	30	40	51	60	64	60	50	40	30
NW	18	13	9	6	3	1	0	0	0	2	4	8	11	15	19	23	30	37	45	49	48	41	33	25

Wall Number 5

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	13	10	8	6	5	3	2	3	5	6	8	9	12	14	17	19	21	23	24	24	23	21	18	15
NE	13	10	8	6	5	3	3	7	14	20	25	27	28	28	28	28	28	28	27	26	23	21	18	15
E	14	11	9	7	5	4	4	8	17	26	33	39	40	40	38	37	35	34	32	29	26	23	20	17
SE	14	12	9	7	5	4	3	6	11	18	25	32	37	39	39	38	37	35	33	30	27	24	20	17
S	15	12	9	7	5	4	3	2	3	4	8	13	19	25	31	35	36	36	34	32	28	24	21	18
SW	22	18	14	11	8	6	5	4	4	5	6	9	12	17	25	33	40	46	49	48	44	38	32	26
W	25	20	16	13	10	7	5	4	4	5	7	9	11	15	20	28	37	45	52	54	50	44	37	30
NW	21	17	13	10	8	6	4	3	4	4	6	8	11	14	17	21	27	34	40	42	40	35	30	25

Wall Number 6

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	13	11	9	8	6	5	4	5	6	7	8	10	12	14	16	18	20	21	22	23	21	20	17	15
NE	14	12	10	8	6	5	6	10	15	20	23	25	25	26	26	27	27	27	26	25	23	21	18	16
E	16	13	11	9	7	6	7	11	18	25	31	35	36	36	35	35	34	33	31	29	26	24	21	18
SE	16	14	11	9	8	6	6	8	13	18	24	29	33	35	36	35	34	33	32	29	27	24	21	18
S	16	13	11	9	7	6	5	4	4	6	9	13	18	24	28	31	33	33	31	29	27	24	21	18
SW	23	19	16	14	11	9	7	6	6	7	8	10	13	18	24	31	37	42	44	43	40	35	31	27
W	26	22	18	15	13	10	8	7	7	7	8	10	12	15	20	27	35	42	47	48	45	40	35	30
NW	21	18	15	12	10	8	7	6	6	6	8	9	11	14	16	21	26	32	36	38	36	32	28	25

Table 32 July Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls 40°North Latitude (*Continued*)

Wall Number 7

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	13	12	10	9	7	6	6	7	8	8	9	11	12	14	16	17	18	19	20	20	19	18	16	15
NE	15	13	11	10	9	8	9	13	17	20	22	23	23	24	24	25	25	25	24	23	22	20	18	16
E	17	15	13	12	10	9	11	16	21	26	30	32	32	32	32	32	31	30	29	27	25	23	21	19
SE	17	15	13	12	10	9	9	12	16	21	25	28	31	32	32	32	31	30	29	27	25	23	21	19
S	16	14	13	11	10	8	7	7	7	9	12	15	19	23	26	28	29	29	28	26	24	22	20	18
SW	23	20	18	16	13	12	10	10	10	10	11	12	15	20	25	30	35	38	39	37	34	31	28	25
W	25	22	20	17	15	13	12	11	11	11	12	13	14	17	22	28	34	39	42	41	38	34	31	28
NW	20	18	16	14	12	10	9	9	9	9	10	11	13	15	17	21	26	30	33	33	30	28	25	23

Wall Number 9

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	17	15	13	11	9	7	5	4	4	4	5	7	8	10	12	15	17	19	21	22	23	23	22	20
NE	18	15	13	11	9	7	5	5	6	10	16	20	23	25	26	27	27	28	28	27	26	25	23	20
E	20	17	14	12	10	8	6	5	7	12	19	26	32	36	37	37	37	36	34	33	31	29	26	23
SE	20	17	15	12	10	8	6	5	6	9	13	19	25	31	34	36	37	36	35	34	32	29	26	23
S	21	18	15	12	10	8	6	5	4	3	4	6	10	14	20	25	29	33	34	34	32	30	27	24
SW	31	26	22	18	15	12	9	7	6	5	5	6	8	10	14	19	26	33	39	43	45	44	40	36
W	35	30	25	21	17	14	11	8	7	6	6	7	8	10	12	16	22	30	37	44	48	48	45	41
NW	29	25	21	17	14	11	9	7	5	5	5	6	7	9	11	14	18	22	28	34	37	38	36	33

Wall Number 10

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	17	15	13	11	9	7	6	5	5	5	6	7	8	10	12	14	17	18	20	22	22	22	21	19
NE	18	16	13	11	9	7	6	6	8	12	16	20	22	24	25	26	27	27	27	27	26	24	22	20
E	20	17	15	12	10	8	7	7	10	14	20	26	31	34	35	36	36	35	34	33	31	28	26	23
SE	21	18	15	13	10	8	7	6	7	10	15	20	25	30	33	34	35	35	34	33	31	29	26	23
S	21	18	15	13	11	9	7	5	4	4	5	7	11	15	20	24	28	31	32	32	31	29	26	24
SW	31	27	23	19	16	13	10	8	7	6	6	7	8	11	15	20	26	32	38	41	42	41	38	35
W	34	30	26	22	18	15	12	9	8	7	7	7	8	10	13	17	23	30	37	42	45	45	42	39
NW	28	24	21	18	15	12	10	8	6	6	6	6	8	10	12	14	18	23	28	33	35	36	34	31

Wall Number 11

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	16	14	13	12	10	9	8	7	7	7	8	9	10	11	12	14	15	17	18	19	20	19	18	17
NE	18	17	15	13	12	10	9	9	11	14	17	20	21	22	23	23	24	24	25	25	24	23	21	20
E	21	19	17	16	14	12	11	11	13	17	22	26	29	30	31	31	31	31	31	30	29	27	25	23
SE	21	19	17	16	14	12	11	10	11	14	17	21	24	27	29	30	31	31	30	30	29	27	25	23
S	20	18	16	15	13	11	10	9	8	8	8	10	13	16	19	23	25	27	28	28	27	25	24	22
SW	28	25	23	20	18	16	14	12	11	11	10	11	12	14	17	21	25	30	33	36	36	35	33	30
W	31	28	25	22	20	18	16	14	12	12	11	12	12	13	15	19	23	28	33	37	39	38	36	33
NW	25	23	20	18	16	14	12	11	10	9	9	10	11	12	13	15	18	22	26	29	31	31	29	27

Wall Number 12

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	16	14	13	12	11	10	8	8	8	8	8	9	10	11	12	14	15	16	17	18	19	19	18	17
NE	18	17	15	14	13	11	10	10	12	14	17	19	21	21	22	23	23	24	24	24	23	22	21	20
E	22	20	18	17	15	13	12	12	14	17	21	25	28	29	30	30	30	30	30	29	28	27	25	24
SE	22	20	18	16	15	13	12	11	12	14	17	21	24	26	28	29	30	30	30	29	28	27	25	23
S	20	19	17	15	14	12	11	10	9	9	9	11	13	16	19	22	24	26	26	26	26	25	23	22
SW	27	25	23	21	19	17	15	14	12	12	12	12	12	14	17	20	24	28	32	34	34	34	32	30
W	30	28	25	23	21	19	17	15	14	13	13	13	13	14	16	19	23	27	32	35	37	36	35	33
NW	24	22	20	19	17	15	13	12	11	10	10	11	11	12	13	15	18	21	25	28	29	29	28	26

Table 32 July Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls 40°North Latitude (*Concluded*)

Wall Number 13

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	15	14	13	12	11	10	9	9	9	9	9	10	10	11	12	14	15	16	17	18	18	18	17	16
NE	18	17	16	15	13	12	11	12	13	16	18	19	20	21	21	22	23	23	23	23	23	22	21	20

Table 32 July Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls 40°North Latitude (*Concluded*)

Wall Number 13

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
E	22	20	19	17	16	15	14	14	16	19	22	25	27	28	29	29	29	29	29	28	27	26	25	23
SE	22	20	19	17	16	14	13	13	14	16	18	21	24	26	27	28	28	28	28	28	27	26	24	23
S	20	18	17	16	14	13	12	11	10	10	11	12	14	16	19	21	23	24	25	25	24	23	22	21
SW	26	25	23	21	19	18	16	15	14	13	13	13	14	15	18	21	24	28	30	32	32	31	30	28
W	29	27	25	23	21	19	18	16	15	15	14	14	15	15	17	20	23	27	31	34	34	34	32	31
NW	23	22	20	18	17	15	14	13	12	12	12	12	12	13	14	16	18	21	24	26	27	27	26	25

Wall Number 14

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	15	15	14	13	12	11	10	10	10	10	10	10	10	11	12	13	14	15	15	16	17	17	16	16
NE	19	18	17	16	15	14	13	13	14	15	17	18	19	20	20	21	21	22	22	22	22	22	21	20
E	23	22	21	19	18	17	16	15	16	18	21	23	25	26	27	27	28	28	28	28	27	26	25	24
SE	23	21	20	19	18	16	15	15	15	16	18	20	22	24	25	26	27	27	27	27	26	26	25	24
S	20	19	18	17	16	15	14	13	12	12	12	12	14	15	17	19	21	22	23	23	23	23	22	21
SW	26	25	24	22	21	19	18	17	16	15	15	15	15	16	17	19	22	25	27	29	30	30	29	28
W	29	27	26	24	23	21	20	18	17	16	16	16	16	16	17	19	21	24	27	30	32	32	31	30
NW	23	22	21	19	18	17	16	15	14	13	13	13	13	14	14	15	17	19	21	24	25	25	25	24

Wall Number 15

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	19	18	16	14	12	10	9	7	6	6	6	6	7	8	9	11	13	15	17	19	20	21	21	20
NE	21	19	17	15	13	11	9	8	7	9	11	14	18	20	22	23	25	25	26	26	26	26	25	23
E	25	22	20	17	15	12	10	9	9	10	14	18	23	27	30	32	34	34	34	33	32	31	29	27
SE	25	22	20	17	15	13	11	9	8	8	10	14	18	22	26	30	32	33	34	33	33	31	30	27
S	25	22	20	17	15	13	11	9	7	6	6	6	7	10	13	17	21	25	28	30	30	30	29	27
SW	35	32	28	25	22	18	16	13	11	9	8	8	8	9	11	14	18	23	28	33	37	39	39	37
W	39	35	32	28	24	21	18	15	12	10	9	8	8	9	10	13	16	21	26	32	38	41	42	41
NW	31	28	26	23	20	17	14	12	10	8	7	7	7	8	9	11	13	16	20	25	29	32	33	33

Wall Number 16

Wall Face	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	18	17	16	14	13	11	10	9	8	7	7	7	8	9	10	11	13	14	16	17	18	19	19	19
NE	21	20	18	16	14	13	11	10	10	11	13	15	17	19	21	22	23	24	24	25	25	24	24	23
E	25	23	21	19	17	15	13	11	11	12	15	19	22	26	28	30	31	31	32	32	31	30	29	27
SE	25	23	21	19	17	15	13	11	10	11	12	15	18	21	25	27	29	30	31	31	31	30	29	27
S	24	22	20	18	16	14	12	11	9	8	8	8	9	11	14	17	20	23	25	27	27	27	27	25
SW	33	30	28	25	23	20	18	15	13	12	11	10	10	11	12	15	18	22	27	30	33	35	35	34
W	36	33	31	28	25	22	20	17	15	13	12	11	11	11	12	14	17	20	25	30	34	37	38	37
NW	29	27	25	23	20	18	16	14	12	11	10	9	9	10	11	12	14	16	19	23	27	29	30	30

Note 1. Direct application of data

- Dark surface
- Indoor temperature of 78°F
- Outdoor maximum temperature of 95°F with mean temperature of 85°F and daily range of 21°F
- Solar radiation typical of clear day on 21st day of month
- Outside surface film resistance of 0.333 $(h \cdot ft^2 \cdot °F)/Btu$
- Inside surface resistance of 0.685 $(h \cdot ft^2 \cdot °F)/Btu$

Note 2. Adjustments to table data

- Design temperatures

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

where

t_r = inside temperature and

t_m = maximum outdoor temperature – (daily range)/2

- No adjustment recommended for color

Table 33A Wall Types, Mass Located Inside Insulation, for Use with Table 32

Secondary Material	R-Value, $ft^2 \cdot °F \cdot h/Btu$	Principal Wall Material**														
		A1	A2	B7	B10	B9	C1	C2	C3	C4	C5	C6	C7	C8	C17	C18
Stucco and/or plaster	0.0 to 2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2.0 to 2.5	*	5	*	*	*	*	*	*	*	5	*	*	*	*	*
	2.5 to 3.0	*	5	*	*	*	3	*	2	5	6	*	*	5	*	*
	3.0 to 3.5	*	5	*	*	*	4	2	2	5	6	*	*	6	*	*
	3.5 to 4.0	*	5	*	*	*	4	2	3	6	6	10	4	6	*	5
	4.0 to 4.75	*	6	*	*	*	5	2	4	6	6	11	5	10	*	10
	4.75 to 5.5	*	6	*	*	*	5	2	4	6	6	11	5	10	*	10
	5.5 to 6.5	*	6	*	*	*	5	2	5	10	7	12	5	11	*	10
	6.5 to 7.75	*	6	*	*	*	5	4	5	11	7	16	10	11	*	11
	7.75 to 9.0	*	6	*	*	*	5	4	5	11	7	*	10	11	*	11
	9.0 to 10.75	*	6	*	*	*	5	4	5	11	7	*	10	11	4	11
	10.75 to 12.75	*	6	*	*	*	5	4	5	11	11	*	10	11	4	11
	12.75 to 15.0	*	10	*	*	*	10	4	5	11	11	*	10	11	9	12
	15.0 to 17.5	*	10	*	*	*	10	5	5	11	11	*	11	12	10	16
	17.5 to 20.0	*	11	*	*	*	10	5	9	11	11	*	15	16	10	16
	20.0 to 23.0	*	11	*	*	*	10	9	9	16	11	*	15	16	10	16
	23.0 to 27.0	*	*	*	*	*	*	*	*	*	*	*	16	*	15	*
Steel or other light-weight siding	0.0 to 2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2.0 to 2.5	*	3	*	*	*	*	*	2	3	5	*	*	*	*	*
	2.5 to 3.0	*	5	*	*	*	2	*	2	5	3	*	*	5	*	*
	3.0 to 3.5	*	5	*	*	*	3	1	2	5	5	*	*	5	*	*
	3.5 to 4.0	*	5	*	*	*	3	2	2	5	5	6	3	5	*	5
	4.0 to 4.75	*	6	*	*	*	4	2	2	5	5	10	4	6	*	5
	4.75 to 5.5	*	6	*	*	*	5	2	2	6	6	11	5	6	*	6
	5.5 to 6.5	*	6	*	*	*	5	2	3	6	6	11	5	6	*	6
	6.5 to 7.75	*	6	*	*	*	5	2	3	6	6	11	5	6	*	10
	7.75 to 9.0	*	6	*	*	*	5	2	3	6	6	12	5	6	*	11
	9.0 to 10.75	*	6	*	*	*	5	2	3	6	6	12	5	6	4	11
	10.75 to 12.75	*	6	*	*	*	5	2	3	6	7	12	6	11	4	11
	12.75 to 15.0	*	6	*	*	*	5	2	4	6	7	12	10	11	5	11
	15.0 to 17.5	*	10	*	*	*	6	4	4	10	7	*	10	11	9	11
	17.5 to 20.0	*	10	*	*	*	10	4	4	10	11	*	10	11	10	11
	20.0 to 23.0	*	11	*	*	*	10	4	5	11	11	*	10	11	10	16
	23.0 to 27.0	*	*	*	*	*	*	*	*	*	*	*	10	*	11	16
Face brick	0.0 to 2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2.0 to 2.5	3	*	*	*	*	*	*	*	*	11	*	*	*	*	*
	2.5 to 3.0	5	11	*	*	*	*	*	6	11	12	*	*	*	*	*
	3.0 to 3.5	5	12	5	*	*	11	*	11	12	12	*	*	12	*	*
	3.5 to 4.0	5	12	6	*	*	12	6	12	12	13	*	*	12	*	*
	4.0 to 4.75	6	13	6	10	*	13	10	12	12	13	*	11	*	*	16
	4.75 to 5.5	6	13	6	11	*	*	11	12	13	13	*	16	*	*	*
	5.5 to 6.5	6	13	6	11	*	*	11	12	13	13	*	*	*	*	*
	6.5 to 7.75	6	13	6	11	*	*	11	13	*	13	*	*	*	*	*
	7.75 to 9.0	6	13	10	16	*	*	11	13	*	13	*	*	*	*	*
	9.0 to 10.75	6	14	10	16	*	*	11	13	*	14	*	*	*	16	*
	10.75 to 12.75	6	14	10	16	*	*	11	13	*	14	*	*	*	16	*
	12.75 to 15.0	6	*	11	16	*	*	12	13	*	*	*	*	*	*	*
	15.0 to 17.5	10	*	11	*	*	*	12	13	*	*	*	*	*	*	*
	17.5 to 20.0	10	*	11	*	*	*	16	*	*	*	*	*	*	*	*
	20.0 to 23.0	11	*	15	*	*	*	16	*	*	*	*	*	*	*	*
	23.0 to 27.0	*	*	*	*	*	*	16	*	*	*	*	*	*	*	*

*Denotes a wall that is not possible with the chosen set of parameters.
**See Table 11 for definition of Code letters

Table 33B Wall Types, Mass Evenly Distributed, for Use with Table 32

Secondary Material	R-Value, $ft^2 \cdot °F \cdot h/Btu$	Principal Wall Material**														
		A1	A2	B7	B10	B9	C1	C2	C3	C4	C5	C6	C7	C8	C17	C18
Stucco and/or plaster	0.0 to 2.0	1	3	*	*	*	*	*	1	3	3	*	*	*	*	*
	2.0 to 2.5	1	3	1	*	*	2	*	2	4	4	*	*	5	*	*
	2.5 to 3.0	1	4	1	*	*	2	2	2	4	4	*	*	5	*	*
	3.0 to 3.5	1	*	1	*	*	2	2	*	*	*	10	4	5	*	4
	3.5 to 4.0	1	*	1	2	*	*	4	*	*	*	10	4	*	*	4
	4.0 to 4.75	1	*	1	2	*	*	*	*	*	*	10	4	*	*	4
	4.75 to 5.5	1	*	1	2	*	*	*	*	*	*	*	*	*	*	*
	5.5 to 6.5	1	*	2	4	10	*	*	*	*	*	*	*	*	*	*
	6.5 to 7.75	1	*	2	4	11	*	*	*	*	*	*	*	*	*	*
	7.75 to 9.0	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*
	9.0 to 10.75	1	*	2	4	16	*	*	*	*	*	*	*	*	4	*
	10.75 to 12.75	1	*	2	5	*	*	*	*	*	*	*	*	*	4	*
	12.75 to 15.0	2	*	2	5	*	*	*	*	*	*	*	*	*	*	*
	15.0 to 17.5	2	*	2	5	*	*	*	*	*	*	*	*	*	*	*
	17.5 to 20.0	2	*	2	9	*	*	*	*	*	*	*	*	*	*	*
	20.0 to 23.0	2	*	4	9	*	*	*	*	*	*	*	*	*	*	*
	23.0 to 27.0	*	*	*	9	*	*	*	*	*	*	*	*	*	*	*
Steel or other light-weight siding	0.0 to 2.0	1	3	*	*	*	*	*	1	3	2	*	*	*	*	*
	2.0 to 2.5	1	3	1	*	*	2	*	1	3	2	*	*	3	*	*
	2.5 to 3.0	1	4	1	*	*	2	1	2	4	4	*	*	3	*	*
	3.0 to 3.5	1	*	1	*	*	4	1	*	*	*	5	2	4	*	4
	3.5 to 4.0	1	*	1	2	*	*	2	*	*	*	5	2	*	*	4
	4.0 to 4.75	1	*	1	2	*	*	*	*	*	*	10	4	*	*	4
	4.75 to 5.5	1	*	1	2	*	*	*	*	*	*	*	*	*	*	*
	5.5 to 6.5	1	*	1	2	10	*	*	*	*	*	*	*	*	*	*
	6.5 to 7.75	1	*	1	4	11	*	*	*	*	*	*	*	*	*	*
	7.75 to 9.0	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*
	9.0 to 10.75	1	*	2	4	16	*	*	*	*	*	*	*	*	2	*
	10.75 to 12.75	1	*	2	4	*	*	*	*	*	*	*	*	*	4	*
	12.75 to 15.0	1	*	2	5	*	*	*	*	*	*	*	*	*	*	*
	15.0 to 17.5	1	*	2	5	*	*	*	*	*	*	*	*	*	*	*
	17.5 to 20.0	1	*	2	5	*	*	*	*	*	*	*	*	*	*	*
	20.0 to 23.0	2	*	4	9	*	*	*	*	*	*	*	*	*	*	*
	23.0 to 27.0	*	*	*	9	*	*	*	*	*	*	*	*	*	*	*
Face brick	0.0 to 2.0	3	6	*	*	*	*	*	*	*	6	*	*	*	*	*
	2.0 to 2.5	3	10	*	*	*	*	*	5	10	10	*	*	*	*	*
	2.5 to 3.0	4	10	5	*	*	5	*	5	10	11	*	*	10	*	*
	3.0 to 3.5	*	11	5	*	*	10	5	5	11	11	15	10	10	*	10
	3.5 to 4.0	*	11	5	10	*	10	5	5	11	11	16	10	16	*	10
	4.0 to 4.75	*	11	*	11	*	10	5	5	16	11	*	10	16	*	16
	4.75 to 5.5	*	11	*	11	*	10	5	10	16	16	*	10	16	*	16
	5.5 to 6.5	*	16	*	*	*	10	9	10	16	11	*	11	16	*	16
	6.5 to 7.75	*	16	*	*	*	11	9	10	16	16	*	16	16	*	*
	7.75 to 9.0	*	16	*	*	*	15	9	10	16	*	*	15	16	*	*
	9.0 to 10.75	*	16	*	*	*	15	10	10	*	16	*	16	*	10	*
	10.75 to 12.75	*	16	*	*	*	16	10	10	*	*	*	16	*	15	*
	12.75 to 15.0	*	16	*	*	*	16	10	10	*	16	*	*	*	15	*
	15.0 to 17.5	*	*	*	*	*	16	10	15	*	*	*	*	*	16	*
	17.5 to 20.0	*	*	*	*	*	16	15	15	*	*	*	*	*	16	*
	20.0 to 23.0	*	*	*	*	*	*	15	16	*	*	*	*	*	*	*
	23.0 to 27.0	*	*	*	*	*	*	15	*	*	*	*	*	*	*	*

*Denotes a wall that is not possible with the chosen set of parameters.
**See Table 11 for definition of Code letters

Table 33C Wall Types, Mass Located Outside Insulation, for Use with Table 32

Secondary Material	R-Value, ft²·°F·h/Btu	Principal Wall Material**														
		A1	**A2**	**B7**	**B10**	**B9**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C17**	**C18**
Stucco and/or plaster	0.0 to 2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2.0 to 2.5	*	3	*	*	*	*	*	2	3	5	*	*	*	*	*
	2.5 to 3.0	*	3	*	*	*	2	*	2	4	5	*	*	5	*	*
	3.0 to 3.5	*	3	*	*	*	2	2	2	5	5	*	*	5	*	*
	3.5 to 4.0	*	3	*	*	*	2	2	2	5	5	10	4	6	*	5
	4.0 to 4.75	*	4	*	*	*	4	2	2	5	5	10	4	6	*	9
	4.75 to 5.5	*	4	*	*	*	4	2	2	5	6	11	5	10	*	10
	5.5 to 6.5	*	5	*	*	*	4	2	2	5	6	11	5	10	*	10
	6.5 to 7.75	*	5	*	*	*	4	2	2	5	6	11	5	10	*	10
	7.75 to 9.0	*	5	*	*	*	5	2	4	5	6	16	10	10	*	10
	9.0 to 10.75	*	5	*	*	*	5	4	4	5	6	16	10	10	4	11
	10.75 to 12.75	*	5	*	*	*	5	4	4	10	6	16	10	10	9	11
	12.75 to 15.0	*	5	*	*	*	5	4	4	10	10	*	10	11	9	11
	15.0 to 17.5	*	5	*	*	*	5	4	4	10	10	*	10	11	10	16
	17.5 to 20.0	*	5	*	*	*	9	4	4	10	10	*	10	15	10	16
	20.0 to 23.0	*	9	*	*	*	9	9	9	15	10	*	10	15	15	16
	23.0 to 27.0	*	*	*	*	*	*	*	*	*	*	*	15	*	15	16
Steel or other light-weight siding	0.0 to 2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2.0 to 2.5	*	3	*	*	*	*	*	2	3	2	*	*	*	*	*
	2.5 to 3.0	*	3	*	*	*	2	*	2	3	2	*	*	*	*	*
	3.0 to 3.5	*	3	*	*	*	2	1	2	4	3	*	*	4	*	*
	3.5 to 4.0	*	3	*	*	*	2	2	2	4	3	5	2	5	*	4
	4.0 to 4.75	*	3	*	*	*	2	2	2	4	3	10	3	5	*	5
	4.75 to 5.5	*	3	*	*	*	2	2	2	5	3	10	4	5	*	5
	5.5 to 6.5	*	4	*	*	*	2	2	2	5	3	10	4	5	*	5
	6.5 to 7.75	*	4	*	*	*	2	2	2	5	4	11	5	5	*	6
	7.75 to 9.0	*	5	*	*	*	2	2	2	5	4	11	5	5	*	6
	9.0 to 10.75	*	5	*	*	*	2	2	2	5	4	11	5	5	4	10
	10.75 to 12.75	*	5	*	*	*	4	2	2	5	5	11	5	5	4	10
	12.75 to 15.0	*	5	*	*	*	4	2	2	5	5	11	5	10	5	10
	15.0 to 17.5	*	5	*	*	*	4	2	4	5	5	16	9	10	9	10
	17.5 to 20.0	*	5	*	*	*	4	4	4	9	5	16	9	10	10	10
	20.0 to 23.0	*	9	*	*	*	4	4	4	9	9	16	10	10	10	11
	23.0 to 27.0	*	*	*	*	*	*	*	*	*	*	16	10	*	10	15
Face brick	0.0 to 2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2.0 to 2.5	3	*	*	*	*	*	*	*	*	11	*	*	*	*	*
	2.5 to 3.0	3	10	*	*	*	*	*	5	10	11	*	*	*	*	*
	3.0 to 3.5	3	11	5	*	*	10	*	5	11	11	*	*	11	*	*
	3.5 to 4.0	3	11	5	*	*	10	5	6	11	11	*	*	11	*	*
	4.0 to 4.75	3	11	5	10	*	10	5	10	11	11	*	10	11	*	16
	4.75 to 5.5	3	12	5	10	*	10	9	10	11	12	*	11	16	*	16
	5.5 to 6.5	4	12	5	10	*	10	10	10	12	12	*	15	16	*	16
	6.5 to 7.75	4	12	5	10	*	11	10	10	12	12	*	16	*	*	16
	7.75 to 9.0	5	12	5	15	*	11	10	10	16	12	*	16	*	*	*
	9.0 to 10.75	5	12	9	15	*	11	10	10	16	12	*	16	*	15	*
	10.75 to 12.75	5	12	10	15	*	11	10	10	*	12	*	16	*	15	*
	12.75 to 15.0	5	*	10	16	*	11	10	11	*	*	*	16	*	15	*
	15.0 to 17.5	5	*	10	16	*	15	10	11	*	*	*	16	*	*	*
	17.5 to 20.0	5	*	10	16	*	16	15	15	*	*	*	*	*	*	*
	20.0 to 23.0	9	*	15	16	*	16	15	15	*	*	*	*	*	*	*
	23.0 to 27.0	*	*	*	*	*	*	15	*	*	*	*	*	*	*	*

*Denotes a wall that is not possible with the chosen set of parameters.
**See Table 11 for definition of Code letters

The composite effect of the various forms of interior shading on solar radiation from glass, relative to unshaded clear double-strength glass, is represented by a shading coefficient (SC) or decimal multiplier, tabulated in Chapter 29 for a wide variety of conditions.

Exterior Shading. Where glass is shaded by exterior means of a permanent nature, the hourly mitigating effect of such shading may be estimated by separate evaluations of shaded areas relative to unshaded areas for each situation as previously noted.

Example 7. Cooling load from south and west glass. Determine the cooling load caused by glass on the south and west walls of a building at 1200, 1400, and 1600 h in July. The building is located at 40°N latitude with outside design conditions of 90°F dry-bulb temperature and a 20°F daily range. The inside design dry bulb temperature is 78°F. Assume the room configuration includes two exposed walls, vinyl floor covering, and gypsum partitions, and that the building is a single story. The south glass is insulating type (0.25 in. air space) with an area of 100 ft^2 and no interior shading. The west glass is 7/32 in. single grey-tinted glass with an area of 100 ft^2 and with light-colored venetian blinds.

Table 34 Cooling Load Temperature Differences (CLTD) for Conduction through Glass

Solar Time, h	CLTD, °F	Solar Time, h	CLTD, °F
0100	1	1300	12
0200	0	1400	13
0300	–1	1500	14
0400	–2	1600	14
0500	–2	1700	13
0600	–2	1800	12
0700	–2	1900	10
0800	0	2000	8
0900	2	2100	6
1000	4	2200	4
1100	7	2300	3
1200	9	2400	2

Corrections: The values in the table were calculated for an inside temperature of 78°F and an outdoor maximum temperature of 95°F with an outdoor daily range of 21°F. The table remains approximately correct for other outdoor maximums 93 to 102°F and other outdoor daily ranges 16 to 34°F, provided the outdoor daily average temperature remains approximately 85°F. If the room air temperature is different from 78°F and/or the outdoor daily average temperature is different from 85°F see note 2, Table 32.

Solution: By the room configuration described and with inside shading for half the exposed glass area, Table 35B indicates the SCL factors should be selected for a Zone C condition.

Data required for the calculation are as follows:

Variable		South Glass	West Glass
U, Btu/(h·ft^2·°F)*		0.61	0.81
Area A, ft^2		100	100
SC (Chapter 29)		0.82	0.53
SCL (Table 36, Zone C)	1200	79	37
	1400	80	98
	1600	40	153

*U-factors based on previous edition of this Handbook. See Table 5, Chapter 29 for current values.

Table 35A Zone Types for Use with CLF Tables, Interior Rooms

Zone Parameters[a]				Zone Type	
Room Location	Middle Floor	Ceiling Type	Floor Covering	People and Equipment	Lights
Single story	N/A	N/A	Carpet	C	B
	N/A	N/A	Vinyl	D	C
Top floor	2.5 in. Concrete	With	Carpet	D	C
	2.5 in. Concrete	With	Vinyl	D	D
	2.5 in. Concrete	Without	b	D	B
	1 in. Wood	b	b	D	B
Bottom floor	2.5 in. Concrete	With	Carpet	D	C
	2.5 in. Concrete	b	Vinyl	D	D
	2.5 in. Concrete	Without	Carpet	D	D
	1 in. Wood	b	Carpet	D	C
	1 in. Wood	b	Vinyl	D	D
Mid-floor	2.5 in. Concrete	N/A	Carpet	D	C
	2.5 in. Concrete	N/A	Vinyl	D	D
	1 in. Wood	N/A	b	C	B

[a]A total of 14 zone parameters is fully defined in Table 20. Those not shown in this table were selected to achieve an error band of approximately 10%.
[b]The effect of this parameter is negligible in this case.

Table 35B Zone Types for Use with SCL and CLF Tables, Single-Story Building

Zone Parameters[a]				Zone Type			Error Band	
No. Walls	Floor Covering	Partition Type	Inside Shade	Glass Solar	People and Equipment	Lights	Plus	Minus
1 or 2	Carpet	Gypsum	b	A	B	B	9	2
1 or 2	Carpet	Concrete block	b	B	C	C	9	0
1 or 2	Vinyl	Gypsum	Full	B	C	C	9	0
1 or 2	Vinyl	Gypsum	Half to None	C	C	C	16	0
1 or 2	Vinyl	Concrete block	Full	C	D	D	8	0
1 or 2	Vinyl	Concrete block	Half to None	D	D	D	10	6
3	Carpet	Gypsum	b	A	B	B	9	2
3	Carpet	Concrete block	Full	A	B	B	9	2
3	Carpet	Concrete block	Half to None	B	B	B	9	0
3	Vinyl	Gypsum	Full	B	C	C	9	0
3	Vinyl	Gypsum	Half to None	C	C	C	16	0
3	Vinyl	Concrete block	Full	B	C	C	9	0
3	Vinyl	Concrete block	Half to None	C	C	C	16	0
4	Carpet	Gypsum	b	A	B	B	6	3
4	Vinyl	Gypsum	Full	B	C	C	11	6
4	Vinyl	Gypsum	Half to None	C	C	C	19	–1

[a]A total of 14 zone parameters is fully defined in Table 20. Those not shown in this table were

Load (SCL). The error band for Lights and People and Equipment is approximately 10%.

Table 36 July Solar Cooling Load For Sunlit Glass 40°North Latitude

Zone Type A

Glass Face	Hour (Solar Time) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	0	0	0	0	1	25	27	28	32	35	38	40	40	39	36	31	31	36	12	6	3	1	1	0
NE	0	0	0	0	2	85	129	134	112	75	55	48	44	40	37	32	26	18	7	3	2	1	0	0
E	0	0	0	0	2	93	157	185	183	154	106	67	53	45	39	33	26	18	7	3	2	1	0	0
SE	0	0	0	0	1	47	95	131	150	150	131	97	63	49	41	34	27	18	7	3	2	1	0	0
S	0	0	0	0	0	9	17	25	41	64	85	97	96	84	63	42	31	20	8	4	2	1	0	0
SW	0	0	0	0	0	9	17	24	30	35	39	64	101	133	151	152	133	93	35	17	8	4	2	1
W	1	0	0	0	0	9	17	24	30	35	38	40	65	114	158	187	192	156	57	27	13	6	3	2
NW	1	0	0	0	0	9	17	24	30	35	38	40	40	50	84	121	143	130	46	22	11	5	3	1
Hor	0	0	0	0	0	24	69	120	169	211	241	257	259	245	217	176	125	70	29	14	7	3	2	1

Zone Type B

Glass Face	Hour (Solar Time) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	2	2	1	1	1	22	23	24	28	32	35	37	38	37	35	32	31	35	16	10	7	5	4	3
NE	2	1	1	1	2	73	109	116	101	73	58	52	48	45	41	36	30	23	13	9	6	5	3	3
E	2	2	1	1	2	80	133	159	162	143	105	74	63	55	48	41	34	25	15	10	7	5	4	3
SE	2	2	1	1	1	40	81	112	131	134	122	96	69	58	49	42	35	26	15	10	8	6	4	3
S	2	2	1	1	1	8	15	21	36	56	74	86	87	79	63	46	37	27	16	11	8	6	4	3
SW	6	5	4	3	2	9	16	22	27	31	36	58	89	117	135	138	126	94	46	31	21	15	11	8
W	8	6	5	4	3	9	16	22	27	31	35	37	59	101	139	166	173	147	66	43	30	21	15	11
NW	6	5	4	3	2	9	16	22	27	31	34	37	37	46	76	108	128	119	51	33	22	16	11	8
Hor	8	6	5	4	3	22	60	104	147	185	214	233	239	232	212	180	137	90	53	37	27	19	14	11

Zone Type C

Glass Face	Hour (Solar Time) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	5	5	4	4	4	24	23	24	27	30	33	34	35	34	32	29	29	34	14	10	8	7	6	6
NE	7	6	6	5	6	75	106	107	88	61	49	47	45	43	40	36	31	25	16	13	11	10	9	8
E	9	8	8	7	8	83	130	148	145	124	89	62	56	52	47	43	37	30	20	17	15	13	12	11
SE	9	8	7	6	6	45	82	107	121	121	107	82	59	51	47	42	36	29	19	16	14	13	11	10
S	7	7	6	5	5	12	18	23	36	54	70	79	79	70	54	40	33	26	16	13	12	10	9	8
SW	14	12	11	10	9	15	21	26	29	33	36	57	86	110	124	125	111	80	37	28	23	20	17	15
W	17	15	13	12	11	17	22	27	31	34	36	37	59	98	132	153	156	128	50	35	28	24	21	19
NW	12	11	10	9	8	14	20	25	29	32	34	36	36	44	73	102	118	107	39	26	21	17	15	13
Hor	24	21	19	17	16	34	68	107	144	175	199	212	215	207	189	160	123	83	53	44	38	34	30	27

Zone Type D

Glass Face	Hour (Solar Time) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	8	7	6	6	6	21	21	21	24	27	29	31	32	31	30	28	29	32	17	14	12	11	10	9
NE	11	10	9	8	9	63	87	90	77	58	49	48	46	44	42	39	35	29	22	19	17	15	14	12
E	15	13	12	11	11	70	107	123	124	110	85	65	60	57	53	48	43	37	29	25	22	20	18	16
SE	14	13	11	10	10	39	68	90	102	104	95	78	60	55	51	47	42	35	27	24	21	19	17	16
S	11	10	9	8	7	12	17	21	32	46	59	67	69	63	52	41	36	30	22	19	17	15	14	12
SW	21	19	17	15	14	18	22	25	28	31	34	51	74	94	106	109	100	78	45	37	33	29	26	23
W	25	23	20	18	17	21	24	28	30	33	34	35	53	84	112	130	135	116	57	46	39	35	31	28
NW	18	16	15	13	12	17	21	24	27	30	32	33	34	41	64	87	101	94	42	33	29	25	22	20
Hor	37	33	30	27	24	38	64	95	124	150	171	185	191	188	176	156	128	96	72	63	56	50	45	41

Notes:
1. Values are in $Btu/h \cdot ft^2$.
2. Apply data directly to standard double strength glass with no inside shade.
3. Data applies to 21st day of July.
4. For other types of glass and internal shade, use shading coefficients as multiplier. See text. For externally shaded glass, use north orientation. See text.

The conduction heat gain component of cooling load by Equation (42) is:

Time	CLTD (Table 34)	CLTD Corrected	South Glass, Btu/h	West Glass, Btu/h
1200	9	4	244	324
1400	13	8	488	648
1600	14	9	549	729

The correction factor applied to the above CLTDs was –5°F, computed from the notes of Table 34. Heat gain values are rounded.

The solar heat gain component of cooling load by Equation (43) is:

Time	South Glass		SHG, Btu/h	West Glass		SHG, Btu/h
	SC	SCL		SC	SCL	
1200	0.82	79	6478	0.53	37	1961
1400	0.82	70	5740	0.53	98	5194
1600	0.82	40	3280	0.53	153	8109

The total cooling load due to heat gain through the glass is, therefore:

Time	South Glass, Btu/h	West Glass, Btu/h
1200	6722	2285
1400	6198	5842
1600	3829	8838

HEAT SOURCES WITHIN CONDITIONED SPACE

People

The basic principles of evaluating heat gain and moisture generation from people are the same as those previously described for the TFM. Latent heat gains are considered instantaneous cooling loads.

The total sensible heat gain from people is not converted directly to cooling load. The radiant portion is first absorbed by the surroundings (floor, ceiling, partitions, furniture) then convected to the space at a later time, depending on the thermal characteristics of the room. The radiant portion of the sensible heat gain from people varies widely depending on the circumstances, as indicated by Table 3 and in more detail by Chapter 8. A 70% value was used to generate CLFs for Table 37, which considers the storage effect on this radiant load in its results, plus the 30% convective portion. The instantaneous sensible cooling load is thus:

$$q_s = N(\text{SHG}_p)(\text{CLF}_p) \quad (44)$$

and the latent cooling load is:

$$q_l = N(\text{LHG}_p) \quad (45)$$

Table 37 Cooling Load Factors for People and Unhooded Equipment

Hours in Space	Number of Hours after Entry into Space or Equipment Turned On																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Zone Type A																								
2	0.75	0.88	0.18	0.08	0.04	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.75	0.88	0.93	0.95	0.22	0.10	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.75	0.88	0.93	0.95	0.97	0.97	0.23	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.75	0.88	0.93	0.95	0.97	0.97	0.98	0.98	0.24	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
10	0.75	0.88	0.93	0.95	0.97	0.97	0.98	0.98	0.99	0.99	0.24	0.12	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
12	0.75	0.88	0.93	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.25	0.12	0.07	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01
14	0.76	0.88	0.93	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.25	0.12	0.07	0.05	0.03	0.03	0.02	0.02	0.01	0.01
16	0.76	0.89	0.94	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.25	0.12	0.07	0.05	0.03	0.03	0.02	0.02
18	0.77	0.89	0.94	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25	0.12	0.07	0.05	0.03	0.03
Zone Type B																								
2	0.65	0.74	0.16	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.65	0.75	0.81	0.85	0.24	0.17	0.13	0.10	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
6	0.65	0.75	0.81	0.85	0.89	0.91	0.29	0.20	0.15	0.12	0.09	0.07	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
8	0.65	0.75	0.81	0.85	0.89	0.91	0.93	0.95	0.31	0.22	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01
10	0.65	0.75	0.81	0.85	0.89	0.91	0.93	0.95	0.96	0.97	0.33	0.24	0.18	0.14	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01
12	0.66	0.76	0.81	0.86	0.89	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.34	0.24	0.19	0.14	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02
14	0.67	0.76	0.82	0.86	0.89	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.35	0.25	0.19	0.15	0.11	0.09	0.07	0.05	0.04	0.03
16	0.69	0.78	0.83	0.87	0.90	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.35	0.25	0.19	0.15	0.11	0.09	0.07	0.05
18	0.71	0.80	0.85	0.88	0.91	0.93	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.35	0.25	0.19	0.15	0.11	0.09
Zone Type C																								
2	0.60	0.68	0.14	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
4	0.60	0.68	0.74	0.79	0.23	0.18	0.14	0.12	0.10	0.08	0.06	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
6	0.61	0.69	0.74	0.79	0.83	0.86	0.28	0.22	0.18	0.15	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01
8	0.61	0.69	0.75	0.79	0.83	0.86	0.89	0.91	0.32	0.26	0.21	0.17	0.14	0.11	0.09	0.08	0.06	0.05	0.04	0.04	0.03	0.02	0.02	0.02
10	0.62	0.70	0.75	0.80	0.83	0.86	0.89	0.91	0.92	0.94	0.35	0.28	0.23	0.18	0.15	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.03
12	0.63	0.71	0.76	0.81	0.84	0.87	0.89	0.91	0.93	0.94	0.95	0.96	0.37	0.29	0.24	0.19	0.16	0.13	0.11	0.09	0.07	0.06	0.05	0.04
14	0.65	0.72	0.77	0.82	0.85	0.88	0.90	0.92	0.93	0.94	0.95	0.96	0.97	0.97	0.38	0.30	0.25	0.20	0.17	0.14	0.11	0.09	0.08	0.06
16	0.68	0.74	0.79	0.83	0.86	0.89	0.91	0.92	0.94	0.95	0.96	0.96	0.97	0.98	0.98	0.98	0.39	0.31	0.25	0.21	0.17	0.14	0.11	0.09
18	0.72	0.78	0.82	0.85	0.88	0.90	0.92	0.93	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.99	0.99	0.99	0.39	0.31	0.26	0.21	0.17	0.14
Zone Type D																								
2	0.59	0.67	0.13	0.09	0.08	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
4	0.60	0.67	0.72	0.76	0.20	0.16	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
6	0.61	0.68	0.73	0.77	0.80	0.83	0.26	0.20	0.17	0.15	0.13	0.11	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.02	0.02
8	0.62	0.69	0.74	0.77	0.80	0.83	0.85	0.87	0.30	0.24	0.20	0.17	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03
10	0.63	0.70	0.75	0.78	0.81	0.84	0.86	0.88	0.89	0.91	0.33	0.27	0.22	0.19	0.17	0.14	0.12	0.11	0.09	0.08	0.07	0.06	0.05	0.05
12	0.65	0.71	0.76	0.79	0.82	0.84	0.87	0.88	0.90	0.91	0.92	0.93	0.35	0.29	0.24	0.21	0.18	0.16	0.13	0.12	0.10	0.09	0.08	0.07
14	0.67	0.73	0.78	0.81	0.83	0.86	0.88	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.37	0.30	0.25	0.22	0.19	0.16	0.14	0.12	0.11	0.09
16	0.70	0.76	0.80	0.83	0.85	0.87	0.89	0.90	0.92	0.93	0.94	0.95	0.95	0.96	0.96	0.97	0.38	0.31	0.26	0.23	0.20	0.17	0.15	0.13
18	0.74	0.80	0.83	0.85	0.87	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.97	0.97	0.97	0.98	0.98	0.39	0.32	0.27	0.23	0.20	0.17

Note: See Table 35 for zone type. Data based on a radiative/convective fraction of 0.70/0.30.

where

q_s = sensible cooling load due to people
N = number of people
SHG_p = sensible heat gain per person (Table 3)
CLF_p = cooling load factor for people (Table 37)
q_l = latent cooling load due to people
LHG_p = latent heat gain per person (Table 3)

The CLF for people load is a function of the time such people spend in the conditioned space and the time elapsed since first entering. As defined for estimating cooling load from fenestration, the space under consideration is categorized as a zone, identified in Table 35. The appropriate CLF is selected from Table 37 by zone type, occupancy period, and number of hours after entry.

CLF Usage Exceptions. If the space temperature is not maintained constant during the 24-h period, for example, if the cooling system is shut down during the night (night shutdown), a "pulldown load" results because a major part of the stored sensible heat in the structure has not been removed, thus reappearing as cooling load when the system is started the next day. In this case, a CLF of 1.0 should be used.

When there is a *high occupant density*, as in theaters and auditoriums, the quantity of radiation to the walls and room furnishings is proportionately reduced. In these situations, a CLF of 1.0 should also be used.

Example 8. Cooling load from occupants. Estimate the cooling load in a building at 1200, 1400, and 1600 h from four moderately active people occupying an office from 0900 to 1700 h. The office temperature is 78°F, and the cooling system operates continuously. Assume the conditions of the space as applied to Table 33A; define it as Type D.

Solution: The sensible cooling load is calculated by Equation (44), and the latent cooling load is calculated by Equation (45). The period of occupancy is 8 h. Therefore,

Time	No. of People	Hours in Space	Hours after Entry	Btu/h Each (Table 3) Sen.	Btu/h Each (Table 3) Lat.	CLF*p* (Table 37) Zone D	Cooling Load Sen., Btu/h	Cooling Load Lat., Btu/h
1200	4	8	3	255	255	0.74	755	1020
1400	4	8	5	255	255	0.80	816	1020
1600	4	8	7	255	255	0.85	867	1020

Lighting

As discussed for the TFM, the cooling load from lighting does not immediately reflect the full energy output of the lights. Kimura and Stephenson (1968), Mitalas and Kimura (1971), and Mitalas (1973) indicated the effect on cooling load of light fixture type, type of air supply and return, space furnishings, and the thermal characteristics of the space. The effect of these influencing parameters have been incorporated in the *Cooling and Heating Load Calculation Manual* (McQuiston and Spitler 1992) into the CLF values for lighting listed in Table 38, and for which selection zones are identified as appropriate by Tables 35. At any time, the space cooling load from lighting can be estimated as:

$$q_{el} = HG_{el}(CLF_{el}) \tag{46}$$

where

q_{el} = cooling load from lighting, Btu/h
HG_{el} = heat gain from lighting, Btu/h, as $WF_{ul}F_{sa}$ [Equation (9)]
W = total lamp watts
F_{ul} = lighting use factor
F_{sa} = lighting special allowance factor
CLF_{el} = lighting cooling load factor (Table 38)

CLF_{el} data in Table 38 are based on the assumptions that (1) the conditioned space temperature is continuously maintained at a constant value, and (2) the cooling load and power input to the lights eventually become equal if the lights are on for long enough.

Operational Exceptions. If the cooling system operates only during occupied hours, the CLF_{el} should be considered 1.0 in lieu of

Table 38 Cooling Load Factors for Lights

Hours Lights On	Number of Hours after Lights Turned On																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Zone Type A																								
8 h	0.85	0.92	0.95	0.96	0.97	0.97	0.97	0.98	0.13	0.06	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10 h	0.85	0.93	0.95	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.14	0.07	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
12 h	0.86	0.93	0.96	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.14	0.07	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
14 h	0.86	0.93	0.96	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.15	0.07	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02
16 h	0.87	0.94	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.15	0.08	0.05	0.04	0.03	0.03	0.03	0.02
Zone Type B																								
8 h	0.75	0.85	0.90	0.93	0.94	0.95	0.95	0.96	0.23	0.12	0.08	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01
10 h	0.75	0.86	0.91	0.93	0.94	0.95	0.95	0.96	0.96	0.97	0.24	0.13	0.08	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02
12 h	0.76	0.86	0.91	0.93	0.95	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.24	0.14	0.09	0.07	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03
14 h	0.76	0.87	0.92	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.25	0.14	0.09	0.07	0.06	0.05	0.05	0.04	0.04	0.03
16 h	0.77	0.88	0.92	0.95	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.25	0.15	0.10	0.07	0.06	0.05	0.05	0.04
Zone Type C																								
8 h	0.72	0.80	0.84	0.87	0.88	0.89	0.90	0.91	0.23	0.15	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03
10 h	0.73	0.81	0.85	0.87	0.89	0.90	0.91	0.92	0.92	0.93	0.25	0.16	0.13	0.11	0.09	0.08	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04
12 h	0.74	0.82	0.86	0.88	0.90	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.26	0.18	0.14	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.05
14 h	0.75	0.84	0.87	0.89	0.91	0.92	0.92	0.93	0.94	0.94	0.95	0.95	0.96	0.96	0.27	0.19	0.15	0.13	0.11	0.10	0.09	0.08	0.08	0.07
16 h	0.77	0.85	0.89	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.95	0.96	0.96	0.97	0.97	0.97	0.28	0.20	0.16	0.13	0.12	0.11	0.10	0.09
Zone Type D																								
8 h	0.66	0.72	0.76	0.79	0.81	0.83	0.85	0.86	0.25	0.20	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04
10 h	0.68	0.74	0.77	0.80	0.82	0.84	0.86	0.87	0.88	0.90	0.28	0.23	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.06
12 h	0.70	0.75	0.79	0.81	0.83	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.30	0.25	0.21	0.19	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08
14 h	0.72	0.77	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.32	0.26	0.23	0.20	0.18	0.16	0.14	0.13	0.12	0.10
16 h	0.75	0.80	0.83	0.85	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.95	0.96	0.96	0.34	0.28	0.24	0.21	0.19	0.17	0.15	0.14

Note: See Table 35 for zone type. Data based on a radiative/convective fraction of 0.59/0.41.

the Table 38 values. Where one portion of the lights serving the space is on one schedule of operation and another portion is on a different schedule, each should be treated separately. Where lights are left on for 24 h a day, the CLF_{el} is 1.0.

Example 9. Cooling load from lighting. Estimate the cooling load in a building at 1200, 1400, and 1600 h from recessed fluorescent lights, turned on at 0800 h and turned off at 1800 h. Lamp wattage is 800 W. The use factor is 1.0, and the special allowance factor is 1.25. The room is an interior type in a one-story building, has tile flooring over a 3-in. concrete floor, and a suspended ceiling. The cooling system runs 24 h/day, including weekends.

Solution: From Table 35B, the room is categorized as Type C for lighting load purposes. Therefore,

Time	Hours in Space	Hours after Entry	Lamp Watts	Heat Gain, Btu/h [Eq. (9)]	CLF_{el} (Table 38) Zone C	Cooling Load, Btu/h [Eq. (39)]
1200	8	3	800	3410	0.85	2489
1400	8	5	800	3410	0.89	2660
1600	8	7	800	3410	0.91	2796

Power and Appliances

Heat gain of power-driven equipment can be estimated by means of Equations (15), (16), or (17) as applicable, or taken directly from Tables 4 and/or 5.

Equations (18) and (19) can be used to estimate heat gain values under various circumstances, and Tables 6 through 9 provide representative data for direct use or as input to the equations.

The radiant component of sensible heat gain from power-driven equipment or appliances is delayed in becoming cooling load in the same manner as that of other load categories already discussed. For power-driven equipment, the CLF values tabulated for unhooded equipment (Table 37) are considered appropriate. Tables 37 and 39 tabulate cooling load factors (CLF_a) for appliances. Multiplying the sensible portion of heat gain by the appropriate CLF_a will produce the following approximate cooling load values:

$$q = SHG\ (CLF) \tag{47}$$

Example 10. Appliance cooling load. Determine the cooling load in a building at 1200, 1400, and 1600 h caused by an electric coffee brewer with one brewer and one warmer. The brewer operates continuously

Table 39 Cooling Load Factors for Hooded Equipment

Hours in Operation	Number of Hours after Equipment Turned On: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Zone Type A																								
2	0.64	0.83	0.26	0.11	0.06	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.64	0.83	0.90	0.93	0.31	0.14	0.07	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.64	0.83	0.90	0.93	0.96	0.96	0.33	0.16	0.09	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.64	0.83	0.90	0.93	0.96	0.96	0.97	0.97	0.34	0.16	0.09	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
10	0.64	0.83	0.90	0.93	0.96	0.96	0.97	0.97	0.99	0.99	0.34	0.17	0.10	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00
12	0.64	0.83	0.90	0.94	0.96	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.36	0.17	0.10	0.06	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01
14	0.66	0.83	0.90	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.36	0.17	0.10	0.07	0.04	0.04	0.03	0.03	0.03	0.01
16	0.66	0.84	0.91	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.36	0.17	0.10	0.07	0.04	0.04	0.04	0.03
18	0.67	0.84	0.91	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.36	0.17	0.10	0.08	0.07	0.04
Zone Type B																								
2	0.50	0.63	0.23	0.16	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.50	0.64	0.73	0.79	0.34	0.24	0.19	0.14	0.10	0.09	0.06	0.04	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
6	0.50	0.64	0.73	0.79	0.84	0.87	0.41	0.29	0.21	0.17	0.13	0.10	0.07	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00
8	0.50	0.64	0.73	0.79	0.84	0.87	0.90	0.93	0.44	0.31	0.24	0.19	0.14	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.01	0.01	0.01	0.01
10	0.50	0.64	0.73	0.79	0.84	0.87	0.90	0.93	0.94	0.96	0.47	0.34	0.26	0.20	0.16	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.03	0.01
12	0.51	0.66	0.73	0.80	0.84	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.49	0.34	0.27	0.20	0.16	0.11	0.09	0.07	0.06	0.05	0.04	0.03
14	0.53	0.66	0.74	0.80	0.84	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.99	0.99	0.50	0.36	0.27	0.21	0.16	0.13	0.10	0.08	0.07	0.06
16	0.56	0.69	0.76	0.81	0.86	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.50	0.36	0.27	0.21	0.16	0.14	0.13	0.10
18	0.59	0.71	0.79	0.83	0.87	0.90	0.93	0.94	0.96	0.97	0.97	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.50	0.36	0.27	0.23	0.21	0.16
Zone Type C																								
2	0.43	0.54	0.20	0.16	0.13	0.10	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
4	0.43	0.54	0.63	0.70	0.33	0.26	0.20	0.17	0.14	0.11	0.09	0.07	0.06	0.06	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
6	0.44	0.56	0.63	0.70	0.76	0.80	0.40	0.31	0.26	0.21	0.17	0.14	0.11	0.10	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.01	0.01
8	0.44	0.56	0.64	0.70	0.76	0.80	0.84	0.87	0.46	0.37	0.30	0.24	0.20	0.16	0.13	0.11	0.09	0.07	0.06	0.06	0.04	0.03	0.03	0.03
10	0.46	0.57	0.64	0.71	0.76	0.80	0.84	0.87	0.89	0.91	0.50	0.40	0.33	0.26	0.21	0.17	0.14	0.11	0.10	0.09	0.07	0.06	0.06	0.04
12	0.47	0.59	0.66	0.73	0.77	0.81	0.84	0.87	0.90	0.91	0.93	0.94	0.53	0.41	0.34	0.27	0.23	0.19	0.16	0.13	0.10	0.09	0.09	0.07
14	0.50	0.60	0.67	0.74	0.79	0.83	0.86	0.89	0.90	0.91	0.93	0.94	0.96	0.96	0.54	0.43	0.36	0.29	0.24	0.20	0.16	0.14	0.13	0.11
16	0.54	0.63	0.70	0.76	0.80	0.84	0.87	0.89	0.91	0.93	0.94	0.94	0.96	0.97	0.97	0.97	0.56	0.44	0.36	0.30	0.24	0.22	0.20	0.16
18	0.60	0.69	0.74	0.79	0.83	0.86	0.89	0.90	0.91	0.93	0.94	0.96	0.96	0.97	0.97	0.99	0.99	0.99	0.56	0.44	0.37	0.33	0.30	0.24
Zone Type D																								
2	0.41	0.53	0.19	0.13	0.11	0.09	0.07	0.07	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.43	0.53	0.60	0.66	0.29	0.23	0.19	0.16	0.14	0.11	0.10	0.09	0.07	0.07	0.06	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.01	0.01
6	0.44	0.54	0.61	0.67	0.71	0.76	0.37	0.29	0.24	0.21	0.19	0.16	0.13	0.11	0.10	0.09	0.07	0.07	0.06	0.04	0.04	0.04	0.04	0.03
8	0.46	0.56	0.63	0.67	0.71	0.76	0.79	0.81	0.43	0.34	0.29	0.24	0.21	0.19	0.16	0.14	0.11	0.10	0.09	0.07	0.07	0.06	0.06	0.06
10	0.47	0.57	0.64	0.69	0.73	0.77	0.80	0.83	0.84	0.87	0.47	0.39	0.31	0.27	0.24	0.20	0.17	0.16	0.13	0.11	0.10	0.09	0.09	0.07
12	0.50	0.59	0.66	0.70	0.74	0.77	0.81	0.83	0.86	0.87	0.89	0.90	0.50	0.41	0.34	0.30	0.26	0.23	0.19	0.17	0.14	0.13	0.13	0.11
14	0.53	0.61	0.69	0.73	0.76	0.80	0.83	0.84	0.87	0.89	0.90	0.91	0.93	0.93	0.53	0.43	0.36	0.31	0.27	0.23	0.20	0.18	0.17	0.16
16	0.57	0.66	0.71	0.76	0.79	0.81	0.84	0.86	0.89	0.90	0.91	0.93	0.93	0.94	0.94	0.96	0.54	0.44	0.37	0.33	0.29	0.26	0.24	0.21
18	0.63	0.71	0.76	0.79	0.81	0.84	0.87	0.89	0.90	0.91	0.93	0.93	0.94	0.96	0.96	0.96	0.97	0.97	0.56	0.46	0.39	0.35	0.33	0.29

Note: See Table 35 for zone type. Data based on a radiative/convective fraction of 1.0/0.

from 0900 to 1500 h and does not have an exhaust hood. The room is a "midfloor" type in a multistory building, has carpet over a 3-in. concrete floor, and a suspended ceiling. The cooling system runs 24 h/day, including weekends.

Solution: From Table 7, q_s and q_t for an unhooded, two-burner coffee brewer is 3750 and 1910 Btu/h, respectively (thus 1875 and 955 Btu/h each burner), and for a coffee heater (per warming burner) is 230 and 11032 Btu/h, respectively. The brewer is on for 6 h, and 1200 h is 3 h after the brewer is turned on. From Table 35B, the room is categorized as Type D for equipment load purposes. Therefore,

					Cooling Load		
Time	q_s, Btu/h	Hours in Use	Hours after Start	CLF_a (Table 37)	Sensible, Btu/h	Latent, Btu/h	Total, Btu/h
1200	2105	6	3	0.73	1537	1065	2602
1400	2105	6	5	0.80	1684	1065	2749
1600	2105	6	7	0.26	547	0	547

Total Space Cooling Load

The estimated total space cooling load for a given application is determined by summing the individual components for each hour of interest.

EXAMPLE COOLING LOAD CALCULATION USING CLTD/CLF METHOD

Example 11. For this example, the one-story commercial building in Example 6 will be the basis for calculating a cooling load by the CLTD/SCL/CLF method. Refer to Example 6 for the statement of conditions.

Find (for stated design conditions):

1. Sensible cooling load
2. Latent cooling load
3. Total cooling load

Solution: By inspection, the cooling load from the roof can be expected to be the variable making the greatest contribution to the overall cooling load for the building. Therefore, the time of maximum cooling load occurrence will probably be close to the time of maximum CLTD for the roof. The maximum cooling load for the building as a whole can be expected to occur in one of the summer months—June, July, or August. From Table 31, a "mass inside" roof with no ceiling and an R-factor of 11.11 is classified as Type 4. From Table 30, the CLTD for Roof No. 4 at 40°N latitude has a maximum tabulated value of 78°F at 1800 h, but is only somewhat less (73) at 1600 h.

South-facing glass can also be expected to wield considerable influence on the cooling load for this particular building. From Table 35A, a one-story building with three exposed walls, uncarpeted floor, masonry partitions, and fully inside-shaded windows is classified B for solar loads, and C for loads from people, equipment, or lights. Cross-checking the variation of SCLs for glass facing south, in Table 36, the maximum cooling load from these windows would be only slightly more at noon or 1300 h than at 1400 for 40°N latitude. Sometime in the early afternoon seems obvious, but it is necessary to make a quick estimate to establish the peak load hour:

Roof [Equation (41)]

$U = 0.09$ Btu/(h·ft²·°F) Area = 4000 ft²

Time	1300	1400	1500	1600	1700
CLTD	42	54	65	73	77
C_1	3	3	3	3	3
C_2	–1	–1	–1	–1	–1
Corr. CLTD	44	56	67	75	79
Btu/h	15840	20160	24120	27000	28440

$C_1 = (78 - 75)$ = indoor design temperature correction

$C_2 = (94 + 74)/2 - 85$ = daily average temperature correction

South Glass, Solar [Equation (43)]:

SC = 0.55 Area = 60 ft²

Time		1300	1400	1500	1600	1700
SCL at 40°,		87	79	63	46	37
Btu/h	=	2871	2607	2079	1518	1221
Roof and south glass, Btu/h	=	18711	22767	26199	28518	29661

Evaluation of the foregoing indicates that 1600 h will be the probable hour of maximum cooling load for this building, considering that although the roof and south glass loads increase another 1143 Btu/h for 1700 h, the trend has slowed and most other load components of significance can be expected to be leveling off or moving toward lower values at that time. In some cases there would be no such clear cut indication, and it would be necessary to estimate the total load for a number of hours, including the potential impact of other significant variables which could exert a determining influence at a different time (such as a major load from appliances, known to occur only in the morning, etc.), before selecting the peak load hour for the overall calculation.

Cooling Load from Heat Gain through Roof, Exposed Walls, and Doors

Such loads are estimated using Equation (41), where the CLTDs are taken from Table 30 after determining appropriate type numbers from Table 31 whose insulation placement, U-factors and general construction are as close to the actual components as possible. Corrections to CLTD values are made in accordance with footnote instructions to Table 30 similar to the above preliminary evaluation. (Note that there are no corrections to CLTD values for building mass variations, per the foregoing discussion, as considered of only limited significance to the overall results. Tabulated data for roofs, walls and doors assume Room Transfer Functions for "light to medium" construction.)

Cooling Load from Heat Gain through Fenestration Areas

The load component from conduction heat gain is calculated using Equation (42), where the CLTD value is taken from Table 34, corrected by −1°F because of a 1°F lower average daily temperature than that for which the table was generated, and +3°F to recognize the 75°F design space temperature. The U-factor of the glass is taken as 0.81 Btu/(h·ft²·°F) for single sheet plate glass, under summer conditions.

The load component from solar heat gain is calculated using Equation (43) as indicated above. A shading coefficient (SC) of 0.55 is used for clear glass with light-colored venetian blinds. SCL values are taken from Table 36 in this chapter, after first identifying the appropriate zone type as B for solar load from Table 35A. Results are tabulated in Table 40.

Table 40 Solar Cooling Load for Windows, Example 11

Section	Net Square Feet	SC	CLF Table 36	Cooling Load, Btu/h
South windows	60	0.55	46	1518
North windows	30	0.55	32	528

Cooling Load from Heat Gain through Party Walls

For the north and west party walls, cooling load is calculated using Equation (16) for wall and door areas, using appropriate U-factors from Chapter 24 and the temperature differential existing at 1600 h, 18.4°F. Results are tabulated in Table 41.

Cooling Load from Internal Heat Sources

For the cooling load component from lights, Equation (9) is first used to obtain the heat gain. Assuming a use factor of 1.0, and a special allowance factor of 1.0 for tungsten lamps and 1.20 for fluorescent lamps, these gains are:

$$q_{tung} = 4000 \times 1.0 \times 1.0 \times 3.41 = 13{,}640 \text{ Btu/h}$$

$$q_{fluor} = 17{,}500 \times 1.0 \times 1.2 \times 3.41 = 71{,}610 \text{ Btu/h}$$

Since the tungsten lamps are operated continuously, the previously stored radiant heat from this source currently being reconvected to the space equals the rate of new radiant heat from this source being stored, thus the cooling load from this source equals heat gain. The fluorescent lamps however are operated only 10 hours per day, 0800 through hour 1700, and thus contribute radiant heat to cooling load in a cyclic and

Table 41 Conduction Cooling Load Summary for Enclosing Surfaces, Example 11

Section	Net ft^2	U-Factor, $Btu/(h \cdot ft^2 \cdot °F)$	Δt, °F	CLTD, °F	Ref. for CLTD	1600 h Cooling Load, Btu/h
Roof	4000	0.09		73	Table 30 Roof 4	27000
South wall	405	0.24		19	Table 32 Wall 16	1847
East wall	765	0.48		38	Table 32 Wall 10	13954
North exposed wall	170	0.48		16	Table 32 Wall 10	1306
W. and N. party wall	1065	0.25	18.4			4899
Doors in S. Wall	35	0.19		50	Table 32 Wall 2	333
Doors in N. Wall	35	0.18	18.4			116
Doors in E. Wall	35	0.19		36	Table 32 Wall 2	239
South windows	60	0.81		16	Table 34	778
North windows	30	0.81		16	Table 34	389

Summary of Calculations for Example 11

	Dry Bulb, °F	Wet Bulb, °F	Humidity Ratio
Outdoor conditions	93.4	76.8	0.0161
Indoor conditions	75	62.5	0.0093
Difference	19		0.0068
Sensible Cooling Load at 1600 h			Btu/h
Roof and Exposed Walls			
Roof			27,000
South wall			1,847
East wall			13,954
North wall			1,306
South wall doors			333
East wall doors			239
Fenestration Areas			
South windows			2,296
North windows			917
Party Walls			
West and North Walls			4,899
North Wall doors			116
Internal Sources			
People			19,550
Tungsten lights			13,640
Fluorescent lights			65,881
Outside Air			
Infiltration			1,356
Ventilation			25,806
Total			179,140
Latent Cooling Load at 1600 h			Btu/h
People			17,000
Infiltration			2,205
Ventilation			41,963
Total			63,208
Grand Total Load			242,348

somewhat delayed manner. From Table 35A, the zone type is identified as C for lighting loads, and from Table 38 a CLF value of 0.92 is obtained for lights which are operated for 10 hours, for a calculation hour 9 hours after the lights have been turned on. The cooling load from fluorescent lights for this estimate is thus:

$$q_{cl\ fluor} = 71{,}610 \times 0.92 = 65{,}881 \text{ Btu/h}$$

For people, Table 3 is used to select heat gains for seated occupants doing light office work, as 250 Btu/h per person, sensible, and 200 Btu/h, latent for 75°F space temperature. The CLF for the sensible component is taken from Table 37 as 0.92, for a condition of 10 total hours in a type C space and a load calculation taken 9 h after entry. Cooling load from people is thus estimated at:

$$q_{ps} = 85 \text{ people} \times 250 \times 0.92 = 19{,}550 \text{ Btu/h}$$
$$q_{pl} = 85 \text{ people} \times 200 = 17{,}000 \text{ Btu/h}$$

Cooling Load from Power Equipment and Appliances

For this example, none are assumed.

Cooling Load from Infiltration and Ventilation Air

As determined in Example 6, ventilation for this building is established at 15 cfm/person, or 1275 cfm, and infiltration (through doors) at 67 cfm. For this example, ventilation is assumed to enter directly into the space (as opposed to first passing through the cooling equipment), and thus is included as part of the space cooling load.

The sensible and latent portions of each load component are calculated using Equations (22) and (23), respectively, where at 1600 h: t_o = 93.4°F; t_i = 75°F; W_o = 0.0161; and W_i = 0.0093; thus:

For ventilation:

Q_s	Factor	Δ*t*	Δ*W*	*q*, Btu/h
1275	1.1	18.4		25,806 Sensible
1275	4840		0.0068	41,963 Latent

For infiltration:

Q_s	Factor	Δ*t*	Δ*W*	*q*, Btu/h
67	1.1	18.4		1,356 Sensible
67	4840		0.0068	2,205 Latent

Limitations of CLTD/SCL/CLF Methods

The results obtained from using CLTD/CLF data depend on the characteristics of the space and how they vary from those used to generate the weighting factors. Variations can appear in the amplitude and when radiant heat gain components are felt as cooling loads, which affect the hourly cooling loads for the space. Two types of error are possible:

1. The computer software that generated CLTD/SCL/CLF tables uses the TFM to determine cooling loads based on various types of heat gain. The cooling loads for each type of heat gain are normalized appropriately to obtain CLTDs, SCLs, or CLFs. Except, as discussed next, use of the CLTD/SCL/CLF method in conjunction with these tables will yield the same results as the TFM, but only when the same 14 zone parameters are specified.

   Three inherent errors in the TFM are carried through to the CLTD/SCL/CLF data:

   a. Each set of weighting factors or conduction transfer function coefficients are used for a group of walls, roofs, or zones with similar thermal response characteristics. Groups were chosen so that error would be minimal and conservative (Harris and McQuiston 1988, Sowell 1988).

   b. The scheme used for calculating weighting factors is based on 14 discrete parameters applied to a rectangular room. Rarely does a room fit exactly into these parameters. Therefore, engineering judgment must be used to choose the values of the 14 parameters that most closely represent the room for which load calculations are being performed. Deviations of

Table 42 Potential Errors for Roof and Wall CLTDs in Tables 30 and 32

Roof No.	Error, % Plus	Error, % Minus	Wall No.	Error, % Plus	Error, % Minus
1	13	5	1	18	7
2	13	5	2	17	8
3	12	5	3	17	7
4	13	5	4	16	7
5	11	4	5	13	8
6	—	—	6	14	6
7	—	—	7	12	6
8	10	4	—	—	—
9	10	4	9	13	6
10	9	3	10	10	6
11	—	—	11	8	3
12	—	—	12	4	7
13	7	4	13	4	4
14	5	4	14	5	8
15	—	—	15	11	6
16	—	—	16	8	7

Note: Percent error = [(Table Value – TFM Value)/TFM Value] × 100

the room from the available levels of the 14 parameters may result in errors that are not easily quantifiable.

c. A fundamental presupposition of the TFM is that total cooling load for a zone can be calculated by simple addition of the individual components. For example, radiation heat transfer from individual walls and roofs is assumed to be independent of the other surfaces. O'Brien (1985) has shown this assumption can cause some error.

2. The printed tables for CLTDs, SCLs, and CLFs have undergone a further grouping procedure. The maximum potential errors due to the second grouping procedure have been analyzed and are tabulated in Tables 35 and 42. These errors are in addition to those inherent in the TFM. However, for usual construction, these errors are modest.

In summary, the CLTD/SCL/CLF method, as with any method, requires engineering judgment in its application. When the method is used in conjunction with custom tables generated by appropriate computer software (McQuiston and Spitler 1992) and for buildings where external shading is not significant, it can be expected to produce results very close to those produced by the TFM. When the printed tables are used, some additional error is introduced. In many cases, the accuracy should be sufficient.

TETD/TA CALCULATION PROCEDURE

To calculate a space cooling load using the TETD/TA convention, the same general procedures for data assembly and precalculation analysis apply as for the TFM. Similarly, the following factors are handled in an identical manner and are not repeated here.

- Basic heat gain calculation concepts of solar radiation (solar and conductive heat gain through fenestration areas, conversion to cooling load)
- Total heat gain through exterior walls and roofs (sol-air temperature, heat gain through exterior surfaces, tabulated temperature values, surface colors, air temperature cycle and adjustments, average sol-air temperature, hourly air temperatures, and data limitations)
- Heat gain through interior surfaces (adjacent spaces, floors)
- Heat gain through infiltration and ventilation

This section describes how the TETD/TA technique differs from the TFM. For sources of the space cooling load, equations, appropriate references, tables, and sources of other information for an overall analysis, see Table 43.

Treatment of Heat Gain and Cooling Load Conversion Procedures

The TETD/TA method was oriented primarily as a manual procedure. Tables of precalculated time-lags, decrement factors, and total equivalent temperature differential values listed a number of representative wall and roof assemblies for use in the appropriate heat gain equations. These data were based on a Fourier series solution to the one-dimensional unsteady-state conduction equation for a multiple-component slab, as used to calculate the heat flow through each of the walls and roofs selected for that purpose. All calculations were based on an inside air temperature of 75°F and a sol-air temperature at the outside equal to those given in Table 1 for horizontal and vertical surfaces of various orientations, at 2-h increments throughout a typical design day, as outlined by Stewart (1948) and Stephenson (1962). Basic equations were also presented to facilitate a computer solution.

Heat gain through walls and roofs. The results of the foregoing calculations were generalized by dividing the derived hourly heat gain values by the U-factor for each typical wall and roof. The quantity obtained from this generalization is called the total equivalent temperature differential (TETD). This establishes the basic heat gain equation for exterior surfaces as:

$$q = UA(\text{TETD}) \tag{48}$$

where

q = heat gain, Btu/h
U = coefficient of heat transfer, Btu/(h·ft²·°F)
A = area of surface, ft²
TETD = total equivalent temperature differential (as above)

Heat flow through a similar wall or roof (similar in thermal mass as well as U-factor) can be obtained by multiplying the TETDs listed in the appropriate table by the U-factor of the wall or roof of interest. Any errors introduced by this approach depend on the extent of the differences between the construction in question (components, size, color, and configuration) and the one used for calculating the TETDs.

TETD as Function of Decrement and Time Lag Factors. The heat gain results for representative walls and roofs were also generalized in another way. Effective decrement factors λ and time lags δ were determined for each assembly, such that the equivalent temperature differentials and the corresponding sol-air temperatures are related by:

$$\text{TETD} = t_{ea} - t_i + \lambda(t_{e\delta} - t_{ea}) \tag{49}$$

where

t_{ea} = daily average sol-air temperature, including consideration for surface color
t_i = indoor air temperature
λ = effective decrement factor
$t_{e,\delta}$ = sol-air temperature δ hours before the calculation hour for which TETD is intended

This relationship permits the approximate calculation of the heat gain through any of the walls or roofs tabulated, or their near equivalents, for any sol-air temperature cycle.

Manual Versus Automated Calculation. Manual application of the TETD/TA procedure, especially the time-averaging calculation itself, is tedious in practice. This fact, plus growing interest in the TFM, led to ASHRAE research with the objective of comparing the differences and similarities of the TETD and TFMs.

Table 43 Summary of TETD/TA Load Calculation Procedures

External Heat Gain

$$t_e = t_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \quad (6)$$

$$t_{ea} = t_{oa} + \alpha / h_o (I_{DT} / 24) - \varepsilon \Delta R / h_o \quad (10)$$

t_e = sol-air temperature
t_o = current hour dry-bulb temperature, from design db (Chapter 26, Table 1) adjusted by Table 2, percentage at daily range values
α = absorptance of surface for solar radiation
α/h_o = surface color factor = 0.15 for light colors, 0.30 for dark
I_t = total incident solar load = 1.15 (SHGF), with SHGF per Chapter 29, Tables 15 through 21
$\varepsilon\Delta R/h_o$ = long-wave radiation factor = –7°F for horizontal surfaces, 0°F for vertical
t_e = 24-h average sol-air temperature
t_{oa} = 24-h average dry-bulb temperature
I_{DT} = total daily solar heat gain (Chapter 29, Tables 15 through 21)

Roofs and Walls

$$q = UA \text{ (TETD)} \quad (48)$$

$$\text{TETD} = t_{ea} - t_i + \lambda(t_{e\delta} - t_{ea}) \quad (49)$$

U = design heat transfer coefficient for roof or wall, from Chapter 24, Table 4
A = area of roof or wall, calculated from building plans
TETD = total equivalent temperature difference, roof or wall
t_i = interior design dry-bulb temperature
λ = decrement factor, from Table 14 or 19
$t_{e\delta}$ = sol-air temperature at time lag δ hours (Table 14 or 19) previous to calculation hour

Roofs

Identify layers of roof construction from Table 11. With R-value of dominant layer, identify R-value Range number *R* and Roof Group number from Table 12. From Table 14 obtain decrement factor and time lag data with which to calculate TETD values for each sol-air temperature value by Equation (52). Calculate hourly heat gain with Equation (48).

Walls

Identify layers of wall construction from Table 11. With R-value of dominant layer, identify R-value Range number and Wall Group number from Table 15, 16, or 17.

Glass

Convective $q = UA(t_o - t_i)$

Solar $q = A\text{(SC)(SHGF)}$

U = design heat transfer coefficients, glass—Chapter 29
SC = shading coefficient—Chapter 29
SHGF = solar heat gain factor by orientation, north latitude, hour, and month—Chapter 29, Tables 15 to 21.

Partitions, Ceilings, Floors

$$q = UA\,(t_b - t_i) \quad (8)$$

t_b = temperature in adjacent space
t_i = inside design temperature in conditioned space

Internal Heat Gain

People

$$q_{sensible} = N \times \text{Sensible heat gain}$$

$$q_{latent} = N \times \text{Latent heat gain}$$

N = number of people in space, from best available source. Sensible and latent heat gain from occupancy—Table 3, or Chapter 8; adjust as required.

Lights

$$q_{el} = 3.41\, W F_{ul} F_{sa} \quad (9)$$

W = watts input from electrical plans or lighting fixture data
F_{ul} = lighting use factor, from the first section, as appropriate
F_{sa} = special allowance factor, from from section, as approp.

Power

$$q_p = 2545\, P E_F \quad (15)(16)(17)$$

P = horsepower rating from electrical plans or manufacturer's data
E_F = efficiency factors and arrangements to suit circumstances

Appliances

$$q_{sensible} = q_{input} F_U F_R \quad (18)$$

or

$$q_{sensible} = q_{input} F_L \quad (19)$$

q_{input} = rated power input from appliances from Tables 5 to 9 or manufacturer's data (Set latent heat = 0, if appliance is under exhaust hood.)
F_U, F_R, F_L = usage factors, radiation factors, flue loss factors

Ventilation and Infiltration Air

$$q_{sensible} = 1.10\, Q(t_o - t_i) \quad (22)$$

$$q_{latent} = 4840\, Q(W_o - W_i) \quad (23)$$

$$q_{total} = 4.5\, Q(H_o - H_i) \quad (20)$$

Q = ventilation airflow—ASHRAE *Standard* 62; infiltration cfm—Chapter 25
t_o, t_i = outside, inside air temperature, °F
W_o, W_i = outside, inside air humidity ratio, lb (water)/lb (da)
H_o, H_i = outside, inside air enthalpy, Btu/lb (dry air)

Cooling Load

Sensible

$$q_{sensible} = q_{cf} + q_{arf} + q_c$$

$$q_{cf} = q_{s,1}(1 - rf_1) + q_{s,2}(1 - rf_2) + \ldots + rf_n$$

$$q_{arf} = \sum_{\gamma = h_{a+1-\theta}}^{\theta} \frac{(q_{s,1} \times rf_1 + q_{s,2} \times rf_2 + \ldots + rf_n)_\gamma}{\theta}$$

$$q_c = (q_{sc,1} + q_{sc,2} + q_{sc,\beta})$$

$q_{sensible}$ = sensible cooling load
q_{cf} = convective fraction of hourly sensible heat gain (current hour) for n load elements
$q_{s,1}$ = sensible hourly heat gain for load element 1, … n
rf_1 = radiation fraction (Table 44) of sensible hourly heat gain for load element 1, … n
q_{arf} = average of radiant fractions of hourly sensible heat gain for n load element 1, … n
θ = number of hour over which to average radiant fractions of sensible heat gain
h_a = current hour, 1 to 24, for which cooling load is to be calculated
γ = one of calculations hours, from $h_{a+1-\theta}$ to h_a, for which the radiant fraction of sensible heat gain is to be averaged for each of n load elements
q_c = convective hourly sensible heat gain (current hour) for β load elements having no radiant component

Latent

$$q_{latent} = (q_{l,1} + q_{l,2} + q_{l,\beta})$$

q_{latent} = latent cooling load
q_l = hourly latent heat gain (current hour) for β load elements

Later research completed the circle of relationships between the TFM, its subsystem CLTD/CLF, and the TETD/TA techniques for dealing with the conversion of heat gain to cooling load. It also confirmed the logic of maintaining these various approaches to solving the problem, depending on the orientation and needs of the individual user and the means available. Finally, the research showed no further need to continue developing manual TETD/TA procedures. Thus, the tabulated values of TETDs have been eliminated from this Handbook in favor of calculation of TETD values by use of the material in the previous section that discusses the TFM.

U-Factors. The values for TETD, originally tabulated in the 1967 *Handbook of Fundamentals*, were calculated using an outside surface conductance of 3.0 Btu/(h · ft^2 · °F) and an inside surface conductance of 1.2 Btu/(h · ft^2 · °F), and thus should most appropriately be used with U-factors based on the same surface conductances. TETD data tabulated in the 1972 *Handbook of Fundamentals* and all data listed in this chapter are based on outside and inside surface conductances of 3.0 and 1.46, respectively. U-factors listed in Tables 14 for roofs and 19 for walls can, however, be used with the 1972 TETD data with negligible error, while calculated TETD values are directly compatible with the Table 14 and 19 U-factors.

Example 12. Wall heat gain by TETD. A wall is constructed of 4 in. heavyweight concrete, 2 in. insulation (2.0 lb/ft^3, R = 6.667 h · ft^2 · °F/Btu), 3/4 in. indoor plaster, and with outdoor and indoor surface resistances of 0.333 and 0.685 h · ft^2 · °F/Btu, respectively. There is an air space between the plaster and the insulation. The wall faces west, the outside design temperature is 95°F, the outdoor daily range is 21°F, the indoor temperature is 75°F, and the color of the exterior surface is light (α/h_o = 0.15). The time is 1400 h on a July day in the central part of the United States (40°N latitude).

Find the heat gain per unit area of wall area.

Solution: Turning first to Table 11, the code numbers for the various layers of the wall described above are:

Outside surface resistance	=	A0
4 in. heavyweight concrete	=	C5
2 in. insulation	=	B3
Air space resistance	=	B1
3/4 in. plaster	=	E1
Inside surface resistance	=	E0

Construction of the wall being "mass out" (as defined in TFM section), Table 17 represents the appropriate arrangement of layers. The dominant wall layer C5 is indicated to have a Wall Material column number of 10, which, combined with an E1 layer, dictates use of the upper array of code numbers for wall assembly "groups." Entering this array with an R value range of 9 (R = 6.667) indicates under column 10 that Wall Group 6 is that most nearly representative of the wall under consideration. The appropriate data from Wall Group 6 as listed in Table 19 are:

$$h = 5.28 \text{ h} = \text{time lag}$$

$$\lambda = 0.54 = \text{effective decrement factor}$$

$$U = 0.199 \text{ Btu/(h} \cdot \text{ft}^2 \cdot \text{°F)} = \text{heat transfer coefficient}$$

For this example, the sol-air temperature value for 1400 h t_e, as listed in Table 1, is 121°F, that for 0900 h (5 h earlier) is 85°F, and the daily average is 91°F. Thus, from Equation (49):

$$\text{TETD} = 91 - 75 + [0.54(85 - 91)] = 12.76\text{°F}$$

and from Equation (48)

$$q = 0.122 \times 1 \times 12.76 = 2.54 \text{ Btu/(h} \cdot \text{ft}^2)$$

Roof Heat Gain by TETD. The procedure for estimating heat gain from an exposed roof assembly is similar to that described for a wall—first identifying the code letters for the various layers from Table 11; identifying the appropriate roof group number from Table 12; reading the time lag, effective decrement factor, and U-factor for the selected roof group from Table 14; calculating the TETD for the hour of interest from these data and reference to Table 1; and then calculating the heat gain by means of Equation (48).

Heat Gain from Adjacent Unconditioned Spaces. In a manner similar to that described for the TFM, heat gain from adjacent unconditioned spaces can be estimated in two ways, depending on the thermal storage characteristics of the intervening surface. When storage effect is minor, sufficient accuracy can be obtained by use of Equation (8); otherwise, the appropriate TETD value should be calculated by the manner described for an exposed wall surface and the heat gain calculated by Equation (48).

Instantaneous Heat Gain from All Other Sources. Conductive and solar heat gain through fenestration, heat gain from the various internal sources (e.g., people, lighting, power, appliances, etc.), heat gain due to infiltration and ventilation, and latent heat gain from moisture through permeable building surfaces are each calculated in the same manner as described in the TFM section. The basic differences in calculation techniques between TFM and TETD/TA lie in the manner in which the heat gain data are converted to cooling load, as described later.

COOLING LOAD BY TIME AVERAGING

The time-averaging technique for relating instantaneous heat gain to instantaneous cooling load is an approximation of the TFM two-step conversion concept. It recognizes thermal storage by building mass and contents of the radiant portions of heat gain entering a space at any time, with subsequent release of stored heat to the space at some later time. It further recognizes that the cooling load for a space at a given hour is the sum of all convective heat gain and the nonradiant portion of conductive heat gain to that space, plus the amount of previously stored radiant heat gain released back to the space during that same hour.

The effect of room transfer coefficients on hourly heat gain is to generate a load profile that tracks the instantaneous heat gain in amplitude (greater or lower) and delay (negligible for very light structures with a predominance of glass, up to several hours for very massive, monumental construction). Being functions of the mass and configuration of the building and its contents, such coefficients place major emphasis on the immediately preceding hour, and rapidly lessening emphasis on each hour previous to that.

Such TFM-generated cooling load profiles can be closely approximated by averaging the hourly radiant components of heat gain for the previous one to seven or eight hours with those for the current hour, and adding the result to the total convective heat gain for the current hour. As long as results are consistent with results from the more rigorous TFM analysis, those from TETD/TA can be obtained with far less computational effort. The convenient ability to vary the averaging period independently (in recognition of previous experience of the probable thermal performance of an individual building) is also a valuable means of exerting professional judgment on the results.

Success of this approach depends on the accuracy with which the heat gain components are broken down into convective and radiant percentages, as well as on the number of hours used for the averaging period. Weakness of this approach lies in the absence of verified data in the technical literature regarding either determining factor, and the corresponding necessity for experienced judgment by the user.

Heat gain values for either the TFM or TETD/TA method are essentially identical for all load components. Derived cooling load values from properly applied averaging techniques closely track those from the TFM for external heat gain sources. Cooling loads from internal heat gains, however, averaged over the same period as for the external components, normally have peaks that occur more quickly and with greater amplitudes (up to full value of the source heat gain) than those generated by the TFM. This difference is due primarily to the almost constant level of radiant heat input during

Table 44 Convective and Radiant Percentages of Total Sensible Heat Gain for Hour Averaging Purposes

Heat Gain Source	Radiant Heat, %	Convective Heat, %
Window solar, no inside shade	100	—
Window solar, with inside shade	58	42
Fluorescent lights	50	50
Incandescent lights	80	20
People	33	67
Transmission, external roof and walls	60	40
Infiltration and ventilation	—	100
Machinery and appliances	20 to 80	80 to 20

[a]The load from machinery or appliances varies, depending on the temperature of the surface. The higher the surface temperature, the greater the percentage of heat gain that is radiant.

the occupied periods and the resultant "flattening" of the cooling load curves by the TFM as discussed in the TFM section.

The conservative results obtained from the time-averaging method compared with those of the TFM should be viewed in proper perspective. In the CLTD technique, for example, CLF values profile internal loads as a function of time in the space (up to the hour of interest) versus total time to be in effect during the day, and the tabulated fractional values are used *only* when HVAC equipment is operated 24 h a day and space temperature is not allowed to rise during unoccupied periods; otherwise, internal heat gains are considered instantaneous cooling loads at *full* value. On the other hand, the TFM, while not dealing directly with individual load components when space temperatures are permitted to rise overnight, applies space air transfer functions to estimate resultant increased rates of total sensible heat extraction from that space during periods of equipment operation. Regardless of methodology, good engineering judgment must be applied to predict realistic cooling loads from internal heat gains.

Time-averaging data in this chapter are empirical and offered only as information found dependable in practice by users of the technique. Basic assumptions regarding the percentages of radiant heat gain from various sources are used as default values by the TFM in establishing envelope transfer coefficients and room transfer coefficients. The TETD/TA method requires a specific breakdown by the user to determine what values are to be averaged over time. Table 44 suggests representative percentages for this purpose.

The convective portion of heat gain is treated as instantaneous cooling load. The radiant portion of instantaneous heat gain is considered as reduced or averaged over time by the thermal storage of the building and its contents. For lightweight construction, the instantaneous cooling load may be considered as an average of the radiant instantaneous heat gain over a 1 to 3-h period up to and including the hour of calculation interest, plus the nonradiant component of that hour's heat gain. For very heavy construction, the averaging period for hourly values of radiant instantaneous heat gain may be as long as 6 to 8 h, including the hour of calculation interest. Most users of this technique rarely consider application of an averaging period longer than 5 h, with a general norm of 3 h for contemporary commercial construction.

The load from machinery or appliances varies, depending on the temperature of the surface. The higher the surface temperature, the greater the percentage of heat gain that is radiant.

The two-step nature of the TETD/TA procedure offers a unique convenience in calculating cooling load through externally shaded fenestration. As described in the beginning of this section, the hourly history of fenestration heat gain as modified by external shading devices is directly usable for averaging purposes. Thus, the engineer has excellent control and can readily use the effect of external shading on cooling load in the conditioned space. Sun (1968) identified convenient algorithms for analysis of moving shade lines on glass from external projections.

EXAMPLE COOLING LOAD CALCULATION USING TETD/TA

Example 13. Cooling load calculation of small office building. For this example, the one-story building used to illustrate the TFM in Example 6 (and indicated in Figure 4) is also used for calculating a cooling load by the TETD/TA method. Refer to Example 6 for the statement of conditions.

Find (for stated design conditions):
1. Sensible cooling load
2. Latent cooling load
3. Total cooling load

Solution: By TETD/Time-averaging method.

1. Daily Load Cycle

The cooling loads are calculated once per hour for a period of time necessary to cover the hour of anticipated peak design load. For the purposes of this example, the full range of loads over a typical 24-h cycle are presented.

2. Hourly Heat Gain Components

Hourly heat gain values for each load component must be calculated for the same range as those for the cooling load, plus as many preceding hours as will be needed for the purposes of time-averaging (in the case of this example, all 24-h values have been calculated). The methodology involving use of time lag, effective decrement factor, and calculated TETD values is used to calculate heat gain components through walls and roof.

3. Thermal Storage

The heat storage effect of the room is accounted for by averaging the radiant elements of heat gain components for the hour in question with those of the immediately previous hours making up the selected averaging period, and combining the result with the convective heat gain elements for the current hour.

4. Summary

The data and summary of results using TETD/TA are tabulated in Table 45. Following the table is a step by step description of the calculation procedure used to determine the values listed.

1. **Sensible Cooling Load**

(a) *General*

Line 1, Time of day in hours. Various temperatures and heat flow rates were calculated for every hour on the hour, assuming that hourly values are sufficient to define the daily profile.

Line 2, Outside air temperatures. Hourly values were derived by the procedure given previously, using the specified maximum dry-bulb temperature of 94°F and daily range of 20°F.

(b) *Solar Heat Gain Factors*

Lines 3, 4, 5, and 6, Solar heat gain through opaque surfaces. The values in these columns are copies of the SHGF values listed in Table 4 for July 21 and 40°N latitude. These SHGF values are used to calculate sol-air temperatures of various outside surfaces, and solar heat gain through windows.

The June values might have been used, since the solar irradiation of horizontal surface (i.e., roof) is maximum at that time of year and since the heat gain through the roof appears to be the major component of exterior heat gain in this example problem. The difference between June and August values is relatively small however, compared to the large percentage increase in solar heat gain through south glass in August versus June at this latitude, thus indicating that August might be the better choice. For this example, data for July were selected as reasonable, and to provide better comparison with the results from other techniques for which tabular data are limited. For better assurance of accuracy it is preferable to evaluate and compare the relative loads of various surfaces for several months, before making a final determination as to that in which the maximum load will occur.

(c) *Sol-Air Temperatures*

Lines 7, 8, 9, and 10, Sol-air temperatures at opaque surfaces. Sol-air temperatures were calculated by Equation (6).

(d) *Total Equivalent Temperature Differentials*

Lines 10a through 10h, Calculated TETD values. Hourly TETD values for each of the expose surfaces, are calculated by Equation

Table 45 Tabulation of Data for Example 13—TETD/TA Method

1	**Time, hour**	**0100**	**0200**	**0300**	**0400**	**0500**	**0600**	**0700**	**0800**	**0900**	**1000**	**1100**	**1200**
2	Outside air temperature, °F	76	75	74	74	74	74	75	77	79	82	86	89
3	SHGF, Btu/h·ft², Horizontal	0	0	0	0	0	32	88	145	194	231	254	262
4	North	0	0	0	0	1	37	30	28	32	35	37	38
5	South	0	0	0	0	0	11	21	30	52	81	102	109
6	East	0	0	0	0	2	137	204	216	193	146	81	41
7	Sol-air temperature, °F, Horizontal	69	68	67	67	67	77	94	114	130	144	155	161
8	North	76	75	74	74	74	80	80	81	84	87	92	95
9	South	76	75	74	74	74	76	78	82	87	94	101	105
10	East	76	75	74	74	74	95	106	109	108	104	98	95
10a	Calculated TETD, °F, Roof	10	8	7	6	5	5	4	3	3	4	12	24
10b	North wall	10	8	7	6	5	5	4	3	3	3	6	7
10c	South wall	16	15	14	14	13	12	11	11	10	10	10	9
10d	East wall	11	10	9	8	7	7	5	5	4	4	17	24
10e	North and west party wall	10	10	10	9	9	8	8	7	7	6	6	6
10f	North door (to adjacent building)	3	2	1	0	0	0	0	0	1	4	6	10
10g	South door	3	2	1	0	0	0	0	2	6	11	17	24
10h	East door	3	2	1	0	0	0	14	27	33	33	30	24
	Instant Sensible Heat Gain, Btu/h												
11	Roof	3722	3193	2718	2347	2106	1814	1580	1393	1264	1681	4518	8802
12	North wall	827	710	605	518	454	446	348	305	273	259	556	592
13	South wall	1599	1536	1457	1379	1306	1213	1141	1090	1044	1005	976	968
14	East wall	4326	3801	3323	2938	2648	2614	2170	1979	1832	1774	6246	9099
15	North and west party wall	2686	2740	2724	2652	2532	2380	2221	2079	1954	1848	1768	1747
16	North door (to adjacent building)	19	17	7	1	–3	–5	–3	2	11	26	44	64
17	South door	21	19	8	2	–2	–5	6	20	41	74	117	160
18	East door	21	19	8	2	–2	–4	93	185	219	223	204	166
19	Windows, air to air heat gain	117	44	–15	–58	–73	–44	29	160	350	569	816	1050
20	North windows, solar heat gain	0	0	0	0	17	611	495	462	528	578	611	627
21	South windows, solar heat gain	0	0	0	0	0	363	693	990	1716	2673	3366	3597
22	Lights, tungsten (always on)	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640
23	Lights, fluorescent (on-off)	0	0	0	0	0	0	0	71610	71610	71610	71610	71610
24	People	0	0	0	0	0	0	0	21250	21250	21250	21250	21250
25	Infiltration	0	0	0	0	0	0	0	162	354	575	825	1061
26	Ventilation	2244	841	–281	–1122	–1403	–841	561	3086	6732	10940	15708	20196
27	Total instant sensible heat gain	29222	26560	24194	22299	21220	22182	22974	118413	122818	128725	14 2255	154629
	Latent Heat Gain/Cooling Load, Btu/h												
28	People	0	0	0	0	0	0	0	17000	17000	17000	17000	17000
29	Infiltration	0	0	0	0	0	0	0	2205	2205	2205	2205	2205
30	Ventilation	41963	41963	41963	41963	41963	41963	41963	41963	41963	419 63	41963	41963
31	Total latent heat gain/cooling load	41963	41963	41963	41963	41963	41963	41963	61168	61168	61168	61168	61168
32	Sum: sensible + latent heat gain, Btu/h	71185	68523	66157	64262	63183	64145	64937	179581	183986	189893	2 03423	215797
	Sensible Cooling Load from Convective Heat Gain, Btu/h												
33	Windows, air to air heat gain	117	44	–15	–58	–73	–44	29	160	350	569	816	1050
34	Lights, tungsten (20% convective)	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	272 8
35	Lights, fluorescent (50% conv.)	0	0	0	0	0	0	0	35805	35805	35805	35805	35805
36	People (67% convective)	0	0	0	0	0	0	0	14238	14238	14238	14238	14238
37	Infiltration (100% convective)	0	0	0	0	0	0	0	162	354	575	825	1061
38	Ventilation (100% convective)	2244	841	–281	–1122	–1403	–841	561	3086	6732	10940	15708	20 196
	Sensible Cooling Load from Radiant Heat Gain, Btu/h												
39	Lights, tungsten (80% radiant)	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10 912	10912
40	Lights, fluorescent (50% radiant)	0	0	0	0	0	0	0	7161	14322	21483	28644	35805
41	People (33% Radiant)	0	0	0	0	0	0	0	1403	2805	4208	5610	7013
	Sensible Cooling Load from Exposed Surfaces; From Convective Heat Gain, Btu/h												
42a	North windows, SHG (42% convective)	0	0	0	0	7	257	208	194	222	243	257	263
43a	South windows, SHG (42% convective)	0	0	0	0	0	152	291	416	721	1123	1414	1511
44a	Roof (40% convective)	1489	1277	1087	939	842	726	632	557	506	672	1807	3521
45a	North wall (40% convective)	331	284	242	207	182	178	139	122	109	104	222	237
46a	South wall (40% convective)	640	614	583	552	522	485	456	436	418	402	390	387
47a	East wall (40% convective)	1730	1520	1329	1175	1059	1046	868	792	733	710	2498	3640
48a	N. and W. party wall (40% conv.)	1074	1096	1090	1061	1013	952	888	832	782	739	707	699
49a	N. door to adj. bldg. (40% conv.)	8	7	3	0	–1	–2	–1	1	4	10	18	26
50a	South door (40% convective)	8	8	3	1	–1	–2	2	8	16	30	47	64
51a	East door (40% convective)	8	8	3	1	–1	–2	37	74	88	89	82	66
	Sensible Cooling Load from Exposed Surfaces; From Radiant Heat Gain, Btu/h												
42b	SHG at north windows (58% radiant)	0	0	0	0	2	73	130	184	245	310	310	325
43b	SHG at south windows (58% radiant)	0	0	0	0	0	42	122	237	436	746	1095	1432
44b	Roof heat gain (60% radiant)	5056	3532	2515	1959	1691	1461	1268	1109	978	928	1253	2119
45b	North wall heat gain (60% radiant)	742	648	545	439	373	328	285	249	219	196	209	238
46b	South wall heat gain (60% radiant)	904	932	932	910	874	827	780	735	695	659	631	610
47b	East wall heat gain (60% radiant)	3532	3110	2697	2325	2044	1839	1643	1482	1349	1244	1681	2511
48b	N. and W. party wall HG (60% rad.)	1428	1515	1576	1605	1600	1563	1501	1423	1340	1258	1185	1127
49b	North door heat gain (60% radiant)	24	18	13	9	5	2	–1	–1	1	4	9	17
50b	South door heat gain (60% radiant)	26	19	14	9	6	3	1	2	8	16	31	49
51b	East door heat gain (60% radiant)	26	19	14	10	6	3	12	33	59	86	111	120
52	Total sensible cooling load, Btu/h	33027	29132	25990	23662	22387	22686	23491	84540	97175	111027	129 243	147770
53	Sum: sens. + lat. cooling load, Btu/h	74990	71095	67953	65625	64350	64649	65454	145708	158343	172195	1 90411	208938

Table 45 Tabulation of Data for Example 13—TETD/TA Method (*Concluded*)

1	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**	**2100**	**2200**	**2300**	**2400**	**24 h Total**	**Heat Loss, Btu/h**
2	91	93	94	93	92	89	87	84	82	80	78	77		
3	254	231	194	145	88	32	0	0	0	0	0	0	2150	
4	37	35	32	28	30	37	1	0	0	0	0	0	438	
5	102	81	52	30	21	11	0	0	0	0	0	0	703	
6	37	35	31	26	20	11	0	0	0	0	0	0	1180	
7	160	155	145	130	111	92	80	77	75	73	71	70		
8	97	98	99	97	97	95	87	84	82	80	78	77		
9	106	105	102	98	95	91	87	84	82	80	78	77		
10	97	98	99	97	95	91	87	84	82	80	78	77		
10a	37	48	57	64	67	66	62	54	44	31	19	12		
10b	7	9	11	14	16	18	18	19	18	17	17	12		
10c	9	9	9	9	9	10	10	11	13	14	16	16		
10d	27	27	24	20	18	19	20	20	19	18	16	13		
10e	6	5	5	5	5	5	6	6	7	8	9	9		
10f	13	15	17	18	18	17	15	12	10	8	6	4		
10g	28	31	30	27	24	20	17	13	10	8	6	4		
10h	21	21	23	23	22	20	17	13	10	8	6	4		
Instantaneous Sensible Heat Gain, Btu/h														
11	13511	17460	20729	23087	24307	23947	22406	19674	15890	11192	6984	4342	238667	23400
12	630	802	962	1184	1358	1488	1529	1561	1490	1462	1404	997	20760	5304
13	930	911	896	889	926	973	1047	1160	1307	1454	1563	1612	28382	6318
14	9969	9958	9110	7627	6870	7300	7487	7630	7311	6767	6033	4990	133802	23868
15	1640	1590	1550	1528	1544	1595	1691	1834	2010	2213	2412	2572	49510	17306
16	84	100	112	117	116	109	96	81	65	51	38	27	1176	410
17	192	206	202	184	161	139	117	90	69	54	41	30	1946	432
18	140	146	153	157	151	137	118	91	70	55	41	30	2423	432
19	1224	1341	1385	1341	1239	1079	889	700	540	393	277	189	13542	4739
20	611	578	528	462	495	611	17	0	0	0	0	0	7231	
21	3366	2673	1716	990	693	363	0	0	0	0	0	0	23199	
22	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	13640	327360	–13640
23	71610	71610	71610	71610	71610	0	0	0	0	0	0	0	716100	–71610
24	21250	21250	21250	21250	21250	0	0	0	0	0	0	0	212500	–21250
25	1238	1356	1400	1356	1253	0	0	0	0	0	0	0	9580	4791
26	23562	25806	26648	25806	23843	20757	17111	13464	10379	7574	5330	3646	260587	91163
27	163597	169427	171891	171228	169456	72138	66148	59925	52771	44855	37763	32075	2046765	
Latent Heat Gain/Cooling Load, Btu/h														
28	17000	17000	17000	17000	17000	0	0	0	0	0	0	0	170000	
29	2205	2205	2205	2205	2205	0	0	0	0	0	0	0	22050	
30	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	41963	1007112	
31	61168	61168	61168	61168	61168	41963	41963	41963	41963	41963	41963	41963	1199162	
32	224765	230595	233059	232396	230624	114101	108111	101888	94734	86818	79726	74038	3245927	
Sensible Cooling Load from Convective Heat Gain, Btu/h														
33	1224	1341	1385	1341	1239	1079	889	700	540	393	277	189	13542	
34	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	2728	65472	
35	35805	35805	35805	35805	35805	0	0	0	0	0	0	0	358050	
36	14238	14238	14238	14238	14238	0	0	0	0	0	0	0	142380	
37	1238	1356	1400	1356	1253	0	0	0	0	0	0	0	9580	
38	23562	25806	26648	25806	23843	20757	17111	13464	10379	7574	5330	3646	260587	
Sensible Cooling Load from Radiant Heat Gain, Btu/h														
39	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	10912	261888	
40	35805	35805	35805	35805	35805	28644	21483	14322	7161	0	0	0	358050	
41	7013	7013	7013	7013	7013	5610	4208	2805	1403	0	0	0	70130	
Sensible Cooling Load from Exposed Surfaces; From Convective Heat Gain, Btu/h														
42a	257	243	222	194	208	257	7	0	0	0	0	0	3039	
43a	1414	1123	721	416	291	152	0	0	0	0	0	0	9745	
44a	5404	6984	8292	9235	9723	9579	8962	7870	6356	4477	2794	1737	95468	
45a	252	321	385	474	543	595	612	624	596	585	562	399	8305	
46a	372	364	358	356	370	389	419	464	523	582	625	645	11352	
47a	3988	3983	3644	3051	2748	2920	2995	3052	2924	2707	2413	1996	53521	
48a	656	636	620	611	618	638	676	734	804	885	965	1029	19805	
49a	34	40	45	47	46	44	38	32	26	20	15	11	471	
50a	77	82	81	74	64	56	47	36	28	22	16	12	779	
51a	56	58	61	63	60	55	47	36	28	22	16	12	967	
Sensible Cooling Load from Exposed Surfaces; From Radiant Heat Gain, Btu/h														
42b	343	349	343	325	310	310	245	184	130	73	2	0	4193	
43b	1707	1818	1707	1432	1095	746	436	237	122	42	0	0	13452	
44b	3573	5517	7802	10030	11891	13143	13738	13610	12747	11173	9137	6970	143200	
45b	277	341	425	500	592	695	782	855	891	904	893	830	12456	
46b	591	575	562	551	547	552	568	599	650	713	784	851	17032	
47b	3470	4446	5326	5491	5224	4904	4607	4430	4392	4380	4228	3928	80283	
48b	1075	1031	995	967	942	937	949	983	1041	1121	1219	1325	29706	
49b	27	38	48	57	64	66	67	63	56	49	40	31	706	
50b	70	90	105	113	114	107	96	83	69	56	45	34	1166	
51b	115	106	98	91	90	89	86	79	68	56	45	34	1456	
52	156283	163149	167774	169082	168376	105964	92708	78902	64574	49474	43046	37319	204678	178163
53	217451	224317	228942	230250	229544	147927	134671	120865	106537	91437	85009	79282	3245943	71663

(49) to incorporate individual thermal characteristics and orientation.

Line 10a, Roof TETD. Referring to Table 11, the major element of the roof (that with the most mass) is the gypsum slab with code number C14. Other elements are the metal deck (A3), rigid insulation (B3), built-up roofing (E3), and gravel surface (E2). Entering Table 12 with these data, the C14 roof slab with no ceiling and R-values of 11.11calls for an R range of 3. From the "mass-in" part of the upper table these pointers indicate roof group 5 as that whose thermal characteristics will best represent the roof in question.

The time lag and effective decrement factors are then obtained from Table 14, as tabulated for roof group 5. These values are:

$$\text{Time lag } (\delta) = 4.82 \text{ h}$$

$$\text{Effective decrement factor } (\lambda) = 0.68$$

The TETD values were then calculated for the roof surface with Equation (49), using the sol-air temperature cycle given in line 7 and t_i = 75°F.

Lines 10b through 10e, Wall TETD. The TETD values for the various walls were calculated by the same approach as that described for the roof. Time lag and effective decrement factors were selected from Table 19, as:

North and East Exterior Walls
- Dominant element C8, from Table 11;
- Interior finish E1 from Table 11;
- R-value indicating R range of 2 from Table 16 (integral mass);
- C8 dominant layer indicating Material Layer 13 from Table 16;
- From Table 16 select Wall Group 5 from the upper section (combining Layer 13 with E1 finish) as the most representative, and from Table 19 obtain δ = 5.11 h and λ = 0.64.

South Wall
- Dominant element C9, or Layer 14 in Integral mass table;
- Exterior layer A2 or A7;
- Interior layer E1 (plywood panel ignored as trivial);
- R-value indicating R of 6;
- Select wall group 24 for representative performance factors of δ = 11.29 h and λ = 0.23.

North and West Party Walls
- With no specific data for a 13 in. brick wall, use a layer of 8 in. common brick (C9) and a layer of 4 in. face brick (A2 or A7) as an approximation;
- Dominant element C9, or Layer 14 in Integral Mass table;
- Exterior layer A2 or A7;
- R-value indicating R of 6;
- Select wall group 24 for representative factors δ = 11.29 h and λ = 0.23. Calculate TETD values as above.

Lines 10f, 10g, and 10h, Door TETD values. Heat storage of the doors may be assumed negligible, and the heat gain, therefore, is calculated with Equation (8) as:

$$q_{DT} = U_D A_D (t_{DT} - t_i)$$

where

U_D = 0.19 Btu/h·ft²·°F , U-factor of doors (0.18 for interior doors)
A_D = 35 ft², area of a door
t_i = 75°F, inside temperature
t_{DT} = outside temperature. For the door in the north party wall, t_{DT} equals outside air temperature. For the doors in east and south walls t_{DT} equals the east and south wall sol-air temperatures, respectively.

While the foregoing calculation would be reasonable in estimating the minor loads involved, for this example, the relatively brief storage effect of the solid core doors has been considered as:

- Dominant element B7, or Layer 3 in Integral Mass table;
- Interior finish A6;
- R-factor indicating R range of 8;

Select wall group 1 for representative time lag δ of 1.30 h and λ = 0.98, and follow the above procedures to calculate the associated TETD values.

(e) *Instantaneous Sensible Heat Gain*

Line 11, Roof heat gain. Instantaneous heat gain through the roof, calculated with Equation (48) and the TETD values on line 10a.

Lines 12 through 18, Wall and door heat gain. The instantaneous heat gains through the various walls and doors were calculated the same way as heat gain through the roof was calculated. TETD values from lines 10b through 10h were used in Equation (48).

Lines 19, 20, and 21, Window heat gain. The air to air heat gain (line 19) is

$$q_{a-a} = U_w A_w (t_{o\theta} - t_i)$$

where

U_w = 0.81 Btu/h·ft²·°F, U-factor of window
A_w = , area of windows
$t_{o\theta}$ = outside air temperature at hour θ

The solar radiation heat gain (Lines 20 and 21) through south and north windows is:

$$q_r = A_w \text{SC}(\text{SHGF})_\theta$$

where

$(\text{SHGF})_\theta$ = Solar heat gain factors given in line 5 for south and line 6 for north
SC = 0.55; shading coefficient for clear window with light-colored curtain or blind

Lines 22 and 23, Heat gain from tungsten and fluorescent lights. For the gain from lighting, Equation (9) was used with a use factor of unity, and special allowance factors of 1.20 for the fluorescent lamps and of unity for the tungsten lamps. Thus:

$$q_{el\ tung} = 4000 \times 1 \times 1 \times 3.41 = 13{,}640 \text{ Btu/h}$$

and

$$q_{el\ fluor} = 17{,}500 \times 1 \times 1.20 \times 3.41 = 71{,}610 \text{ Btu/h}$$

Line 24, People. Sensible heat gain due to people. For the occupants, the data of Table 3 was used for moderately active office work. Thus:

$$q_p = (\text{Number of people})(\text{Sensible heat generated per person})$$
$$= 85 \times 250 = 21{,}250 \text{ Btu/h}$$

Lines 25 and 26, Sensible heat gain from infiltration and ventilation. As developed previously, the value to be used for infiltration was established as 67 cfm, and that for ventilation as 1275 cfm. Heat gain from all air entering as infiltration is routinely part of the space load. In this example (because ventilation is delivered directly to the space, rather than first through the cooling equipment), its gain is also included as a direct space load.

Note: Had the ventilation air been mixed with return air after leaving the occupied space and before entering the cooling equipment, only that portion which passed through the cooling coil without being treated by it—as a function of the coil inefficiency or "Bypass Factor," which is normally 3 to 5% for a chilled water coil of six or more rows and close fin spacing to 15% or more for refrigerant coils in packaged air-conditioning units—and/or that quantity deliberately bypassed around the coil in response to a "face and bypass" or "conventional multizone" space dry-bulb temperature control scheme, would become a part of the space heat gain rather than a part of the cooling coil load. While of potential significance to the design of a cooling system, the details of this concept are not considered in this chapter.

The sensible loads are determined from Equation (22). At 1500 hours for example, when t_o = 94°F and t_i = 75°F, this generates:

$$q_{si} = 1.1(\text{Infiltration rate})(t_o - t_i)$$
$$= 1.1 \times 67(94 - 75) = 1400 \text{ Btu/h}$$

and

$$q_{sv} = 1.1(\text{Ventilation rate})(t_o - t_i)$$
$$= 1.1 \times 1275(94 - 75) = 26{,}600 \text{ Btu/h}$$

Line 27, Total instantaneous sensible heat gain. The sum of sensible heat gain values on lines 11 through 26 for each calculation hour. This represents the total amount of such gain that actually enters the building during each hour, including any delaying effects of the individual surfaces on the passage of heat, but before any consideration of the storage and subsequent release of the radiant components of such heat.

(f) Instantaneous Latent Heat Gain

Line 28, People. The latent heat gain due to people, using Table 3 data

= (number of persons)(latent heat generated by one person)

= 85 × 200 = 17,000 Btu/h during the occupied period

Lines 29 and 30, Latent heat gain from infiltration and ventilation. The latent loads are determined from Equation (23). At 1500 h for example, when W_o = 0.0161 and W_s = 0.0093, this generates:

$$q_{li} = 4840(\text{Infiltration rate})(W_o - W_i)$$
$$= 4840 \times 67(0.0161 - 0.0093) = 2205 \text{ Btu/h}$$

and

$$q_{lv} = 4840(\text{Ventilation rate})(W_o - W_i)$$
$$= 4840 \times 1275(0.0161 - 0.0093) = 41{,}963 \text{ Btu/h}$$

Line 31, Total latent heat gain. The total latent heat gain is the sum of lines 27, 28, and 29.

(g) *Total Instantaneous Heat Gain*

Line 32, Total instantaneous heat gain. The sum of total instantaneous values on lines 27 and 31, sensible and latent heat gain, respectively. The hourly profile of such a total will normally reach a higher level at an earlier time of day than that of the building total cooling load, although the 24-h totals will be identical.

(h) *Cooling Load from Convective Sensible Heat Gain Components*

Lines 33 through 38. Direct inclusion of the instantaneous heat gain components listed in Lines 19, 25, and 26, and 20%, 50%, and 67% of lines 22, 23, and 24, respectively. These room sensible heat gain components (i.e., loads due to air-to-air heat gain through windows, tungsten lights, fluorescent lights, people, infiltration, and ventilation) all appear as cooling load without delay. Percentages of sensible heat gain considered convective are taken from Tables 3 and 42. Selection of 67% of sensible gain from people as convective is an approximation for purposes of this example.

(i) *Cooling Load Involving Time-Averaging*

Radiant elements of instantaneous heat gain will be felt as cooling load in the space only after having first been absorbed by the mass of building and contents, and later released back into the space as convective heat. This delaying action is approximated by time-averaging, or taking the average of such a heat gain value for the current hour with those from some number of immediately previous hours. An averaging period of about 5 h is used for this example, in which, for example, the value of cooling load for hour 1200 is derived as the average of the radiant fractions of hourly sensible heat gain for hours 1200, 1100, 1000, 0900, and 0800; thus delaying the full impact of such heat gain becoming cooling load for 5 h, and extending the period after the heat gain has ended for some amount of cooling load to be felt by the space.

Line 39, Cooling load from tungsten light sensible heat gain. Although 80% of the sensible heat gain from tungsten lights is radiant heat and subject to the storage/re-release phenomenon, data on line 39 appears as a constant value for every hour. This is due to the constant heat input to the room (line 22), from lights switched on all the time and thus with the radiant heat gain component from prior hours being released as cooling load at the same rate as the absorption by the room of the current hour's radiant component.

Line 40, Cooling load from lighting cycled on and off. Fifty percent (the radiant component) of the fluorescent lighting heat gain from line 23, showing the effect of such gain being processed by time-averaging, as indicated above.

Line 41, Cooling load due to radiant heat gain from people. Of sensible heat generated by people, 33% is dissipated by radiation and felt by the space as cooling load only after having been absorbed by the mass of the building and its contents.

(j) *Sensible Cooling Load from Exposed Surfaces*

Elements of instantaneous heat gain from solar radiation through windows, walls, doors and roof, i.e., the sum of values listed in lines 11 through 18, 20, and 21, are also delayed in being felt as cooling. The radiant heat gain by solar radiation transmitted through windows is treated the same way as the radiant portion of heat gain through walls and roof surfaces. However, since the windows have inside shading devices, solar radiation is considered reduced to approximately 58% of the solar heat gain through glass because the venetian blind intercepts about 42% of such solar radiation and releases it to the room in a convective form, similar to the treatment of heat gain through walls and roof (see Table 44).

Note: Had there been *no internal shading* of the glass, the solar radiation through windows would have to be treated as 100% radiant, all subject to time-averaging. Translucent draperies fall between these limits, in a linear relationship. Chapter 29 has more specific information on internal shading.

Lines 42a through 51a, Sensible cooling load from convective heat gain through enclosing surfaces. Data on lines 42b and 43b represent 58% of heat gain values for north and south windows, respectively, form lines 20 and 21, but time-averaged. Data for opaque enclosing surfaces on lines 44b through 51b represent 60% of the corresponding heat gain values on lines 11 through 18, but also time-averaged.

Cooling Load from power equipment and appliances. For this example, none are assumed. Had such loads been involved, with starting or ending periods within the time before the hour of calculation interest that can affect the averaging period, 20 to 80% of the sensible heat gain would have been considered as radiant and subject to time-averaging.

Line 52, Total room sensible cooling load. Total sensible cooling load felt by the room, and the design sensible load which is used as the basis for sizing cooling equipment. It is the sum of the values listed in lines 33 through 51b. The almost exact match between the 24-h total of 2,046,781 Btu/h on line 52 and the sum of the 24-h gain totals on line 27 (differing only by 16 Btu/h) does verify completeness of the computation.

2. **Latent Cooling Load**

Line 31—The sum of lines 28, 29, and 30. Total latent heat gain is also the total latent cooling load, as all components occur instantaneously.

3. **Total Cooling Load**

Line 52, The sum of lines 52 and 31. The total cooling load for this example problem is the theoretical total for the conditions as defined, and may or may not represent the actual total cooling load imposed upon a system of cooling equipment attempting to maintain the specified space conditions. An appropriate psychrometric analysis of supply air, space air, return air, and mixed air [when ventilation air is mixed with return air enroute back to the cooling equipment] should be performed, in conjunction with proper consideration of the type of cooling equipment and characteristics of the preferred control scheme, in order to verify the ability of the design to meet the requirements, and to determine whether the actual sensible, latent, and total cooling loads are greater or less than the theoretical values calculated.

Comparison of Results

Each of the calculation procedures outlined in this chapter, TFM, CLTD/SCL/CLF, and TETD/TA have used the same building in Examples 6, 11, and 13, respectively. Although widely different in purpose, approach, and mathematical processes, the results have many similarities as illustrated by Figure 5.

Tabular data for hourly total instantaneous sensible heat gain and total sensible cooling load values from Tables 28 and 45 are plotted to compare the two computer-based techniques, TFM and TETD/TA. The curves for heat gain are almost identical. Those for cooling load, however, happen to peak at the same hour, 1600, but with different magnitudes. The TETD/TA cooling load peak has reached almost the peak of its companion heat gain curve, but one hour later. The TFM heat gain curve reaches a peak at 1600 with a value only 0.5% different from that for TETD/TA, but the TFM

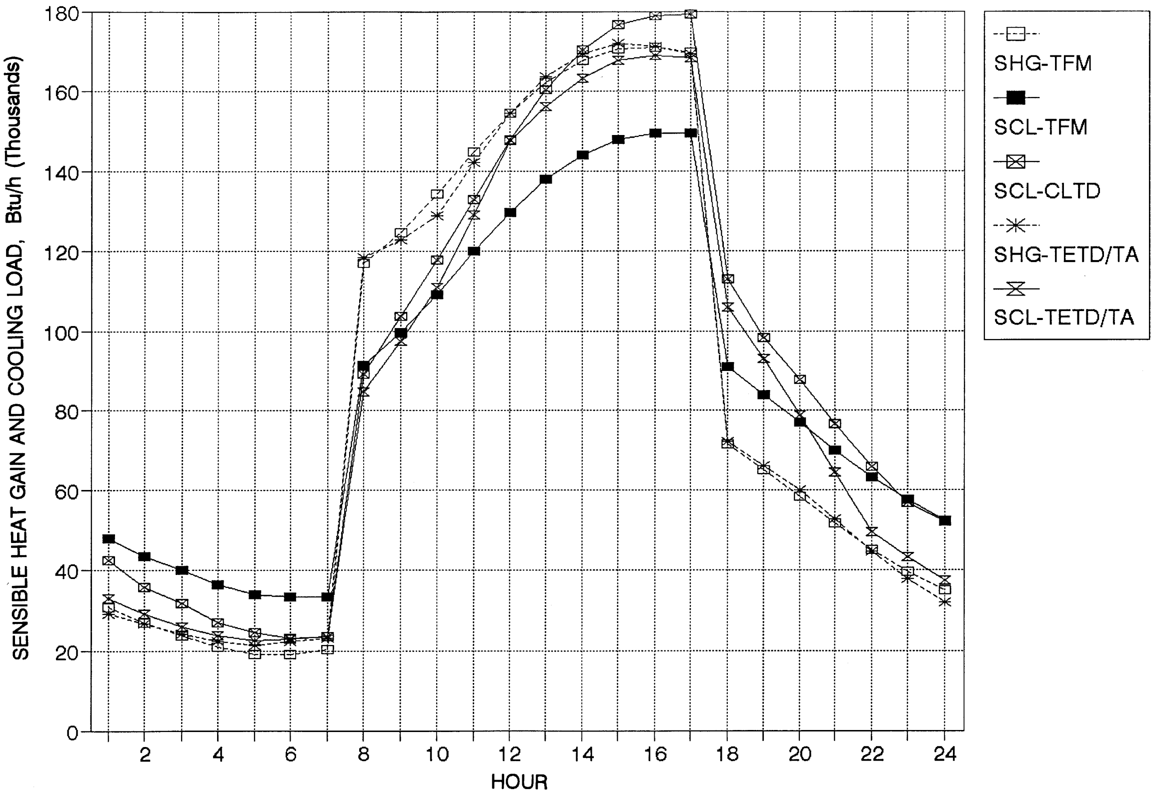


Fig. 5 TFM versus CLTD/SCF/CLF Versus TETD/TA Methods of Calculating Sensible Heat Gain and Cooling Load

cooling load curve peaks at only 87.5% of its heat gain curve. All unoccupied hours show substantially greater TFM cooling loads than for TETD/TA, while 24-h totals vary only by 0.15%.

As a manual procedure, Example 11, illustrating the use of CLTD/SCL/CLF, was carried through for hour 1600 only, in the manner that it would primarily be applied by users. For comparison purposes, it was also calculated for each of the daily 24 h and that cooling load profile plotted on Figure 5. There is no comparable heat gain profile, as this method does not produce such values directly. The curve peaks at 1700 hours, one hour later than the others, but with a total value 19.8% greater than TFM. The profile is somewhat different from and between those for TFM and TETD/TA during unoccupied hours.

Note: The small building used in these examples is more massive than typical for a similar function in post-1990 construction, and it would probably not meet ASHRAE *Standard* 90.1-1989 energy requirements. Calculating the entire building as a single simultaneous load could certainly be questioned, particularly in any larger configuration; thus, it is used here purely to illustrate the techniques discussed.

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