ASHRAE®
Learning Institute

Your Source for HVAC&R Professional Development

Fundamentals of Heating and Cooling Loads (I-P Edition)

A Fundamentals of HVAC&R Series
Self-Directed Learning Course

ASHRAE®

1791 Tullie Circle NE • Atlanta, GA 30329 • www.ashrae.org

ASHRAE® Learning Institute

1791 Tullie Circle, NE • Atlanta, GA 30329-2305 • Phone: 678.539.1146 • Fax 678.539.2146 • www.ashrae.org

Karen M. Murray kmurray@ashrae.org

Manager of Professional Development

Dear Student,

Welcome to this ASHRAE Learning Institute (ALI) self-directed or group learning course. We look forward to working with you to help you achieve maximum results from this course.

You may take this course on a self-testing basis (no continuing education credits awarded) or on an ALI-monitored basis with credits (PDHs, CEUs or LUs) awarded. ALI staff will provide support and you will have access to technical experts who can answer inquiries about the course material. For questions or technical assistance, contact us at 404-636-8400 or edu@ashrae.org.

Skill Development Exercises at the end of each chapter will gauge your comprehension of the course material. If you take this course for credit, please complete the exercises and send copies from each chapter to edu@ashrae.org (preferred method) or ASHRAE Learning Institute, 1791 Tullie Circle, Atlanta, GA 30329-2305. Be sure to include your student ID number with each set of exercises. Your student ID can be the last five digits of your Social Security number or other unique five-digit number you create. We will return answer sheets to the Skill Development Exercises and maintain records of your progress. Please keep copies of your completed exercises for your records.

When you finish all exercises, please submit the course evaluation, which is located at the back of your course book. Once we receive all chapter exercises and the evaluation, we will send you a Certificate of Completion indicating 35 PDHs/LUs or 3.5 CEUs of continuing education credit. The ALI does not award partial credit for self-directed or group learning courses. All exercises must be completed to receive full continuing education credit. You will have two years from the date of purchase to complete each course.

We hope your educational experience is satisfying and successful.

Sincerely,

KMurray

Karen M. Murray
Manager of Professional Development

ASHRAE Learning Institute

Fundamentals of Heating and Cooling Loads

(I-P Edition)

Prepared by

David B. Meredith, P.E.

The Pennsylvania State University

ASHRAE

1791 Tullie Circle NE • Atlanta, GA 30329

ASHRAE Fundamentals of HVAC&R Series

Print

Fundamentals of...

- Psychrometrics
- Air System Design
- Steam System Design
- Heating and Cooling Loads
- Heating Systems
- Thermodynamics
- Water System Design
- Refrigeration

eLearning

Fundamentals of...

- HVAC Control Systems
- HVAC Systems
- Refrigeration
- Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality
- Standard 90.1-2004, Energy Efficiency in New Buildings

Fundamentals of Heating and Cooling Loads I-P
A Course Book for Self-Directed or Group Learning
ISBN 978-1-931862-30-1

ASHRAE Learning Institute

ASHRAE STAFF

ASHRAE Learning Institute

Joyce Abrams
Group Manager of Education and Certification
Karen Murray
Manager of Professional Development
Martin Kraft
Managing Editor
Vickie Warren
Secretary/ Administrative Assistant

Special Publications

Mark Owen
Editor/Group Manager of Handbook and Special Publications
Cindy Sheffield Michaels
Managing Editor
Matt Walker
Associate Editor
Elisabeth Warrick
Assistant Editor
Meaghan O'Neil
Editorial Assistant
Michshell Phillips
Editorial Coordinator

For course information or to order additional materials, please contact:

ASHRAE Learning Institute
1791 Tullie Circle, NE
Atlanta, GA 30329

Telephone: 404/636-8400
Fax: 404/321-5478
Web: www.ashrae.org/ali
E-mail: edu@ashrae.org

Any errors or omissions in the data should be brought to the attention of Special Publications via e-mail at **SDLcorrections@ashrae.org**.

Any updates/errata to this publication will be posted on the ASHRAE Web site at www.ashrae.org/publicationupdates.
Errata noted in the listed dated 2/14/12 have been corrected.

Table of Contents

Appendices

Chapter 1
Heat Transfer and Load Calculation

Contents of Chapter 1

Instructions

Read the material in Chapter 1. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 1

Chapter 1 is an introductory chapter reviewing the fundamentals of heat transfer as it applies to buildings. There are three basic processes through which thermal energy is transferred within buildings: conduction, convection and radiation (see *Figure 1-1*). In this chapter, we will review these processes, and discuss where they must be considered in the calculation of the building thermal loads. The basic equations used to calculate each of these terms will be presented. We will also briefly discuss thermal capacitance and the difference between sensible and latent energy. After studying Chapter 1, you should be able to:

- Give an example of each type of heat transfer.
- Given a thickness and conductivity value, determine the coefficient of heat transfer from $U = k/L$.
- Convert a given R-value to a U factor using $U = 1/R$.
- Explain the difference between heat capacitance and heat transmission.
- Explain the difference between sensible and latent energy.

1.1 Conduction

Conductive heat transfer is associated with heat transfer through solid materials. If one end of a material is in contact with a hot surface, the vibrating molecules (represented by a high temperature) will transfer their energy through the material to the cooler end. A classic example of conduction is when you burn your lips on a hot coffee cup. The high temperature of the coffee is quickly transported through the cup material to your mouth.

In buildings, conduction occurs easily through building materials such as metal, glass and concrete. Poor conducting materials are usually used as insulating materials. Examples include fiberglass, insulating foams and mineral wool. Some materials such as wood fall between these two extremes. The ability of a material to conduct heat is measured by a property called thermal conductivity, k, which has units of (Btu·in/h·ft²·°F). Dividing this value by the thickness of material, L, measured in inches, yields another very important term called the coefficient of heat transfer, or U-factor: $U = k / L$, in units of (Btu/h·ft²·°F).

The reciprocal of this value is called the thermal resistance, $R = 1 / U$, in units of (h·ft²·°F/Btu). This term is frequently encountered in the industry as a rating value for insulating materials. Two important characteristics of R-values are that the R-value increases directly proportionally with the thickness, L, of the material, and that R-values for different materials in a structural cross-section can be added directly.

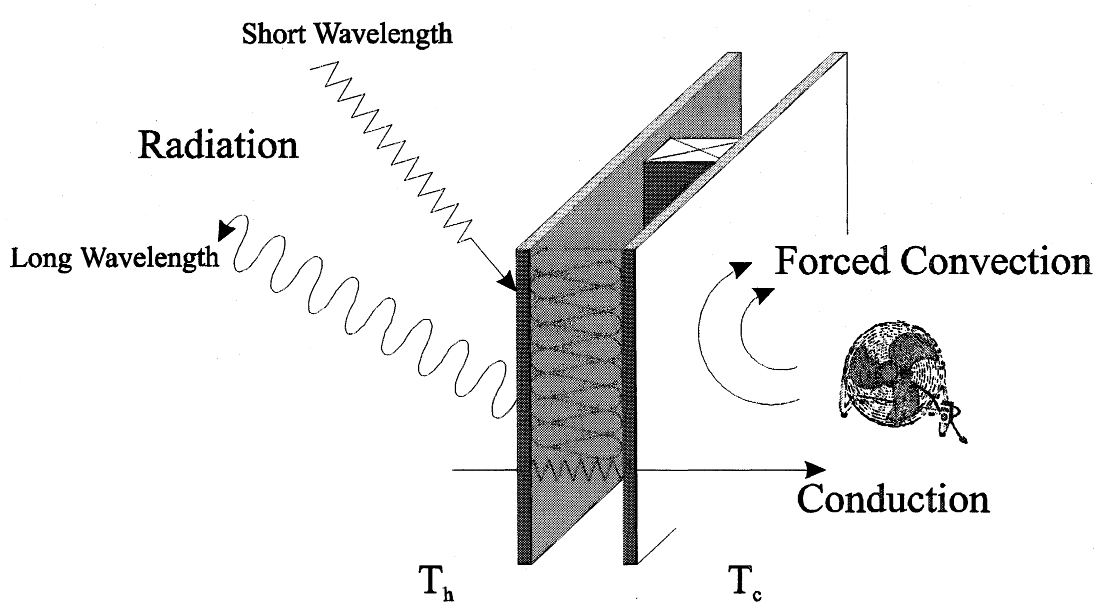


Figure 1-1. Heat Transfer Processes

The normal sequence to solving a conduction problem would be to look up the R-values for the materials in a building cross-section, add those values, and then take the reciprocal of that answer to get the U-factor. Now you are ready to calculate the rate of conductive heat transfer.

The basic equation for calculating conductive heat transfer is given by:

$$Q = UA(T_h - T_c) \tag{1-1}$$

where,

Q = rate of conductive heat transfer, Btu/h

U = coefficient of heat transfer (material property), Btu/h·ft²·°F

A = area of heat transfer perpendicular to the direction of heat flow, ft²

T_h = temperature at the hot side of the material, °F

T_c = temperature at the cold side of the material, °F

Note that the temperature difference (T_h-T_c) is often written in equations as (ΔT). Both terms will be used interchangeably throughout this course because both indicate the same meaning. Standard convention also dictates that thermal energy always flows from high temperature to low temperature. Thus, when a hot cup of coffee cools on the counter, it is experiencing a negative heat gain. This is also referred to as a heat loss. Buildings normally experience a heat gain in summer when it is warmer outside, and a heat loss in winter when it is warmer inside.

Example 1-1

Problem: A material rated at R-11 is added to a wall rated at R-3. The wall dimensions are 8 ft high by 20 ft wide. The inside and outside surface temperatures are 70°F and 5°F, respectively. Find the rate of heat transfer through the wall.

Solution: First determine the total R-value by adding the two given values: R_{total} = 11+3 = 14. Next find the U-factor by taking the reciprocal: $U = 1/R = 1/14 = 0.071$. Finally, substitute the values into the conduction heat transfer equation:

$$\begin{aligned} Q &= UA(T_h - T_c) \\ &= \left(0.071\ \text{Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F}\right)\left(8 \times 20\ \text{ft}^2\right)\left([70-5]^\circ\text{F}\right) \\ &= 738\ \text{Btu/h} \end{aligned}$$

1.2 Convection

Convective heat transfer occurs when fluids at different temperatures move around within the space. A baseboard convection heater is a good example of convective heat transfer. The air is heated by direct contact with the hot surface within the heater. The buoyancy of the air then lifts the heated air upwards, creating enough negative pressure to draw cooler air into the bottom of the heater.

There are two types of convective heat transfer processes: free and forced. Free or natural convection uses only the natural buoyancy of the fluid to drive the convective flow (hot air rises). In the wintertime, cold air cascades down windows, creating unpleasant drafts. In a good design, these drafts are countered by rising currents of heated air from a register or radiator located below the window.

Forced convection depends on a pump or fan to force the flow of heated fluid. A ceiling fan in winter is one example of forced ventilation; the natural thermal stratification of hot air rising to the ceiling is counteracted by the fan pushing the warmer air back down to the living zone. Wind is another example of forced convection. While it is a natural phenomenon, the thermal energy flows that wind creates as it passes over a structure are far greater than those caused by free convection into still air. This difference is what makes wind breaks and screens so valuable.

Calculating convective heat transfer is more complicated than for conduction, so usually the problems are restructured to look like a conduction problem. The key to this transformation is a term called the convective heat transfer coefficient, h_c, which replaces the U term in the conduction equation:

$$Q = h_c A(T_h - T_c) \tag{1-2}$$

In most cases, the value of h_c will be presented in a table, although it can be calculated. The convective heat transfer coefficient is determined from the Nusselt number ($\mathrm{Nu} = h_c \cdot x / k$) which can also be expressed as a function of both the Prandtl number ($\mathrm{Pr} = \mu \cdot c_p / k$) and either the Reynolds number ($\mathrm{Re} = VD\rho / \mu$) for forced convection or the Grashof number ($\mathrm{Gr} = L^3 \cdot \rho^2 \cdot \beta \cdot g \cdot \Delta T / \mu^2$) for free convection.

If you have taken a heat transfer course, these relationships should look familiar to you. If you would like more information on how to calculate convective heat transfer coefficients, refer to Chapter 3 of the *ASHRAE Handbook–Fundamentals* for more details.[1] If these equations look foreign to you, do not worry. For the purposes of this course, any needed convective heat transfer coefficients will be given in the text or in a table.

1.3 Radiation

Radiant heat transfer occurs through electromagnetic waves. This spectrum ranges continuously from very short wavelengths for x-rays and ultraviolet rays, through the visible and infrared portion to the very long wavelengths used for radio and television communications. Only the visible portion and the near-infrared wavelengths are of primary interest in HVAC work. The visible portion is represented by the sunlight streaming through the window, and near-infrared radiation is exchanged among all objects around us.

All objects give off electromagnetic waves based on their temperature. The hotter the object, the shorter the wavelength, and the greater the intensity of radiation, as shown in *Figure 1-2*. For example, the sun is at 10,000°R and radiates visible light at wavelengths from about 0.4 to about 0.7 μm (microns). When you open the door on a hot oven (about 400°F or 860°R), the typical wavelength is about 6 microns. The wavelengths from objects near room temperature are between 9 and 10 microns.

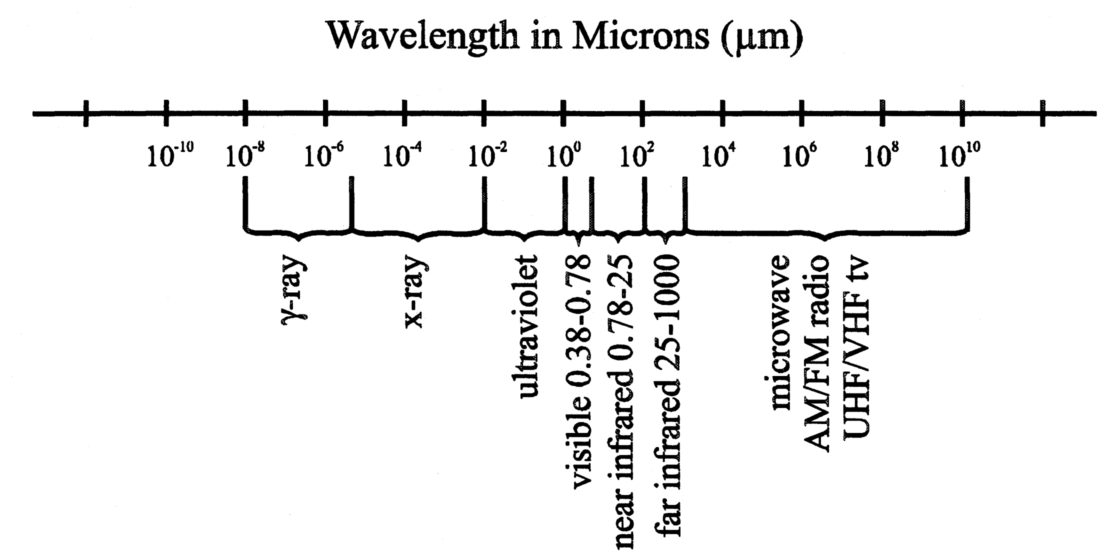


Figure 1-2. Electromagnetic Spectrum

The characteristic wavelength is determined by Wein's Displacement Law, which is given by:

$$\lambda = 5216 / T \tag{1-3}$$

where T is the absolute temperature measured in degrees Rankine (°R = °F + 460°).

The intensity of radiation is determined by using Planck's Law:

$$I = \sigma \cdot T^4 \tag{1-4}$$

where,

I = intensity, Btu/h·ft²

σ = Stefan-Boltzmann Constant = 0.1714×10^{-8}, Btu/h·ft²·°R⁴

T = surface temperature, °R

Note that this equation is for a black body, which is defined as an ideal emitter/absorber. When real surfaces are assumed, the equations become more complex, because they must include the surface properties as a function of the wavelength and also the view angle between the two surfaces.

How materials react to different wavelengths is given by the absorptivity, α. This quantity is equal to the emissivity, ε, of the material at the same temperature. Both of these values range between zero and one. Some references provide this data in table form, while others present it graphically. In either case, the two regions of greatest interest are the visible portion (wavelengths of around 0.5 μm) and the infrared portion (usually around 10 μm for surfaces under 100°F).

The first value determines how the surface will react to sunlight. Dark surfaces (α near 0.9) will absorb most solar radiation, while lighter or shinier surfaces (α near 0.1) tend to reflect the sun's rays. The color of the roof surface and the other outside surfaces of a structure can have a significant impact on how much solar energy is absorbed. Accounting for this gain and modeling the intensity and timing of its effect on the building cooling load are very complicated.

In the infrared range, surfaces with high absorptivity will permit more radiant heat transfer than surfaces with low absorptivity. Remember that the value of absorptivity at any given wavelength is equal to its emissivity at that same wavelength. This property can be used to our advantage in low-e glass. By not allowing thermal radiation to emit from the glass, the rate of heat transfer through the glass due to radiation is decreased.

The effect of view angle between the energy source and receiver is shown in *Figure 1-3*. As the angle between the hot surface and cold surface decreases, more of the available energy is transferred between the two plates. The maximum radiant heat transfer occurs when the two plates are parallel. This geometry frequently occurs in buildings (double-pane glazings, hollow core walls, suspended ceilings and roofs, etc.). Neglecting edge effects, the view factor, $F_{1\text{-}2}$, is given by:

$$F_{1-2} = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \tag{1-5}$$

where,

$F_{1\text{-}2}$ = view factor between surfaces 1 and 2

ε_1 = emissivity of surface 1 at temperature 1

ε_2 = emissivity of surface 2 at temperature 2

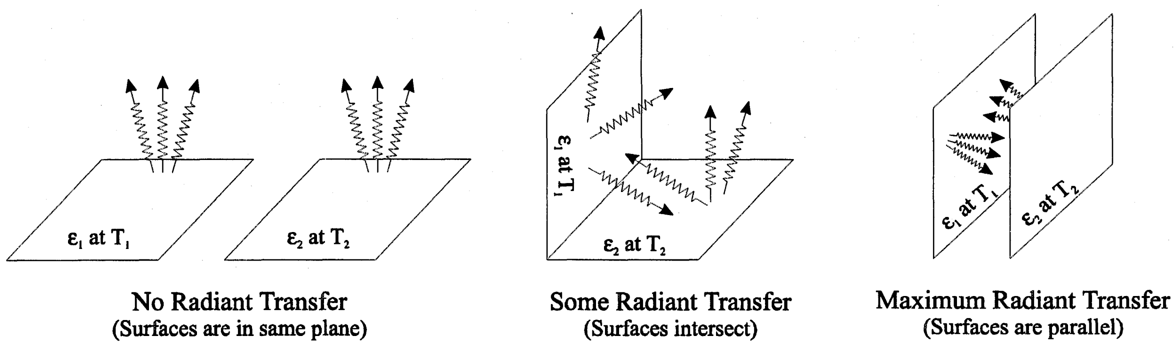


Figure 1-3. View Angle Effects on Radiant Heat Transfer

1.4 Thermal Capacitance, Sensible and Latent Heat Transfer

Three terms that will be used throughout this course are thermal capacitance, sensible energy transfer and latent energy transfer. This section will provide you with some background on each one.

So far, the heat transfer equations have been written assuming steady-state conditions (when both temperatures are constant). Steady-state conditions are usually used for determining the R-value of insulation, the U-factors for doors and windows, and the peak design loads for equipment sizing. However, it is occasionally necessary to consider variable temperature conditions. For example, when a night setback thermostat is used, it is necessary each morning to raise the space temperature back up to the daytime setting. How fast this temperature comes up depends on a concept called thermal capacitance.

Thermal capacitance is the ability of objects to store thermal energy. For example, if a candle is placed under a beaker full of water, it will take a long time (and a lot of energy from the candle) to raise the temperature of the beaker and the water in it. If the beaker is empty (full of air), it would not take nearly as long to see an increase in temperature of the beaker. In fact, most of the energy would be absorbed by the beaker material itself. This is because solids have a higher heat capacitance than gases.

Heat capacitance is the product of two material properties: density (ρ, measured in lb_m/ft^3) and specific heat (C_p, measured in $Btu/lb_m{\cdot}°F$). Water has a specific heat of 1.0 $Btu/lb_m{\cdot}°F$, and air has a specific heat of about 0.241 $Btu/lb_m{\cdot}°F$. Most common building materials have a specific heat in the range of 0.2-0.3 $Btu/lb_m{\cdot}°F$. The value that varies significantly is density. Insulating materials can be as light as 0.5 lb_m/ft^3, while brick and concrete products can exceed 150 lb_m/ft^3. Materials for wood frame buildings are typically around 25 to 50 lb_m/ft^3. Specific values for materials will be presented in Chapter 4.

The basic equation used to calculate thermal capacitance is:

$$Q = m \cdot C_p \cdot \Delta T \qquad (1\text{-}6)$$

where,

Q = heat transfer, Btu

m = mass of the material, lb_m

C_p = specific heat, $Btu/lb_m{\cdot}°F$

ΔT = temperature change in the material as a result of the heat transfer, °F

EXAMPLE 1-2

Problem: Calculate the energy required to raise a 3-in.-thick concrete floor slab from 60°F to 70°F in a 15×20 ft room. Density is 120 lb_m/ft^3 and specific heat is 0.2 $Btu/lb_m \cdot °F$.

Solution: To get the mass of concrete, first calculate the volume, then multiply by the density:

$$
\begin{aligned}
Q &= m \cdot C_p \cdot \Delta T \\
&= (V \cdot \rho) \cdot C_p \cdot \Delta T \\
&= (3/12\ \text{ft})(15 \cdot 20\ \text{ft}^2) \cdot (120\ \text{lb}_m/\text{ft}^3)(0.2\ \text{Btu/lb}_m \cdot °\text{F})(70 - 60°\text{F}) \\
&= 18{,}000\ \text{Btu}
\end{aligned}
$$

The key concept to understand at this point is that two structures of identical size but different materials (such as wood frame and concrete block) can react quite differently to temperature variations. The lighter frame building will warm up much faster than the heavy block building and will require the addition of less energy input in the process. However, the massive structure will remain warmer longer after the furnace shuts off. The same effects are true during the cooling season. In fact, we will find out that this storage effect is even more evident in the calculation of the cooling loads.

Sensible heat refers to energy stored in the form of a temperature change of the material. Two very useful equations for sensible-only energy changes in water and air flows are:

$Q = 500 \cdot \text{gpm} \cdot \Delta T$ for water flow rates measured in gpm

$Q = 1.10 \cdot \text{cfm} \cdot \Delta T$ for air flow rates measured in cfm (heating only)

In both equations, the coefficient includes all the required unit conversions and physical properties to convert from the volumetric flow rate to the heat transfer rate in (Btu/h). For example, the value 500 is equal to the average water density (8.3 lb/gal) times the specific heat of water (1.0 Btu/lb·°F) times 60 minutes per hour. The value 1.10 for air is equal to the average air density (0.075 lb/ft^3) times the average specific heat (0.242 Btu/lb·°F) times 60 (minutes per hour). Note that these equations are most accurate only near room temperature and should be used with caution at all other conditions.

Latent heat is energy stored in the form of a change of phase of matter. Most latent energy changes encountered in HVAC load calculations are related to changes in the moisture level of the air. The latent heat of vaporization is a function of temperature as shown in Table 6.3 of the 1997 *ASHRAE Handbook–Fundamentals*.[2] But a reasonable value to remember is that it takes approximately 1,050 Btu to boil 1 pound of water at 74°F.

The Next Step

The next chapter will present the basic steps required to calculate the rate of heat loss from a simple structure. The succeeding chapters will then examine each step of the basic process in more detail. We will start with the heating load calculation because it has fewer variables to consider than cooling load calculations. But once you have mastered the heating load calculation method, you will be ready to learn how to make cooling load calculations.

Summary

This chapter has introduced the basic concepts of heat transfer, the three methods of heat transfer (conduction, convection and radiation) and some fundamental equations. In addition, the concept of thermal capacitance and its relationship to heat transfer have been explained. Finally, the concepts of sensible and latent heat transfer have been introduced.

After studying Chapter 1, you should be able to:

- Give an example of each of the three types of heat transfer.
- Given a thickness and conductivity value, determine the coefficient of heat transfer from ($U = k / L$).
- Convert a given R-value to a U-factor ($U = 1 / R$).
- Explain the difference between heat capacitance and heat transmission.
- Explain the difference between sensible and latent energy.

Bibliography

1. ASHRAE. 1997. "Heat transfer." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 3.

2. ASHRAE. 1997. "Psychrometrics." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 6.

Skill Development Exercises for Chapter 1

Complete these questions by writing your answers on the worksheets at the back of this book.

1-01. Explain the type of heat transfer in each of the following situations: a gas water heater; the wall of an oven; a whistling teakettle; a light bulb; a hair dryer; a sealed thermos bottle; and an electric baseboard heater.

1-02. If fiberglass insulation has a thermal conductivity of 0.33 (Btu·in/h·ft^2·°F), find the R-value of a 5.5-in.-thick batt.

1-03. A building has a roof with continuous rigid insulation rated at R-26. Neglecting air films and the roof structure, what is the approximate U-factor of this roof?

1-04. A water heater measures 24 in. in diameter and 48 in. high. The outside wall is covered with fiberglass insulation rated at R-3. The shell of the water heater is 130°F and the outside is 75°F. Find the rate of heat loss through the wall of the unit.

1-05. Some people argue that night setback thermostats are worthless, because the furnace has to run so long in the morning to make up the difference in temperature for the space. With your knowledge of heat capacitance and heat conduction as a function of temperature, how would you answer that argument?

Chapter 2
Simple Heat Loss Calculation Procedure

Contents of Chapter 2

Instructions

Read the material in Chapter 2. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 2

To clearly understand all of the variables that affect the flows of energy in a large, complex building, it is important to first understand the basic processes that are involved. In this chapter, we will discuss the heat loss from a simple two-room frame building. All of the design parameters will be given.

In the subsequent chapters, you will learn how to determine these values for different designs and for more complex structures. The main objective for now is to learn what to do with those values once they are determined. We will start with a heating system, because it is the simplest model. Heat gains from the sun and from internal sources within the building are neglected when doing heating load calculations, because as designers we cannot depend on those sources being available on the cold winter nights when we need them most. Because people, water heaters and appliances such as refrigerators will typically be adding heat on these cold nights, keep in mind that our calculated heating loads will be conservative and will slightly overestimate the actual heating loss.

After studying Chapter 2, you should be able to:

- Name the various building surfaces and heat sources that must be considered in building cooling load calculation.
- Define each term in the basic conduction heat transfer equation, tell where to get each value, and the standard units used for that value.
- Discuss basic rules-of-thumb that can be used in thermal load calculations.
- Calculate the rate of heat loss from a simple frame structure.
- List several useful comments that apply to the development of good technique in calculating loads for larger structures.
- Determine the time required for morning warm-up of a building with night setback.

2.1 The Basic Process

Your job will be to calculate the rate of heat loss from this building under given conditions. We will calculate the heat loss from the front room as the example of the process. You will have an opportunity to repeat the process on the back room as a Skill Development Exercise at the end of this chapter.

Actually, this division of labor represents the first step of the calculation process. It is necessary to zone the building into smaller sections that will be separately heated. This action is needed to ensure that thermal energy is supplied at a rate that matches the rate of thermal loss. Otherwise, some areas become too warm and other areas become too cold. Individual rooms are frequently modeled as separate zones, which is the division that will be assumed here.

In each zone, each uniform surface is considered in turn to determine its rate of heat loss. Because rooms normally have four walls, a floor and a ceiling, these become our basic building blocks for calculating the heat loss. Windows and doors lose heat at much different rates than insulated walls, so these components will also be examined separately in our analysis. Finally, the leakage of cold outside air into the building must be considered because it usually represents a significant fraction of the overall heat loss rate.

The most convenient method to present all of these numbers is in a table, as shown in *Table 2.1*. The first column lists each of the separate surfaces of the structure through which heat transfer occurs. Note that each time the materials of construction change, another line is required in this calculation process. The second column presents the dimensional data for each surface. Notice that the area of doors and windows is subtracted from the appropriate wall areas. The third column is the net surface area, or gross wall area minus any doors or windows. In the last line, the building volume is given in the third column. The volume of the building is used to calculate the rate of infiltration, as we shall discuss later. The U column is the heat transfer coefficient ($U = 1 / R_{total}$), which is based on the materials of construction. Finally, the difference between the inside and outside temperatures is shown in column five.

Columns three, four and five are multiplied together to determine the rate of heat transfer from each section: $Q_{surface} = U \cdot A \cdot \Delta T$. The total heat transfer from the zone is found by simply adding up the values in this last column: $Q_{total} = \Sigma\, Q_{surface} = Q_{north} + Q_{east} + Q_{west} + \ldots$

Table 2-1. Front Room Heat Loss

Section	Area or Volume	Net Area	U=1/R	T_{in} - T_{out}	Q = UA (T_{in} - T_{out})
North	20x8-2x4	152	0.06	57	520
East	15x8-2x4	112	0.06	57	383
West	15x8	120	0	0	0
South	20x8-(28x80/144)	144	0.06	57	492
Ceiling	15x20	300	0.04	57	684
Window	2x4+2x4	16	0.5	57	456
Door	76x30/144	16	0.5	57	456
Floor	15x20	300	0.1	20	600
Infiltration	15x20 x8x0.5	1200	0.018	57	1231
			Total Heat Loss		4823 Btu/h

2.2 *Example Building*

The small 15 ft × 30 ft cabin shown in *Figure 2-1* has two rooms, a 15 ft × 20 ft front room, and a 15 ft × 10 ft back sleeping room. There is one front door on the south wall; it measures 76 in. × 30 in., and is made from 2-in.-thick solid wood. There are five small (24 × 48 in.) double-pane windows, one on each wall of each room, except on the south wall where the door is located. The walls and 8-ft-high ceiling are insulated to R-19 and R-30, respectively.

As we will discuss in Chapter 5, the presence of the structural members creates thermal bridging or short-circuits around the insulation, and reduces the effective R-values for the walls and ceiling to 16 h·ft²·°F/Btu and 28 h·ft²·°F/Btu, respectively. The floor is slab-on-grade. The inside temperature is to be maintained at 65°F when the outside temperature is 8°F, and a 15 mph wind is blowing.

As summarized in *Table 2-1*, each wall area (north, east, south) is calculated as width times height less any doors or windows. The U-factor is the reciprocal of the given R-value; for example, U_{wall} = $1/R = 1/16 = 0.06$ Btu/h·ft²·°F). The temperature across the walls is given as 65° - 8° = 57°F.

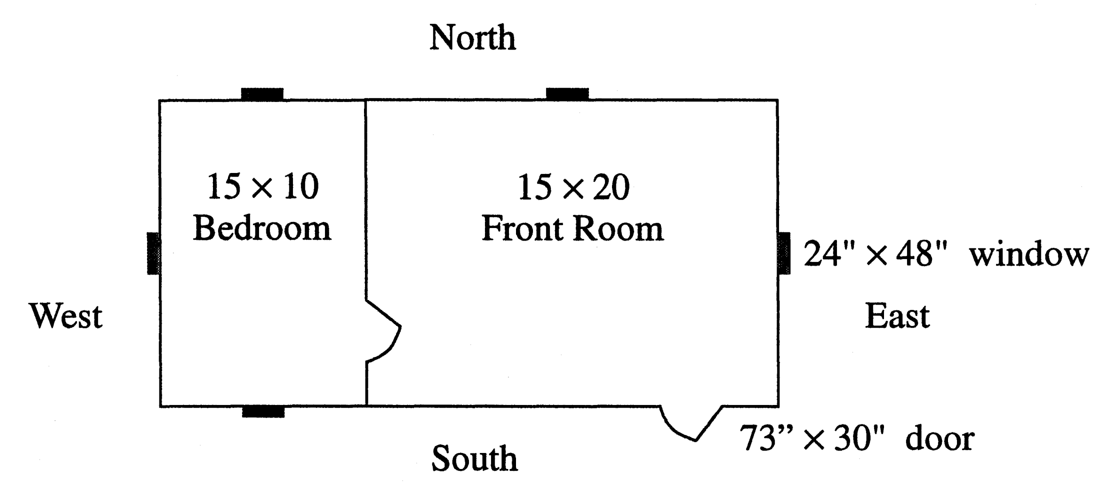


Figure 2-1. Example Building

There is no heat loss through the west wall because it is at the same temperature as the adjacent sleeping room, and therefore loses no heat to that room.

The ceiling U-factor is given by the reciprocal of the given effective R-28 ($U = 1/28 = 0.04$), and the temperature difference is again 57°F.

The total net window area is 16 ft^2. The R-value for windows varies widely (as we will discuss in Chapter 9), depending on parameters like the number and spacing of the panes, the frame type, and special treatments such as low-e coatings and gas fills. To avoid getting lost in those details, here we will assume that the window R-value is approximately equal to the number of panes. So these double pane windows would have a U-factor of about 1/2 or 0.5. Again the temperature difference between the inside and outside surfaces is 57°F.

The door has a net area of 16 ft^2. Wood provides an approximate R-value equal to its thickness in inches, so this 2-in.-thick door would have an R-value of 2 and a U-factor of 1/2 or 0.5, with the temperature difference again being 57°F. *Table 2-2* gives U-factors for a wide range of other door combination possibilities that are commercially available, including both wood and metal construction and installation with or without storm doors.[1]

The floor area is easy to calculate, but what is the insulating value through the floor? And what is a reasonable temperature? Both questions are difficult to answer accurately, so to keep this example simple, we will make some reasonable assumptions. Typically, the R-value for moist soil is about 10 Btu/h·ft^2·°F, and the temperature of the soil averages about 45°F in the wintertime. So we will use values of 1/10 or 0.1, and (65° - 45°) or 20°F in the table for this line.

Table 2-2. Transmission Coefficients (U) for Wood and Steel Doors (Btu/h·ft^2·°F)

Nominal Door Thickness, in.	Description	No Storm Door	Wood Storm Door[c]	Metal Storm Door[d]
Wood Doors[a,b]				
1-3/8	Panel door with 7/16-in. panels[e]	0.57	0.33	0.37
1-3/8	Hollow core flush door	0.47	0.30	0.32
1-3/8	Solid core flush door	0.39	0.26	0.28
1-3/4	Panel door with 7/16-in. panels[e]	0.54	0.32	0.36
1-3/4	Hollow core flush door	0.46	0.29	0.32
1-3/4	Panel door with 1-1/8-in. panels[e]	0.39	0.26	0.28
1-3/4	Solid core flush door	0.40	—	0.26
2-1/4	Solid core flush door	0.27	0.20	0.21
Steel Doors[b]				
1-3/4	Fiberglass or mineral wool core with steel stiffeners, no thermal break[f]	0.60	—	—
1-3/4	Paper honeycomb core without thermal break[f]	0.56	—	—
1-3/4	Solid urethane foam core without thermal break[a]	0.40	—	—
1-3/4	Solid fire rated mineral fiberboard core without thermal break[f]	0.38	—	—
1-3/4	Polystyrene core without thermal break (18 gage commercial steel)[f]	0.35	—	—
1-3/4	Polyurethane core without thermal break (18 gage commercial steel)[f]	0.29	—	—
1-3/4	Polyurethane core without thermal break (24 gage residential steel)[f]	0.29	—	—
1-3/4	Polyurethane core with thermal break and wood perimeter (24 gage residential steel)[f]	0.20	—	—
1-3/4	Solid urethane foam core with thermal break[a]	0.20	—	0.16

Note: All U-factors for exterior doors in this table are for doors with no glazing, except for the storm doors which are in addition to the main exterior door. Any glazing area in exterior doors should be included with the appropriate glass type and analyzed as a window (see Chapter 29). Interpolation and moderate extrapolation are permitted for door thicknesses other than those specified.

[a]Values are based on a nominal 32 in. by 80 in. door size with no glazing.

[b]Outside air conditions: 15 mph wind speed, 0°F air temperature; inside air conditions: natural convection, 70°F air temperature.

[c]Values for wood storm door are for approximately 50% glass area.

[d]Values for metal storm door are for any percent glass area.

[e]55% panel area.

[f]ASTM C 236 hotbox data on a nominal 3 ft by 7 ft door size with no glazing.

The final line of our table represents the infiltration into the structure. Cold outside air is continuously leaking into the house through holes and cracks in the building envelope. This cold air must be heated from its outside temperature to the control temperature within the structure. Estimating the rate of air flow is difficult, because it depends on the quality of construction, the age of the structure, and the direction and strength of the wind. Typical values range from 0.5 for new construction to 1.0 air changes per hour for leaky, older buildings.

We will make the reasonable assumption that the average infiltration is about 0.5 air changes per hour to avoid getting lost in calculation details that will be explained in Chapter 6. Because the volume of the front room is 15 × 20 × 8 ft, or 2,400 ft^3, this calculation indicates that 1,200 ft^3 per hour of outside air must be heated by the furnace. The value of 0.018 shown in the U column represents the product of the air density (0.075 lb/ft^{3}) times the air specific heat (0.24 BTU/15 °F), which yields the energy content in each cubic foot of air per °F temperature difference (Btu/ft^3·°F). When multiplied by the volumetric flow rate of air (ft^3/h) and the temperature difference (°F), this calculation results in a value for the heat loss rate, Q, with the familiar units of (Btu/h).

2.3 *Useful Comments*

Some useful comments are needed to help you develop good technique in calculating loads for larger structures.

Accuracy. Notice that the energy rate values in the last column of *Table 2-1* are all rounded to the nearest Btu. Remember that one Btu is the energy released by burning a single wooden kitchen match. It is not possible to measure values that accurately in the field. So always use your best estimates when determining values to enter into this heat loss table.

Safety factors. It is common practice to install equipment that is somewhat larger than the minimum calculated need. Because commercially available equipment comes in discrete sizes, installing a 5,500 Btu/h unit to meet our calculated 4,800 Btu/h load provides a reasonable 10% safety factor. However, do not overdo it. If safety factors are built into each step of the process, the final design could be oversized too much.

Morning warm-up. If a night setback thermostat is anticipated, it will be necessary to install sufficient heating capacity beyond the calculated load to warm the building back up to the daytime setting in a reasonable length of time. Suppose our space contains an estimated 2,000 pounds of furniture, appliances and interior construction material. If we assume an average specific heat of 0.3 Btu/lb·°F for these materials, then the energy input rate required to raise the space temperature by 10°F in one hour is:

$$
\begin{aligned}
Q &= m \cdot C_p \cdot \Delta T \\
&= (2{,}000 \text{ lb})(0.3 \text{ Btu/lb}\cdot{}^\circ\text{F})(10^\circ \text{F}) \\
&= 6{,}000 \text{ Btu/h}
\end{aligned}
$$

Note that this value is larger than the heating load itself. If we only have the 5500 - 4800 = 700 Btu/h safety factor above to work with, the temperature will increase only about:

$$
\begin{aligned}
\Delta T &= Q / m \cdot C_p \\
&= (700 \text{ Btu/h}) / (2{,}000 \text{ lb})(0.3 \text{ Btu/lb}\cdot{}^\circ\text{F}) \\
&= 1.2^\circ \text{F per hour}
\end{aligned}
$$

To raise the temperature of the space 7°F would take about six hours at design conditions. While this is obviously unacceptable, remember that the space temperature would increase faster under milder weather conditions.

Dimensions. The net inside dimensions usually represent the thermal conditions more accurately. As long as all areas of thermal loss are accounted for somewhere in the calculation, measurements to a fraction of an inch are usually not required.

Zoning. Larger structures will always be divided into several zones for better control. When doing the load calculations, it is important to ensure that the exterior surface areas and construction materials match those in the zone under consideration for maximum accuracy.

Experience. One trait of a good design engineer is to have a feeling about whether a calculated answer seems reasonable. This experience factor develops over an extended period of time, but now would be a great time to start. This room was about the size of a typical living room, and lost about 5,000 Btu/h. So a five-room house might be expected to lose about 25,000 Btu/h. On a per square foot basis, the heat rate would be 4800/300=16 Btu/h·ft^2. This is within the typical range of 10 to 30 Btu/h·ft^2. Larger buildings tend to be located on the lower end of the range, because their floor area increases faster than their wall area.

In residential work, it might also be useful to summarize the percentage of loss from each line of our table. It is not unusual to find that about one-third of the residential heating bill is caused by infiltration; another one-third is lost through windows and doors, with the remainder escaping through the walls, ceiling and floor. This exercise can often help point to the most fruitful areas for further energy conservation analysis.

Operation. The best estimate of a building's thermal load can be destroyed by poor operator skills. In one study of identical families in identical homes, the energy usage varied 30% due to different lifestyles alone. If the operator of a commercial building decides that lots of outside air will minimize complaints about indoor air quality, a design assumption of 15% outside air is shot down the tubes (and so is your budget).

Computerization. For most space heat loss calculations, the equations lend themselves easily to a spreadsheet application. Each area of uniform cross-section is represented by one line of the table. Each line is represented by the terms of the equation $Q = U{\cdot}A{\cdot}\Delta T$. This design tool is especially useful when you consider how many times these values can change during the design process. There are also several commercial software programs available that perform heat loss and heat gain calculations. However, as with any software investment, the responsibility for calculation accuracy rests with the user. So, buyer beware.

Changes. Finally, remember that all of the calculations above are based on one fixed set of conditions. Every time the outside temperature or wind speed changes, the rate of heat loss also changes. Because equipment performance can vary with these changing conditions, to accurately predict the annual energy usage of a building requires many more calculations than those presented here. Energy analysis is an advanced topic that has its roots in heating and cooling load calculations. While it is an interesting and useful topic, it is also beyond the scope of this course.

The Next Step

Chapter 2 has provided the basic tools and processes used in heat loss calculations. The next two chapters will examine each term of the equation $Q = U{\cdot}A{\cdot}\Delta T$ in more detail and present a wider variety of construction details than will be encountered in practice. Chapter 3 will present the sources of outdoor weather data and basic inside control conditions. Chapter 4 will then examine different construction materials, various building cross-sections and other special conditions to be considered.

Summary

The groundwork for basic heat loss calculations has been laid. Each uniform building section exposed to outside conditions must be considered for each heating zone in the structure. So far we have not looked at where the numbers come from, but only what to do with them once they are determined. We have also ignored some important sources of heat such as lights, internal equipment and solar gain through windows. For heating systems, we usually cannot assume that these energy sources will be available. But we will find out that these sources become very critical when determining the cooling loads.

After studying Chapter 2, you should be able to:

- Name the various building surfaces and heat sources that must be considered in building load calculation.
- Define each term in the basic conduction heat transfer equation, tell where to get each value, and the standard units used for that value.
- Discuss basic rules of thumb that can be used for heating and cooling calculations.
- Calculate the rate of heat loss from a simple frame structure.
- List several useful comments that apply to the development of good technique in calculating thermal loads for larger structures.
- Determine the time required for morning warm-up of a building with night setback.

Bibliography

1. ASHRAE. 1997. "Thermal and water vapor transmission data." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 24.

Skill Development Exercises for Chapter 2

Complete these questions by writing your answers on the worksheets at the back of this book.

2-01. Calculate the heat loss from the bedroom of the example cabin.

2-02. Decrease the outside temperature to -5°F, and repeat the calculation for both rooms of the cabin.

2-03. If the door was moved to the east wall, explain if and how the rate of heat loss from the cabin would be affected.

2-04. If the building was rotated on its axis, or mirrored end-to-end, explain if and how the rate of heat loss from the cabin would be affected.

2-05. If you wanted to reduce the rate of heat loss from the cabin, explain what changes you might make.

2-06. Suppose a 20,000 Btu/h heating system is installed in the front room of the cabin with a 4,800 Btu/h design heating load. The total mass of the cabin and its contents is 5,000 lb, with an average specific heat of 0.25 Btu/lb·°F. How long would it take to raise the cabin temperature by 10°F under design conditions? How long would it take to raise this temperature if the outdoor temperature is 32°F?

2-07. Given the mass and specific heat of cabin and its contents in *Exercise 2-06*, how large must the heating system capacity be (in Btu/h) to raise the temperature of the space from 65°F to 70°F in 20 minutes. Remember that your heating system must also provide the heat losses that occur during that time period.

Chapter 3
Temperature Design Conditions and Weather Data

Contents of Chapter 3

Instructions

Read the material in Chapter 3. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 3

"There is nothing you can do about the weather" is a commonly heard saying and a true statement. However, it is important to know something about the local climate when designing the thermal system for a building, because it does have a tremendous impact on the cost of operation and the calculated capacity of the system. In this chapter, we will discuss both the selection of inside control parameters and outside winter and summer design conditions to use in your heat loss calculation. These same sources will be used when we start discussing cooling load calculations in Chapter 7.

After studying Chapter 3, you should be able to:

- Name the main factors that affect human comfort. Give an example of where each factor might apply.
- Explain where indoor design temperature data can be found.
- Give an application that requires the use of each outdoor design condition.
- Explain how microclimate can affect the values for outdoor design conditions.
- Explain how each design condition can affect a building's heat loss and heat gain.

3.1 Inside Design Conditions

There are four parameters that directly affect occupant comfort and must be considered by the mechanical designer: temperature, humidity, air velocity and mean radiant temperature. These effects can vary dramatically between winter and summer. Each parameter is discussed below.

As shown in *Figure 3-1*, the ASHRAE Comfort Zone is defined as the range of temperature and humidity conditions where 80% of people engaged in light office work are satisfied with the thermal condition. In heating situations for cold climates, the introduction of cold dry outside air into the space can result in low space humidities that will cause occupant discomfort due to scratchy throats, nosebleeds and static electricity. Humidification of the air may be required for these situations. In air-conditioning situations, most traditional cooling systems have targeted the upper right corner of the summer comfort zone, with typical conditions being 78°F at 50% relative humidity.

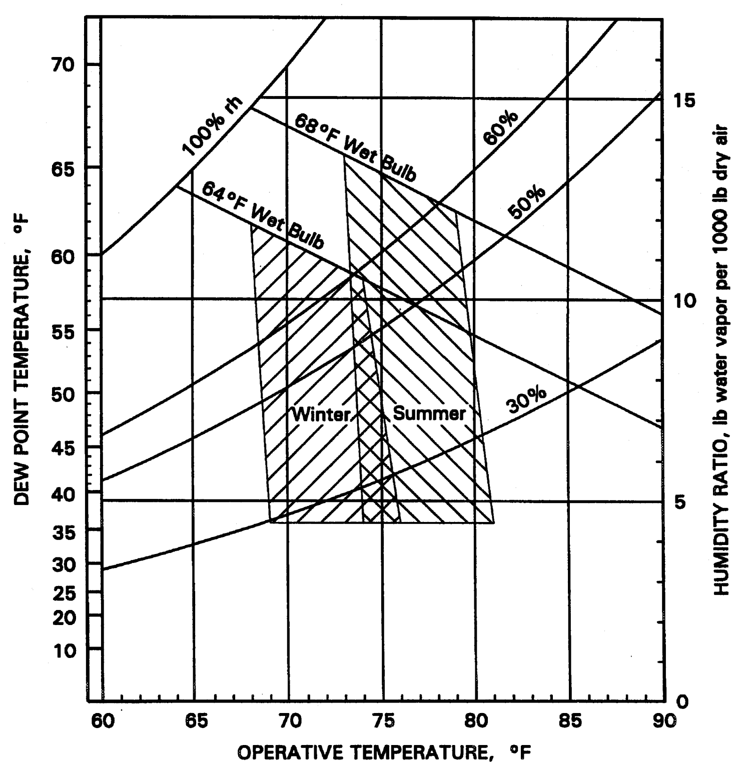


Figure 3-1. ASHRAE Comfort Zone

Moving air increases the rate of convective heat transfer from people's skin and provides evaporative cooling if they are sweating. A blast of cool air, and air movement in general, might be very welcome during the cooling season in many industrial applications. However, during the heating season, high velocities from the air distribution system, or air cascading down large glass windows, can cause annoying drafts. The goal of the air distribution system is usually to deliver the required air flow without being sensed by the occupant. To accomplish this, most air-conditioning designs call for relatively low air velocity (less than 100 fpm) within the controlled space.

Mean radiant temperature represents the average surface temperature of the walls surrounding the zone in question. Most interior walls will be at room temperature and will cause no problem. However, large glass areas or uninsulated outside walls cause high rates of radiant heat loss and result in discomfort. Curtains and blinds are often used in an attempt to block the effective radiant temperature of these surfaces and to improve the comfort level of the occupants. Radiant heating is often used as a method of supplying energy to the space during the heating season.

Thermal stratification can occur within spaces that do not have adequate air circulation. When the temperature near the ceiling is significantly higher than near the floor, action should be taken to mix the air vertically. Ideally, the temperature difference between an occupant's feet and head should be less than 5°F. Floors should be reasonably warm, especially in areas where the occupants are barefoot (such as bathrooms).

There are also some design conditions that you should take into consideration, but over which you have no control. For example, the more active or clothed that people are, the more comfortable they are at lower temperatures. (The insulating effect of various clothing ensembles and typical metabolic heat generations for various activities are discussed in Chapter 4 of the *Fundamentals of HVAC Systems* course of this series.)

The challenge to the designer is when individuals with dissimilar conditions occupy the same space. Consider a basketball game where the spectators are sitting in winter coats and the players are running hard. Which group should you design for? (The old axiom says you should always please the customer.) As another example, a checkout clerk in a store during the winter would be standing and wearing normal indoor attire (sweater and pants). The customer is wearing a winter coat, and has been walking the aisles. Add to this mix the blast of cold outside air every time the door opens, and you have a real design challenge.

The 1995 *ASHRAE Handbook–HVAC Applications* describes the recommended winter and summer design conditions for a wide variety of building spaces.[1] This would make a great starting point for defining the design conditions in a new facility and offer benchmarks to identify problems in existing systems.

There are numerous specialty areas in which people work where the conditions are well above or below the comfort guidelines above. A frozen food facility and a steel mill are examples of these wide-ranging industrial facilities. The US Occupational Safety and Health Administration (OSHA) has developed regulations that apply to individuals working under these extreme conditions. While it is beyond the scope of this course, you should become familiar with these regulations before working in those design areas.

3.2 *Outside Design Conditions*

When calculating the thermal loads for a building, it is very important that the heating and cooling equipment system be capable of maintaining adequate comfort under all reasonable conditions. But sizing a heating system for the coldest temperature ever recorded will result in an oversized furnace that will be more expensive than necessary to buy and often less efficient to operate. So, winter and summer design conditions have been developed that provide adequate and acceptable capacity and save the building owner both construction dollars as well as operating costs.

Several new terms that you may not be familiar with will be used in this discussion of weather data, so those terms must be defined. Air temperature will be referred to here as the dry-bulb (DB) temperature. This is to distinguish it from two other temperature measurements that are related to the humidity in the air. The wet-bulb (WB) temperature measures the lowest temperature that can be obtained through an evaporative process. The dewpoint (DP) temperature is the temperature at which the water vapor in the air begins to condense into moisture. All of these temperatures are measured in degrees Fahrenheit (°F).

Finally, the humidity ratio (HR) is the ratio of the mass of water vapor per mass of dry air. The units used in this chapter for the humidity ratio are grains of water vapor per pound of dry air; one pound equals 7,000 grains. (For a more complete discussion of these terms, see Chapter 6 in the 1997 *ASHRAE Handbook–Fundamentals*.[2])

An extensive record of climatic conditions for the United States and other countries can be found in the 1997 *ASHRAE Handbook–Fundamentals*.[3] Two representative pages are presented here as *Figure 3.2*. (Most major cities in each state, Canadian province or country are included in the original *Handbook* listing.) Some care must be exercised in extrapolating the given data to other locations. Local geography and microclimatic conditions often result in significant differences between any given site and the nearest reported weather station. Elevation changes greater than a few hundred feet can significantly change the design conditions. The distance from large bodies of water or the thermal island that exists in metropolitan areas should be considered. Other sources such as the US Weather Service, the National Climatic Data Center or a qualified applied climatologist should be consulted if there is any doubt regarding the applicability of the values in the ASHRAE tables.

It should be noted that the format of the weather design data in the 1997 *Handbook* is significantly different from previous *Handbooks* and from references based on those earlier *Handbooks*. Previously, different data analysis methods were used for Canadian locations compared to US locations, and some overseas locations were based on limited short-term data. The new format was developed to provide more uniform data and to include additional data not previously provided. However, the use of some of those statistics is beyond the scope of this course and will only be briefly mentioned for completeness.

Heating and Wind Design Conditions—United States

	WHO#	West Lat.	North Long.	Elev. ft	StdP, psia	Dates	Heating Dry Bulb 99.6%	Heating Dry Bulb 99%	Extreme Wind Speed, mph 1%	Extreme Wind Speed, mph 2.5%	Extreme Wind Speed, mph 5%	Coldest Month 0.4% WS	Coldest Month 0.4% MDB	Coldest Month 1% WS	Coldest Month 1% MDB	MWS/MWD to DB 99.6% MWS	MWS/MWD to DB 99.6% MDB	MWS/MWD to DB 0.4% MWS	MWS/MWD to DB 0.4% MWD	Extr. Annual Daily Mean DB Max.	Extr. Annual Daily Mean DB Min.	Extr. Annual Daily StdD DB Max.	Extr. Annual Daily StdD DB Min.
Russell	724585	38.87	98.82	1864	13.732	8293	−4	3	29	26	23	29	33	25	35	11	10	16	190	105	−8	3.6	8.5
Salina	724586	38.80	97.65	1273	14.032	8293	−3	4	27	23	22	28	33	24	34	11	360	15	180	106	−7	2.3	9.9
Topeka	724560	39.07	95.62	886	14.231	6193	−2	4	25	22	20	25	28	22	29	9	320	12	180	100	−8	3.8	7.4
Wichita, Airport	724500	37.65	97.43	1339	13.998	6193	2	8	29	25	23	28	30	26	31	13	360	16	200	105	−4	2.9	6.3
Wichita, McConnell AFB	724505	37.62	97.27	1371	13.982	8293	2	10	25	23	20	25	38	23	36	11	360	12	190	105	−1	2.7	7.7
KENTUCKY																							
Bowling Green	746716	36.97	86.42	548	14.407	8293	7	14	20	19	17	21	40	19	40	6	220	9	230	97	−2	3.2	10.3
Covington/Cincinnati Airport	724210	39.05	84.67	876	14.236	6193	1	7	22	20	18	25	30	22	33	9	250	10	230	95	−7	3.1	8.5
Fort Campbell, AAF	746710	36.67	87.50	571	14.395	8293	9	15	19	16	14	20	40	17	43	4	330	6	240	98	0	3.1	9.5
Fort Knox, Godman AAF	724240	37.90	85.97	755	14.299	8293	9	15	17	15	13	18	42	16	39	4	290	6	270	97	0	4.1	7.9
Jackson	724236	37.60	83.32	1381	13.977	8293	7	14	17	14	13	18	44	16	40	7	230	6	230	94	−3	2.7	9.4
Lexington	724220	38.03	84.60	988	14.179	6193	4	10	21	19	17	23	38	20	38	8	270	9	240	94	−4	3.5	8.3
Louisville	724230	38.18	85.73	489	14.438	6193	6	12	22	19	17	22	40	20	34	10	290	10	250	96	−1	3.1	7.9
Paducah	724350	37.07	88.77	413	14.477	8293	7	13	22	19	17	22	45	19	42	8	40	9	180	98	−1	2.9	9.4
LOUISIANA																							
Alexandria, England AFB	747540	31.33	92.55	89	14.648	8293	27	30	16	13	12	17	53	15	49	7	360	3	180	98	20	2.2	6.3
Baton Rouge	722317	30.53	91.15	69	14.659	6193	27	30	20	18	16	21	48	19	49	8	360	8	270	97	20	2.2	5.4
Bossier City, Barksdale AFB	722485	32.50	93.67	167	14.607	8293	22	27	18	16	14	19	49	16	51	7	360	5	180	99	15	2.3	6.7
Lafayette	722405	30.20	91.98	43	14.673	8293	28	32	21	18	16	21	54	19	53	9	10	8	200	97	19	1.6	8.1
Lake Charles	722400	30.12	93.22	33	14.678	6193	29	32	22	19	17	24	50	21	49	10	20	8	230	96	23	2.3	4.7
Leesville, Fort Polk	722390	31.05	93.20	328	14.522	8293	27	30	16	13	12	16	51	14	52	4	20	4	180	98	20	2.0	5.9
Monroe	722486	32.52	92.03	79	14.654	8293	22	27	19	17	15	20	50	18	47	9	10	7	230	99	17	1.8	8.5
New Orleans, Int'l Airport	722310	29.98	90.25	30	14.680	6193	30	34	21	19	17	21	48	19	49	7	340	8	360	96	23	2.0	5.3
New Orleans, Lakefront A	722315	30.05	90.03	10	14.690	8293	35	39	22	19	18	21	49	20	50	14	360	9	300	94	21	8.1	12.4
Shreveport	722480	32.47	93.82	259	14.558	6193	22	26	20	18	16	22	46	19	48	9	360	8	180	99	16	3.1	5.6
MAINE																							
Augusta	726185	44.32	69.80	351	14.510	8293	−3	1	23	21	19	25	20	22	22	10	320	11	210	93	−10	3.1	3.4
Bangor	726088	44.80	68.83	194	14.593	8293	−7	−2	22	19	17	24	18	21	20	6	300	10	240	94	−16	2.9	5.9
Brunswick, NAS	743920	43.88	69.93	75	14.655	8293	−2	2	20	17	15	21	27	19	25	4	340	9	190	96	−12	7.9	6.1
Caribou	727120	46.87	68.02	623	14.367	6193	−14	−10	28	24	22	30	13	27	11	10	270	13	250	90	−23	2.8	4.5
Limestone, Loring AFB	727125	46.95	67.88	745	14.304	8293	−13	−9	23	20	18	25	12	22	11	7	300	9	260	91	−20	2.3	2.9
Portland	726060	43.65	70.32	62	14.662	6193	−3	2	24	21	18	24	26	21	25	7	320	12	270	93	−13	3.6	5.5
MARYLAND																							
Camp Springs, Andrews AFB	745940	38.82	76.87	282	14.546	8293	13	18	21	18	16	23	30	21	32	7	350	9	230	98	4	2.9	6.7
Baltimore, BWI Airport	724060	39.18	76.67	154	14.614	6193	11	15	24	21	19	25	31	22	31	10	290	11	280	97	4	2.9	5.8
Lex Park, Patuxent River NAS	724040	38.28	76.40	39	14.675	8293	16	21	20	17	15	22	30	19	35	9	340	9	270	98	8	2.3	6.1
Salisbury	724045	38.33	75.52	52	14.668	8293	13	18	20	18	16	20	35	19	37	6	10	9	240	97	4	2.7	5.8
MASSACHUSETTS																							
Boston	725090	42.37	71.03	30	14.680	6193	7	12	29	25	23	30	30	27	28	17	320	14	270	96	0	2.7	4.7
East Falmouth, Otis Angb	725060	41.65	70.52	131	14.626	8293	11	14	26	22	20	26	34	23	33	9	300	10	240	90	5	2.5	3.8
S. Weymouth NAS	725097	42.15	70.93	161	14.610	8293	6	11	19	16	14	18	29	16	29	7	320	9	260	97	−2	3.8	3.8
Worcester	725095	42.27	71.88	1010	14.167	6193	0	5	27	23	20	29	22	26	21	14	270	10	270	90	−6	1.9	4.1
MICHIGAN																							
Alpena	726390	45.07	83.57	692	14.332	6193	−7	−1	21	19	17	22	20	19	20	5	270	11	240	93	−17	3.4	5.9
Detroit, Metro	725370	42.23	83.33	663	14.347	6193	0	5	27	23	21	28	28	24	27	11	240	13	230	95	−7	3.0	5.4
Flint	726370	42.97	83.75	764	14.294	6193	−2	3	25	22	20	27	24	23	23	8	230	13	230	93	−10	3.1	5.0
Grand Rapids	726350	42.88	85.52	804	14.274	6193	0	5	25	22	20	26	25	23	24	8	180	13	240	93	−9	2.1	5.3
Hancock	727440	47.17	88.50	1079	14.131	6193	−9	−4	21	19	18	23	18	20	16	8	270	10	250	90	−16	2.9	5.6
Harbor Beach	725386	44.02	82.80	600	14.379	8293	9	12	26	22	19	26	27	23	27	10	220	9	230	94	2	2.9	4.1
Jackson	725395	42.27	84.47	1001	14.172	8293	−3	4	20	19	17	23	22	20	23	9	240	11	210	93	−11	2.5	5.6
Lansing	725390	42.77	84.60	873	14.238	6193	−3	2	26	23	20	28	23	25	24	8	290	13	250	94	−13	2.8	5.9
Marquette, Sawyer AFB	727435	46.35	87.40	1220	14.059	8293	−11	−6	24	21	18	26	18	23	17	6	280	10	210	91	−18	4.7	4.7
Marquette/Ishpeming, A	727430	46.53	87.55	1424	13.955	8293	−13	−8	22	19	18	22	20	20	16	8	270	11	230	90	−22	4.5	4.5
Mount Clemens, Angb	725377	42.62	82.83	581	14.390	8293	3	7	21	18	16	25	21	21	24	7	280	9	230	95	−3	4.0	2.7
Muskegon	726360	43.17	86.25	633	14.362	6193	3	7	27	24	22	28	25	25	26	10	290	12	200	90	−5	2.7	5.0
Oscoda, Wurtsmith AFB	726395	44.45	83.40	633	14.362	8293	0	3	21	19	17	23	26	21	24	6	220	11	200	95	−7	4.1	4.7
Pellston	727347	45.57	84.80	719	14.318	8293	−9	−3	26	23	20	28	22	24	22	4	300	14	250	92	−21	3.1	4.9
Saginaw	726379	43.53	84.08	669	14.343	8293	0	4	23	21	19	25	22	22	23	10	260	13	240	96	−6	5.8	4.5
Sault Ste. Marie	727340	46.47	84.37	725	14.314	6193	−12	−7	23	20	18	24	19	21	18	7	90	10	230	89	−22	3.5	5.4
Seul Choix Point	726399	45.92	85.92	591	14.385	8293	0	4	28	24	22	30	27	26	27	9	300	8	200	82	−5	2.3	6.3
Traverse City	726387	44.73	85.58	623	14.367	6193	−3	2	21	19	18	23	23	21	23	7	180	13	230	94	−13	2.8	7.3
MINNESOTA																							
Alexandria	726557	45.87	95.40	1424	13.955	8293	−20	−15	25	22	20	28	12	24	8	10	300	14	180	96	−26	3.6	4.5
Brainerd, Pequot Lakes	727500	46.60	94.32	1280	14.029	8293	−24	−17	11	10	9	11	8	10	11	3	320	5	190	95	−30	7.9	6.8
Duluth	727450	46.83	92.18	1417	13.958	6193	−21	−16	25	22	20	25	12	22	11	10	310	12	230	90	−28	2.8	4.7
Hibbing	727455	47.38	92.83	1352	13.992	8293	−25	−20	20	19	17	20	13	19	13	6	330	11	200	92	−34	2.5	4.7
International Falls	727470	48.57	93.38	1184	14.077	6193	−29	−23	22	20	18	22	10	20	8	6	270	11	180	92	−37	3.4	3.8
Minneapolis-St. Paul	726580	44.88	93.22	837	14.257	6193	−16	−11	25	22	20	25	12	22	14	9	300	14	180	97	−22	3.5	5.4
Redwood Falls	726556	44.55	95.08	1024	14.160	8293	−17	−12	26	22	20	28	14	24	15	11	280	14	180	99	−22	4.1	5.2
Rochester	726440	43.92	92.50	1319	14.008	6193	−17	−12	29	26	24	32	12	28	12	13	300	15	200	94	−23	3.7	5.2

WMO# = World Meteorological Organization number Elev. = elevation, ft DB = dry-bulb temperature, °F
Lat. = latitude, degrees north Long. = longitude, degrees west StdP = standard pressure at station elevation, psia WS = windspeed, mph

Figure 3-2. Example of Climatic Conditions for US Cities

Cooling and Dehumidification Design Conditions—United States

	Cooling DB/MWB						WB/MDB						DP/MDB and HR									
	0.4%		1%		2%		0.4%		1%		2%		0.4%			1%			2%			Range
	DB	MWB	DB	MWB	DB	MWB	WB	MDB	WB	MDB	WB	MDB	DP	HR	MDB	DP	HR	MDB	DP	HR	MDB	of DB
Russell	100	72	96	72	94	72	76	91	75	90	73	88	72	126	83	71	120	82	69	116	80	24.1
Salina	101	74	97	73	94	73	77	92	76	90	75	89	74	132	85	72	123	83	71	118	82	23.0
Topeka	96	75	93	75	90	75	79	90	78	89	76	88	76	139	87	74	132	85	73	126	83	20.3
Wichita, Airport	100	73	97	73	94	73	77	91	76	90	74	89	73	129	83	72	123	82	71	118	81	22.2
Wichita, McConnell AFB	100	73	97	73	94	73	77	92	76	90	75	89	74	133	84	72	124	83	71	119	82	21.8
KENTUCKY																						
Bowling Green	94	76	91	75	88	74	78	89	77	87	76	86	76	136	84	75	132	82	74	127	81	20.0
Covington/Cincinnati Airport	91	74	89	73	86	72	77	87	76	86	74	83	74	132	84	73	126	81	72	120	80	18.9
Fort Campbell, AAF	95	77	93	76	90	76	80	90	78	89	77	87	77	143	85	76	136	84	74	132	83	19.4
Fort Knox, Godman AAF	94	76	92	74	89	74	78	90	77	88	76	86	76	138	85	74	132	83	73	126	82	19.4
Jackson	90	74	87	73	85	72	77	87	76	85	74	83	74	135	83	73	130	81	71	122	79	18.2
Lexington	91	74	89	73	86	72	77	87	75	86	74	83	74	130	83	72	124	81	71	120	80	18.4
Louisville	93	76	90	75	88	74	78	90	77	88	76	86	75	134	85	74	129	84	73	125	82	18.2
Paducah	96	77	93	76	92	75	80	91	79	90	78	88	77	143	86	76	138	85	75	132	83	20.2
LOUISIANA																						
Alexandria, England AFB	95	78	94	78	92	77	81	90	80	90	79	89	78	147	86	77	142	85	76	138	85	18.4
Baton Rouge	94	78	92	77	91	77	80	89	79	88	78	87	78	145	84	77	141	84	76	137	83	16.7
Bossier City, Barksdale AFB	96	77	94	77	93	77	80	90	79	90	78	89	77	144	84	76	139	83	76	134	83	20.0
Lafayette	94	78	93	78	91	77	80	89	80	89	79	88	78	146	84	77	143	83	77	140	83	17.1
Lake Charles	93	78	91	78	90	77	80	88	80	88	79	87	78	148	84	78	145	84	77	141	83	16.2
Leesville, Fort Polk	95	77	94	76	92	76	79	89	79	88	78	87	77	144	83	76	140	82	76	136	82	18.2
Monroe	96	78	94	78	93	77	81	91	80	90	79	89	78	147	86	77	143	85	77	139	84	19.3
New Orleans, Int'l Airport	93	79	92	78	90	78	81	90	80	88	80	87	79	151	86	78	146	85	77	142	84	15.5
New Orleans, Lakefront A	93	78	92	78	90	77	81	88	80	87	79	87	79	150	85	78	145	84	77	141	83	11.9
Shreveport	97	77	95	77	93	76	79	91	79	90	78	89	76	139	84	76	135	83	75	132	83	19.1
MAINE																						
Augusta	87	71	84	69	80	67	73	83	71	80	69	77	70	113	77	68	106	75	67	100	74	18.4
Bangor	87	71	84	69	81	67	73	83	71	81	69	77	70	111	78	68	104	75	67	99	73	20.5
Brunswick, NAS	87	71	84	69	80	67	73	83	71	80	70	77	70	111	78	69	105	76	67	100	74	19.1
Caribou	85	69	82	67	79	66	72	81	70	77	68	76	70	112	76	68	104	75	66	97	72	19.5
Limestone, Loring AFB	84	68	80	66	78	64	71	79	69	76	67	74	68	107	75	67	101	72	65	94	71	18.7
Portland	86	71	83	70	80	68	74	83	72	80	70	77	71	114	79	69	107	76	67	101	74	18.7
MARYLAND																						
Camp Springs, Andrews AFB	94	75	91	74	88	73	78	88	77	87	75	85	75	134	83	74	129	82	73	124	80	18.7
Baltimore, BWI Airport	93	75	91	74	88	73	78	88	76	86	75	85	75	132	83	74	125	81	72	120	80	18.8
Lex Park, Patuxent River NAS	93	76	90	75	87	74	79	88	77	87	76	85	76	136	84	75	131	83	74	125	82	15.8
Salisbury	93	77	90	76	88	75	80	88	78	86	77	85	78	144	84	76	137	82	75	132	81	18.7
MASSACHUSETTS																						
Boston	91	73	87	71	84	70	75	87	74	83	72	81	72	119	80	71	113	79	69	108	78	15.3
East Falmouth, Otis Angb	85	72	82	72	79	69	75	81	74	78	72	76	74	125	78	72	118	76	71	113	75	14.6
S. Weymouth NAS	92	73	87	72	85	71	77	87	75	84	73	81	74	129	82	72	118	79	70	111	78	19.6
Worcester	85	71	83	69	80	68	74	82	72	80	70	77	71	119	78	69	112	76	68	105	75	16.6
MICHIGAN																						
Alpena	87	71	84	69	81	67	74	83	72	81	70	78	71	116	79	69	107	76	67	100	74	22.9
Detroit, Metro	90	73	87	72	84	70	76	86	74	84	73	81	73	125	83	71	118	80	70	111	78	20.4
Flint	88	73	86	71	83	70	75	84	74	82	72	80	73	125	81	71	116	78	69	110	77	20.6
Grand Rapids	89	73	86	71	84	70	76	85	74	83	72	81	73	126	81	71	118	79	70	112	77	20.7
Hancock	86	71	83	69	80	67	73	82	71	80	70	77	70	116	79	69	109	76	67	103	74	20.6
Harbor Beach	90	71	86	69	83	68	74	86	72	83	70	80	70	113	82	68	106	80	67	100	78	14.4
Jackson	88	74	86	73	84	71	77	86	75	83	73	81	74	134	83	72	123	81	71	117	78	20.3
Lansing	89	73	86	72	84	70	76	85	74	83	73	81	73	127	81	72	120	79	70	114	78	21.7
Marquette, Sawyer AFB	86	69	83	68	79	65	72	83	70	79	68	75	69	113	77	67	106	74	66	99	73	22.1
Marquette/Ishpeming, A	85	69	82	67	78	65	72	82	70	78	68	75	69	111	77	67	104	75	65	98	72	22.1
Mount Clemens, Angb	90	74	87	72	84	71	77	87	75	83	73	80	74	131	83	72	120	81	70	113	78	19.6
Muskegon	85	71	83	70	81	69	75	82	73	80	71	78	72	122	80	70	115	77	69	109	76	18.1
Oscoda, Wurtsmith AFB	89	72	86	71	83	69	75	86	73	83	71	79	72	120	80	70	112	79	68	106	77	21.4
Pellston	87	71	85	69	81	68	74	83	72	81	70	78	70	115	78	69	108	76	67	103	75	23.9
Saginaw	90	74	87	72	84	70	77	86	75	84	73	81	74	132	83	72	120	80	70	112	78	21.2
Sault Ste. Marie	83	69	80	68	77	66	72	80	70	77	68	74	69	111	76	67	103	74	65	95	72	21.9
Seul Choix Point	78	66	76	65	74	64	70	76	68	72	66	71	68	106	74	67	101	72	65	94	70	13.9
Traverse City	89	71	86	70	83	68	74	84	72	82	70	80	71	117	80	69	109	78	67	103	76	22.0
MINNESOTA																						
Alexandria	89	72	86	70	83	69	75	86	73	82	71	80	72	123	82	70	116	79	68	109	77	19.3
Brainerd, Pequot Lakes	88	70	85	68	81	66	72	85	70	82	68	78	68	108	81	66	102	77	65	96	75	21.6
Duluth	84	69	81	67	78	65	72	81	69	78	67	75	68	110	77	66	102	75	64	94	72	20.2
Hibbing	85	70	81	68	78	66	73	82	71	78	68	75	70	116	78	68	108	76	66	101	73	23.2
International Falls	86	69	83	67	80	66	72	82	70	79	68	77	69	112	78	67	103	75	65	96	73	21.8
Minneapolis-St. Paul	91	73	88	71	85	70	76	88	74	84	72	82	73	124	83	71	116	81	69	109	79	19.1
Redwood Falls	92	74	88	72	86	70	77	89	75	85	73	82	75	135	83	72	123	81	70	116	80	20.7
Rochester	88	72	85	71	82	70	76	85	74	82	72	80	73	128	81	71	120	79	69	111	77	19.7

MDB = mean coincident dry-bulb temperature, °F MWS = mean coincident wind speed, mph StdP = std. deviation HR = humidity ratio, grains (water)/lb (dry air)
MWB = mean coincident wet-bulb temperature, °F MWD = mean coincident wind direction, degrees DP = dew-point temperature, °F

Figure 3-2. Example of Climatic Conditions for US Cities (cont.)

To become familiar with the ASHRAE tables, the first listed site in *Figure 3-2*, Russell, Kansas, will be used as an example throughout this chapter. The latitude, longitude and elevation of the recording station are provided to determine the proximity of your site to the recording station. The standard barometric pressure of 13.732 psia is the basis used to calculate the design dewpoint temperatures. The 8293 in the Dates column indicates that the weather data is for the years 1982 through 1993, inclusive.

3.3 Winter Outdoor Design Temperature

The next two columns in *Figure 3-2* provide two measurements of the winter design temperature (Heating DB) for 99.6% and 99%, respectively. In the average year (8760 hours) in Russell, Kansas, the recorded temperature has been at or above -4°F for 99.6% of the time, and at or above 3°F for 99% of the time. In other words, only 35 hours are below -4°F, and 88 hours are below 3°F in this location during the average year. These heating design temperatures roughly correspond to the 1% and 5% design data provided in previous *Handbooks*, which were based only on the winter heating season, as opposed to the whole year assumed in the current data set.

Because the coldest wintertime temperatures occur around dawn following a clear winter night, there is often very little activity within most buildings at these hours. So if the space temperature dips slightly below the desired setpoint a few hours each year, there will be few complaints in most buildings. In fact, the thermal capacitance of the building material and its contents often helps to buffer the extent of the lowest temperature excursions.

Another factor is the internal energy supplied by the occupants and lighting systems. Because the winter heating load calculations are usually made assuming these sources are unavailable or turned off, they can also help to minimize the chilling effect during record cold weather. It should be noted that studies have shown that, during extremely cold weather, the 99.6% and 99% design conditions can be exceeded for durations of several days.

For residential applications or other applications where occupancy is continuous or temperature control is essential, the recommended design temperatures in this table apply. However for applications that do not open for business for several hours after dawn (such as a luncheonette), it might be appropriate to use a slightly higher design temperature in the thermal load calculations. Remember, if a night setback thermostat is part of the design, it will take longer to bring the space back up to daytime condition with a smaller heating system installed.

3.4 Wind and Annual Extremes Data

The next several columns of *Figure 3-2* present design data on wind speed. The extreme wind speed exceeds the given value for 1%, 2.5% or 5% of the year. In Russell, Kansas, the wind speed is higher than 29 mph for 88 hours in the average year.) For the coldest month for each location, the 0.4% and 1% values for the wind speed and corresponding mean dry-bulb temperature are given. (In Russell, Kansas, for 35 hours each year, the wind speed exceeds 29 mph, and the average temperature during this windy period is 33°F.)

The MWS/MWD to DB columns present the mean wind speed and mean wind direction coincident with the Heating DB discussed above and with the Cooling DB that will be discussed in the next section. The wind directions are given like compass headings; a north wind is 360° (or 0°), east is 90°, etc. (In Russell, Kansas, for the 35 hours that the temperature is below -4°F, the wind is typically out of the north – 10° – at 11 mph. For the summer (0.4%) design condition, the wind is generally out of the south – 190° – at 16 mph.)

The last four columns in *Figure 3-2* present Annual Extreme Daily data. The annual daily high temperatures and low temperatures for the weather period analyzed are averaged and reported here as the Max and Min, respectively. (In Russell, Kansas, the mean summer high temperature is 105°F and the mean winter low temperature is -8°F.) The standard deviation for each of these mean extreme temperatures is provided to allow you to determine how frequently these temperatures are exceeded; for example, if you must ensure that your design can withstand the worst temperature conditions expected for the next 50 years. (Refer to the 1997 *ASHRAE Handbook–Fundamentals* for details on this procedure.)

3.5 Summer Outdoor Design Temperature

Because humidity control is so important in the design of air-conditioning systems, the summer outdoor design conditions presented in *Figure 3-2* include three combinations of the dry-bulb temperature and humidity data. In each case, the 0.4%, 1% and 2% design conditions are representative of the 35, 88 and 175 hottest hours in the year, respectively.

The first set of data, Cooling DB/MWB, presents the dry-bulb temperature with mean coincident wet-bulb temperature. (In Russell, Kansas, the dry-bulb temperature exceeds 100°F for 35 hours in the typical year. During this time, the wet-bulb temperature averages 72°F.) This is the data set that you would normally use to determine the cooling load on a typical building.

Daily maximum temperatures generally occur between 2:00 pm and 4:00 pm. For residences and other continuously occupied or critically controlled buildings, the recommended temperatures in the table should be used. In a building where the maximum occupancy does not occur during the mid-afternoon (such as a church or dance hall), the summer outdoor design temperature can be decreased accordingly.

The second set of data, WB/MDB, presents the design wet-bulb temperature with mean coincident dry-bulb temperature. (In Russell, Kansas, the wet-bulb temperature exceeds 76°F for 35 hours each year, during which time the dry-bulb temperature averages 91°F.) These data are useful in determining the capacity of equipment that uses evaporative processes (such as cooling towers and evaporative coolers). These data are also useful in the design of fresh air ventilation systems.

The third data set, DP/MDB and HR, presents the design dewpoint temperature and corresponding humidity ratio with the mean coincident dry-bulb temperature. (In Russell, Kansas, the dewpoint temperature exceeds 72°F for 35 hours each year, during which time the mean dry-bulb temperature is 83°F. This dewpoint temperature corresponds to 126 grains of water vapor per pound of dry air.) These data are especially useful for applications involving humidity control (such as desiccant cooling and dehumidification). These values are also used as a checkpoint when analyzing the behavior of cooling systems at part-load condition, particularly when such systems are used for humidity control as a secondary function.

The last column, Range of DB, represents the difference between the average daily maximum and the average daily minimum temperatures for the warmest month of the year. These data will be used to adjust our cooling load conditions, and are also useful in determining the rate of natural cooling that a building experiences during its diurnal cycle.

3.6 Other Sources of Climatic Information

Most of the design values in this chapter were developed by an ASHRAE-sponsored research project.[4] Additional data for 7,000 locations worldwide is available on CD-ROM from the International Station Meteorological Climate Summary.[5] Degree-day summary information and climatic normals for the United States and Canada are also available on CD-ROM from other sources. Typical hourly weather conditions can be simulated by several available statistical algorithms. Finally, data on sequences of extreme temperature and humidity conditions are available. (See Chapter 26 of the 1997 *ASHRAE Handbook–Fundamentals* for specific references.)

These data were originally developed primarily as research tools. Traditionally, conventional building designs could neither afford nor justify the expense of making complex calculations. Systems were designed and equipment was sized to meet the design heating and cooling loads that you are learning to calculate in this course. The advent of microcomputers allows designers to analyze and compare the energy usage and cost performance of various systems throughout the year. However, discussion of these methods and procedures is beyond the scope of this course.

The Next Step

The thermal properties of typical building materials will be the focus of the next chapter. You will learn to find and use tabulated values and how to deal with surface resistances, dead air spaces and non-uniform sections. You will also learn how to make thermal performance comparisons among alternatives.

Summary

In Chapter 3, you learned where to locate indoor and outdoor design condition data for winter and summer designs. You learned the fundamental conditions required within a space to provide for human comfort. You learned how to locate weather data for specific locations and how to estimate values for locations not included. It was explained why each column of data is provided and where the values can be applied.

Remember that not all designs will require all of the data provided. But there is still some judgment required to choose which column is appropriate for a given application. That judgment will grow along with your experience as you progress through this course.

After studying Chapter 3, you should be able to:

- Name the main factors that affect human comfort. Give an example of where each factor might apply.
- Explain where indoor design temperature data can be found.
- Give an application that requires the use of each column of outdoor design condition data.
- Explain how a microclimate can affect the values for outdoor design conditions.
- Explain how each design condition can affect a building's heat loss and heat gain.

Bibliography

1. ASHRAE. 1995. *ASHRAE Handbook–HVAC Applications*. Atlanta, GA: ASHRAE.

2. ASHRAE. 1997. "Psychrometrics." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 6.

3. ASHRAE. 1997. "Climatic design information." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 26.

4. ASHRAE. 1997. *Updating the Tables of Design Weather Conditions in the ASHRAE Handbook of Fundamentals*. ASHRAE Research Report RP-890. Atlanta, GA: ASHRAE.

5. NCDC. 1996. *International Station Meteorological Climate Summary*. Asheville, NC: National Climatic Data Center.

Skill Development Exercises for Chapter 3

Complete these questions by writing your answers on the worksheets at the back of this book.

3-01. Assume you are working for a mobile home manufacturer that ships to all of the states shown in *Figure 3-2*. In which state would you expect the highest heating load? The highest cooling load? Explain which data columns you used to make your selection.

3-02. In Massachusetts, Boston and Worcester are only 25 miles apart. How would you explain the large difference in their winter design temperatures?

3-03. In Michigan, Grand Rapids and Muskegon are only 30 miles apart. How would you explain the difference in their summer design temperatures?

3-04. Discuss how the wind speed at a typical single-family house with trees and other vegetation around it might compare with the recorded wind speeds. How would the local terrain (hills and valleys) affect the actual wind speed at a site? How would the recorded wind speed compare to the actual wind speed at the top floor of the tallest office building in town?

Chapter 4
Thermal Properties of Materials

Contents of Chapter 4

Instructions

Read the material of Chapter 4. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 4

The thermal characteristics of the building materials used to construct a structure have a major impact on the energy cost of its operation. In Chapter 4, we will examine both the thermal properties of construction materials and how to determine the composite U-factor for typical cross-sections.

After studying Chapter 4, you should be able to:

- Use the tabulated data in Chapter 24 of the 1997 *ASHRAE Handbook–Fundamentals*.[1]
- For a given building section, calculate the effective R-value and convert it to a U-factor.
- Determine the effective air film coefficient for a given geometry and surface property.

4.1 Building Material Properties

The thermal properties of common building materials are given in the table in *Appendix A*. This table is arranged into 10 basic families of materials, starting with building boards. Where standard material thicknesses are available, they are given after the type of material. The next column indicates the material density. This value, when combined with the specific heat shown in the last column, becomes especially important in calculating the total capacitance of a structure during the cooling season.

The next column shows the thermal conductivity property, k, in units of Btu·in./h·ft^2·°F. Other references often show the same values in units of Btu/h·ft·°F, where the nominal thickness must be given in feet instead of inches. The conductance, shown in the next column, is the given conductivity divided by the nominal thickness, L, measured in inches:

$$C = k / L \tag{4-1}$$

The next two columns give R, the reciprocal of the C value shown in the earlier column ($R = 1/C$). The value is presented per inch of thickness as well as for the shown thickness when given. The reason that the R-value is so important is that for any uniform building section (wall, roof, floor, etc.), the total R is the sum of all the R-values for each material within the section:

$$R_{total} = R_1 + R_2 + R_3 ... \tag{4-2}$$

The section U-factor is then determined by taking the reciprocal of that R_{total} value:

$$U = 1 / R_{total} \tag{4-3}$$

This U-factor is the one needed in the equation for building heat loss calculations:

$$Q = U \cdot A \cdot \Delta T \tag{4-4}$$

The easiest way to see how this process works is by using an example. We will examine a typical stud wall for a warm climate using 2×4 construction and filled with 3.0 in. of fiberglass insulation as shown in *Figure 4-1*. In Chapter 1, we stated that $U = k/L$ which is true for simple homogeneous materials. When analyzing composite walls, it is necessary to determine the U-factor by using the R-values for each of the wall materials. For convenience, we have numbered the components in sequence, starting from the outside. Note that components 4 and 5 represent insulation and a 3.5-in. wood stud rated at R-4.38 (R-1.25 per in.) respectively:

1. Outside air film (15 mph wind)
2. Wood siding (0.5 in. x 8 in. lapped)
3. Sheathing (0.5 in. regular)
4. Insulation (3.0 in. fiberglass)
5. Wood stud (3.5 in.)
6. Gypsum (0.5 in.)
7. Inside air film (still air)

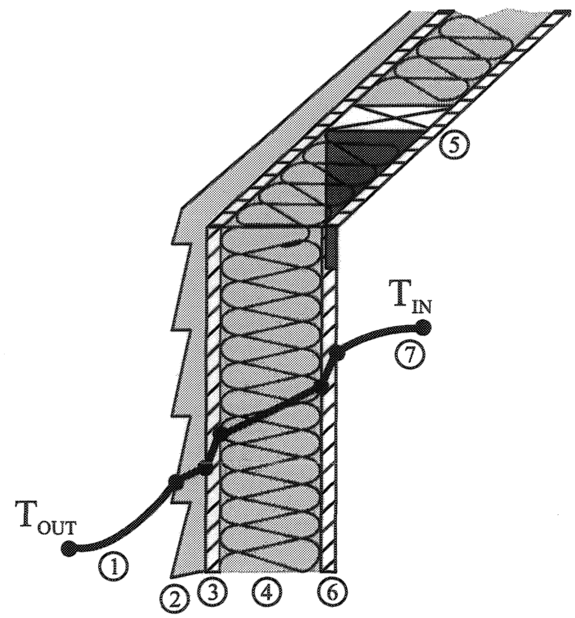


Figure 4-1. Wall Section

The outside and inside air films are actually convective heat transfer values. In this case, they represent the resistance to heat transfer into air from a vertical surface. These air films vary somewhat throughout the building and will be discussed more fully in Section 4.3.

	At cavity	At framing
1. Outside Air Film (15 mph wind)	0.17	0.17
2. Wood siding (0.5 in. x 8 in. lapped)	0.81	0.81
3. Sheathing (0.5 in. regular)	1.32	1.32
4. Insulation (3.0 in. fiberglass)	11.00	
5. Wood Stud (3.5 in.)		4.38
6. Gypsum (0.5 in.)	0.32	0.32
7. Inside air film (still air)	0.68	0.68
Total Thermal Resistance (R_T)	14.3	7.7 h·ft²·°F/Btu

The remaining values are read directly from the table in *Appendix A* and inserted into the column. The values are then added to obtain a total R_T value for the wall cavity of 14.3 h·ft²·°F/Btu, and a value of 7.7 h·ft²·°F/Btu at the framing. By taking the reciprocal of these values, the U-factors are easily determined:

$$U_{cavity} = 1/R_T = 1/14.3 = 0.07 \text{ Btu/h·ft}^2\text{·°F}$$
$$U_{framing} = 1/R_T = 1/7.7 = 0.13 \text{ Btu/h·ft}^2\text{·°F}$$

Notice that the U-factor for the framing is almost twice that of the wall cavity, which means it will lose energy faster. An adjusted U-factor can be obtained by calculating a weighted average between these two values. Typical wall sections consist of almost 25% framing. So, the weighted U-factor value is given by:

$$0.75(0.07) + 0.25(0.13) = 0.085 \text{ Btu / h·ft}^2\text{·°F}$$

The framing members have decreased the effectiveness of the insulation by almost 20%. This degrading effect is so significant that it is the topic of the next section.

4.2 U-Factors for Non-Uniform Sections

Let us look at the same wall section but replacing the wood studs with metal studs which have essentially no thermal resistance.

	At cavity	At framing
1. Outside air film (15 mph wind)	0.17	0.17
2. Wood siding (0.5 x 8 in. lapped)	0.81	0.81
3. Sheathing (0.5 in. regular)	1.32	1.32
4. Insulation (3.5 in. fiberglass)	11.00	
5. Metal stud		0.00
6. Gypsum (0.5 in.)	0.32	0.32
7. Inside air film (still air)	0.68	0.68
Total Thermal Resistance (R_T)	14.3	3.3 h·ft²·°F/Btu
U-factor = 1 / R_T =	0.07	0.30 Btu/h·ft²·°F

Assuming this time that 20% of the wall area is framing results in a weighted U-factor of 0.80(0.07) + 0.20(0.30) = 0.12 Btu/h·ft²·°F.

Again we see a significant reduction in the insulating ability of the wall. Some designers incorrectly ignore the metal when calculating the building heat loss because it is so thin. Because almost one-half of the wall's insulating value is lost to this thermal bridge, their heating load calculations are often much too small. Additional correction factors for framing members are given in *Table 4-1*. For additional examples of typical insulated wall sections, see Chapter 24 of the 1997 *ASHRAE Handbook–Fundamentals*.

Table 4-1. Correction Factors for Wall Sections with Metal Studs

Size of Members	Gauge of Stud[a]	Spacing of Framing, in.	Cavity Insulation R-Value	Correction Factor	Effective Framing/Cavity R-Values
2 × 4	18-16	16 o.c.	R-11 R-13 R-15	0.50 0.46 0.43	R-5.5 R-6.0 R-6.4
2 × 4	18-16	24 o.c.	R-11 R-13 R-15	0.60 0.55 0.52	R-6.6 R-7.2 R-7.8
2 × 6	18-16	16 o.c.	R-19 R-21	0.37 0.35	R-7.1 R-7.4
2 × 6	18-16	24 o.c.	R-19 R-21	0.45 0.43	R-8.6 R-9.0
2 × 8	18-16	16 o.c.	R-25	0.31	R-7.8
2 × 8	18-16	24 o.c.	R-25	0.38	R-9.6

[a]These factors can be applied to metal studs of this gauge or thinner.

Let us look at one final wall example using an insulated masonry cavity wall (see *Figure 4-2*). This time we will consider the thermal effect of the furring strips used to attach the gypsum wallboard to the inside. Assume the use of 0.75-in.-thick by 3-in.-wide vertical furring strips every 16 in. on center. Both calculations for the furring strips as well as the 0.75-in.-thick polystyrene insulation (R-5 per in.) between them are shown in *Table 4-2*.

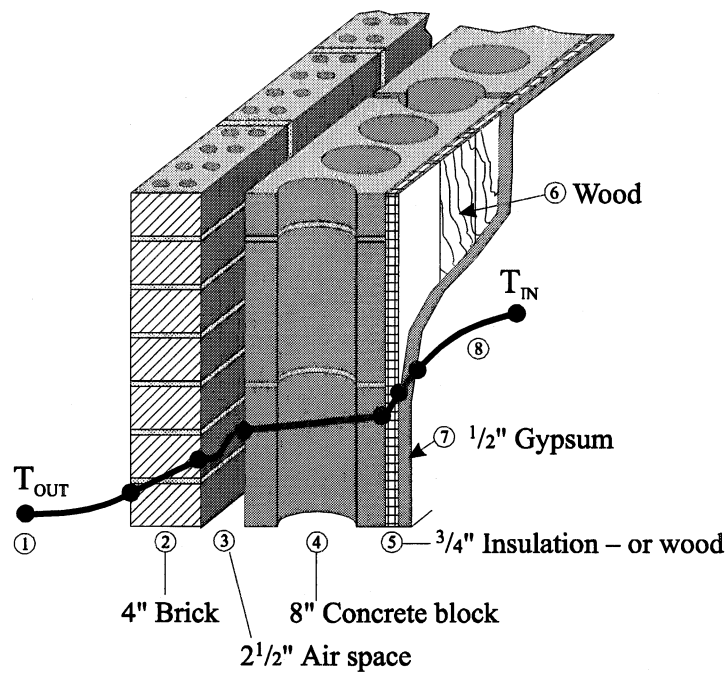


Figure 4-2. Masonry Wall Section

The total R_T values for the two columns in *Table 4-2* add up to 7.87 h·ft²·°F/Btu and 5.06 h·ft²·°F/Btu, respectively. Notice that in this case, the furring strips result in a lower total R-value by about 30%, but structurally they are required. The corresponding U-factors for between and at the furring strips are 0.127 Btu/h·ft²·°F and 0.198 Btu/h·ft²·°F, respectively. An adjusted U-factor is obtained by calculating a weighted average between these two values. Because the 3 in. furring strips are on 16 in. centers, they represent about 3/16 ≈ 20% of the wall area. With additional framing strips at the top and bottom of the wall, we will assume 25% of the area is framing. So the adjusted U-factor would be 75% of the first column plus 25% of the second column:

$$U_{av} = 0.75\cdot(0.127) + 0.25\cdot(0.198)$$
$$= 0.145\ \mathrm{Btu/h\cdot ft^2\cdot{}^\circ F}$$

For this wall section, this is the appropriate U-factor to use in the calculation table. It most closely approximates the value that would result from this type of construction. There are a number of additional variables that have not been included. For example, the nails used to build a typical wall section reduce the effective R_T-value by about R-1.0 but are not accounted for here.

Table 4-2. Masonry Wall Section Data

Construction	Resistance: Between Furring (Ri)	Resistance: At Furring (Rs)
1. Outside surface (15 mph wind)	0.17	0.17
2. Brick (4 in. fired clay)	0.8	0.8
3. Nonreflective air space (2.5 in.) (30°F mean, 10°F temperature difference)	1.1	1.1
4. Concrete block, three oval core, stone and sand aggregate (8 in.)	1.05	1.05
5. Polystyrene insulation (R-5 per in.)	3.75	
6. Nominal vertical furring (0.75 in. x 3 in.)		0.94
7. Gypsum wallboard (0.5 in.)	0.32	0.32
8. Inside surface (still air)	0.68	0.68
Total Thermal Resistance (Rt)	7.87	5.06*
U = 1/Rt	0.127	0.198**

* In h·ft²·°F/Btu
** In Btu/h·ft²·°F

The quality of construction and the quality of materials actually used also impact the rate of heat loss through the wall section. For example, the insulator might leave gaps and holes in the insulation. Loose fill insulation within walls tends to settle over time, creating voids. But because the designer has very little control over these (and other) unknowns during the design phase, you should always show a standard of care and maintain good records on the assumptions and conditions that you used in your calculations.

4.3 Surface Resistances and Dead-Air Spaces

As noted in the problems above, the inside and outside surfaces of each building will offer a small convective resistance to the heat transfer from the building. Notice in these examples that the inside value assumes still air, and the outside surface assumes a 15 mph wind on the building. These are standard heating load assumptions made by the designer unless other information is available. In the summer, a wind speed of 7.5 mph is generally assumed. Notice also that the inside air film offers somewhat more resistance than the outside film, because it is easier for moving air to "scrape" heat away from the building.

The convective resistances offered by various surface positions are shown in *Table 4-3*. Values for both non-reflective ($\varepsilon = 0.90$) and reflective (such as aluminum or mylar, $\varepsilon = 0.05$) surfaces are given. These convective values also include the effects of radiant heat transfer from the surface.

Two values that were used in the wall section examples on the previous pages can be found in *Table 4-3*. The inside and outside air film R-values of 0.68 and 0.17 respectively are the R-values shown for vertical walls with $\varepsilon = 0.90$. Notice that the effect of the wind on the outside surface is much more significant than either the direction of heat flow or surface emissivity properties.

Typical emissivity values for various surfaces can be found in Chapter 3 of the 1997 *ASHRAE Handbook–Fundamentals*.[2] These values are often very difficult to determine accurately, but an educated guess will get you within a few percent of the true value. For many building materials, the emissivity at room temperature is close to 0.90. The effectiveness of low-e glazing materials is also based on these properties. Minimizing the surface emissivity through the use of special films can significantly improve the thermal performance of windows .

Table 4.3 Convective Values

Position of Surface	Direction of Heat Flow	Surface Emittance, ε: Non-reflective ε = 0.90 h_i	R	Reflective ε = 0.20 h_i	R	Reflective ε = 0.05 h_i	R
STILL AIR							
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping—45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping—45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
MOVING AIR (Any position)		h_o	R				
15-mph Wind (for winter)	Any	6.00	0.17	—	—	—	—
7.5-mph Wind (for summer)	Any	4.00	0.25	—	—	—	—

Notes:
1. Surface conductance h_i and h_o measured in Btu/h·ft²·°F; resistance R in °F·ft²·h/Btu.
2. No surface has both an air space resistance value and a surface resistance value.
3. For ventilated attics or spaces above ceilings under summer conditions (heat flow down), see Table 5.
4. Conductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10°F and for surface temperatures of 70°F.
5. See Chapter 3 for more detailed information, especially Tables 5 and 6, and see Figure 1 for additional data.
6. Condensate can have a significant impact on surface emittance (see Table 2).

There is also a thermal resistance provided when an air gap exists between two surfaces. For example, most of the increased resistance provided by ordinary double-pane windows over single-pane windows is due to the difficult time that air has removing heat from the warm surface and depositing it onto the cold surface. However, as the distance between the surfaces increases, a convection current develops within the air space, and the rate of heat transfer begins to increase.

There are several factors that affect the thermal resistance of plane air spaces as shown in *Table 4-4*. The orientation of the air space and the direction of heat flow must be known. Convection currents increase the rate of heat transfer from a floor but have less effect on heat transfer downward from the ceiling. The mean temperature of the air in the space and the temperature difference across the space have an influence on the convective driving force and viscous friction of the moving air. The thickness of the air space and the effective emittance, ε_{eff}, also affect the rate of convective heat transfer. Between two surfaces, the effective emittance is the weighted average of both the inside value, ε_i, and the outside value, ε_o, through the following formula:

$$1/\varepsilon_{eff} = 1/\varepsilon_i + 1/\varepsilon_o - 1 \tag{4-5}$$

Example 4-1

Problem: Determine the R-value for a 1-in. air space between the brick and concrete block of a vertical masonry wall. The brick and block temperatures are 25°F and 55°F respectively, and each has an emittance of $\varepsilon = 0.9$.

Solution: Using the above equation to determine the effective emittance as:

$$\begin{aligned}\varepsilon_{eff} &= 1/(1/0.9 + 1/0.9 - 1) \\ &= 0.82\end{aligned}$$

Entering the last column ($\varepsilon_{eff} = 0.82$) of the top right quadrant of *Table 4-4* (because our 1 in. space is closest to 0.75 in.), go down to the line for horizontal heat flow, mean temperature of 50°F, and 30°F temperature difference. The R-value given is 0.99 °F·ft²·h/Btu.

As a final note, always be aware that these values for resistances of air spaces assume an enclosed space with parallel surfaces. As building construction tends to be less perfect than test laboratory samples, be cautious about assuming full credit for air gaps in construction assemblies. Wide gaps may allow free convection loops to occur. Air gaps can also provide paths for infiltration air to bypass the insulation system.

Table 4-4. Thermal Resistances of Plane Air Spaces[a,b,c]

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d], °F	Air Space Temp. Diff.[d], °F	0.5-in. Air Space[c] Effective Emittance ε_{eff}[d,e] 0.03	0.05	0.2	0.5	0.82	0.75-in. Air Space[c] Effective Emittance ε_{eff}[d,e] 0.03	0.05	0.2	0.5	0.82
		90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		50	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
Horiz.	Up	0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		−50	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
		−50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
		90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81
		50	30	2.06	1.98	1.56	1.10	0.83	1.99	1.92	1.52	1.08	0.82
		50	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94
45° Slope	Up	0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.00
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12
		−50	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16
		−50	10	2.62	2.56	2.17	1.66	1.33	2.53	2.47	2.10	1.62	1.30
		90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
Vertical	Horiz.	0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		−50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		−50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
		90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84
		50	30	2.64	2.52	1.87	1.24	0.91	3.43	3.23	2.24	1.39	0.99
		50	10	2.67	2.55	1.89	1.25	0.92	3.81	3.57	2.40	1.45	1.02
45° Slope	Down	0	20	2.91	2.80	2.19	1.52	1.15	3.75	3.57	2.63	1.72	1.26
		0	10	2.94	2.83	2.21	1.53	1.15	4.12	3.91	2.81	1.80	1.30
		−50	20	3.16	3.07	2.52	1.86	1.45	3.78	3.65	2.90	2.05	1.57
		−50	10	3.26	3.16	2.58	1.89	1.47	4.35	4.18	3.22	2.21	1.66
		90	10	2.48	2.34	1.67	1.06	0.77	3.55	3.29	2.10	1.22	0.85
		50	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02
		50	10	2.67	2.55	1.89	1.25	0.92	3.84	3.59	2.41	1.45	1.02
Horiz.	Down	0	20	2.94	2.83	2.20	1.53	1.15	4.18	3.96	2.83	1.81	1.30
		0	10	2.96	2.85	2.22	1.53	1.16	4.25	4.02	2.87	1.82	1.31
		−50	20	3.25	3.15	2.58	1.89	1.47	4.60	4.41	3.36	2.28	1.69
		−50	10	3.28	3.18	2.60	1.90	1.47	4.71	4.51	3.42	2.30	1.71

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d], °F	Air Space Temp. Diff.[d], °F	1.5-in. Air Space[c] 0.03	0.05	0.2	0.5	0.82	3.5-in. Air Space[c] 0.03	0.05	0.2	0.5	0.82
		90	10	2.55	2.41	1.71	1.08	0.77	2.84	2.66	1.83	1.13	0.80
		50	30	1.87	1.81	1.45	1.04	0.80	2.09	2.01	1.58	1.10	0.84
		50	10	2.50	2.40	1.81	1.21	0.89	2.80	2.66	1.95	1.28	0.93
Horiz.	Up	0	20	2.01	1.95	1.63	1.23	0.97	2.25	2.18	1.79	1.32	1.03
		0	10	2.43	2.35	1.90	1.38	1.06	2.71	2.62	2.07	1.47	1.12
		−50	20	1.94	1.91	1.68	1.36	1.13	2.19	2.14	1.86	1.47	1.20
		−50	10	2.37	2.31	1.99	1.55	1.26	2.65	2.58	2.18	1.67	1.33
		90	10	2.92	2.73	1.86	1.14	0.80	3.18	2.96	1.97	1.18	0.82
		50	30	2.14	2.06	1.61	1.12	0.84	2.26	2.17	1.67	1.15	0.86
		50	10	2.88	2.74	1.99	1.29	0.94	3.12	2.95	2.10	1.34	0.96
45° Slope	Up	0	20	2.30	2.23	1.82	1.34	1.04	2.42	2.35	1.90	1.38	1.06
		0	10	2.79	2.69	2.12	1.49	1.13	2.98	2.87	2.23	1.54	1.16
		−50	20	2.22	2.17	1.88	1.49	1.21	2.34	2.29	1.97	1.54	1.25
		−50	10	2.71	2.64	2.23	1.69	1.35	2.87	2.79	2.33	1.75	1.39
		90	10	3.99	3.66	2.25	1.27	0.87	3.69	3.40	2.15	1.24	0.85
		50	30	2.58	2.46	1.84	1.23	0.90	2.67	2.55	1.89	1.25	0.91
		50	10	3.79	3.55	2.39	1.45	1.02	3.63	3.40	2.32	1.42	1.01
Vertical	Horiz.	0	20	2.76	2.66	2.10	1.48	1.12	2.88	2.78	2.17	1.51	1.14
		0	10	3.51	3.35	2.51	1.67	1.23	3.49	3.33	2.50	1.67	1.23
		−50	20	2.64	2.58	2.18	1.66	1.33	2.82	2.75	2.30	1.73	1.37
		−50	10	3.31	3.21	2.62	1.91	1.48	3.40	3.30	2.67	1.94	1.50
		90	10	5.07	4.55	2.56	1.36	0.91	4.81	4.33	2.49	1.34	0.90
		50	30	3.58	3.36	2.31	1.42	1.00	3.51	3.30	2.28	1.40	1.00
		50	10	5.10	4.66	2.85	1.60	1.09	4.74	4.36	2.73	1.57	1.08
45° Slope	Down	0	20	3.85	3.66	2.68	1.74	1.27	3.81	3.63	2.66	1.74	1.27
		0	10	4.92	4.62	3.16	1.94	1.37	4.59	4.32	3.02	1.88	1.34
		−50	20	3.62	3.50	2.80	2.01	1.54	3.77	3.64	2.90	2.05	1.57
		−50	10	4.67	4.47	3.40	2.29	1.70	4.50	4.32	3.31	2.25	1.68
		90	10	6.09	5.35	2.79	1.43	0.94	10.07	8.19	3.41	1.57	1.00
		50	30	6.27	5.63	3.18	1.70	1.14	9.60	8.17	3.86	1.88	1.22
		50	10	6.61	5.90	3.27	1.73	1.15	11.15	9.27	4.09	1.93	1.24
Horiz.	Down	0	20	7.03	6.43	3.91	2.19	1.49	10.90	9.52	4.87	2.47	1.62
		0	10	7.31	6.66	4.00	2.22	1.51	11.97	10.32	5.08	2.52	1.64
		−50	20	7.73	7.20	4.77	2.85	1.99	11.64	10.49	6.02	3.25	2.18
		−50	10	8.09	7.52	4.91	2.89	2.01	12.98	11.56	6.36	3.34	2.22

[a]See Chapter 22, section Factors Affecting Heat Transfer across Air Spaces. Thermal resistance values were determined from the relation, $R = 1/C$, where $C = h_c + \varepsilon_{eff} h_r$, h_c is the conduction-convection coefficient, $\varepsilon_{eff} h_r$ is the radiation coefficient ≈ $0.0068\varepsilon_{eff}[(t_m + 460)/100]^3$, and t_m is the mean temperature of the air space. Values for h_c were determined from data developed by Robinson et al. (1954). Equations (5) through (7) in Yarbrough (1983) show the data in this table in analytic form. For extrapolation from this table to air spaces less than 0.5 in. (as in insulating window glass), assume $h_c = 0.159(1 + 0.0016\,t_m)/l$ where l is the air space thickness in inches, and h_c is heat transfer through the air space only.

[b]Values are based on data presented by Robinson et al. (1954). (Also see Chapter 3, Tables 3 and 4, and Chapter 36). Values apply for ideal conditions, i.e., air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no air leakage to or from the space. When accurate values are required, use overall U-factors determined through calibrated hot box (ASTM C 976) or guarded hot box (ASTM C 236) testing. Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space.

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

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

[e]Effective emittance ε_{eff} of the air space is given by $1/\varepsilon_{eff} = 1/\varepsilon_1 + 1/\varepsilon_2 - 1$, where ε_1 and ε_2 are the emittances of the surfaces of the air space (see Table 2).

4.4 Thermal Performance Among Alternatives

The final topic to be considered in this chapter involves comparing the thermal performance of various insulation option packages. To show how these comparisons can be made, we will consider several alternative insulation thicknesses for a commercial flat masonry roof with built-up roofing and suspended ceiling, as shown in *Figure 4-3*.

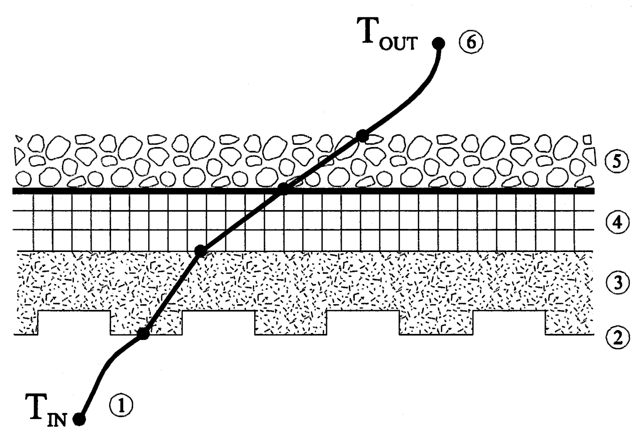


Figure 4-3. Flat Masonry Roof Section

The materials of construction are given in *Table 4-5*. Notice that no thermal resistance credit is taken for the ceiling tile or the horizontal air space. This is due to the high rate of air leakage through lighting fixtures that typically are recessed into a suspended ceiling. Due to the convection loops that will occur within this large air space, it is recommended that neither of these elements be included in your calculation.

Table 4-5. Materials of Construction for Flat Masonry Roof

	None	1 in.	2 in.	3 in.	
1. Inside surface (still air)	0.61	0.61	0.61	0.61	
2. Corrugated metal deck	0	0	0	0	
3. Concrete slab, lightweight aggregate, 2 in. (30 lb/ft³)	2.22	2.22	2.22	2.22	
4. Rigid roof deck insulation (1.5 lb/ft³)	0.0	4.17	8.34	12.51	
5. Built-up roofing (0.375 in.)	0.33	0.33	0.33	0.33	
6. Outside surface (15 mph wind)	0.17	0.17	0.17	0.17	
Total Thermal Resistance, R_T	3.33	7.50	11.67	15.84	h·ft²·°F/Btu
U-factor = $1/R_T$	0.30	0.13	0.09	0.06	Btu / h·ft²·°F

Item 4 assumes the addition of 1 in. to 3 in. of expanded polystyrene bead board. While the total thermal resistance continues to increase with each additional inch (and the corresponding U-factor to decrease), notice that the first inch of insulation results in the greatest savings, cutting by one-half the rate of heat transfer (from U = 0.3 to U = 0.13).

The next 2 in. again cut the rate of heat transfer in half (to U = 0.06), but it requires twice the insulation to accomplish it (2 in. as opposed to 1 in.). This demonstrates a classic case of diminishing economic return, but to accurately calculate the economic value of these alternatives requires several additional assumptions and methods beyond the scope of this course.

The Next Step

In the next chapter, we will discuss in detail how to calculate the heat loss through examples of each building surface (wall, ceiling and floor) and different building geometries (such as gables and dormers). We will also describe how to calculate heat loss through different types of floors (slab-on-grade, crawlspaces and basements). Finally, we will discuss how to handle the heat loss to attached unheated spaces.

Summary

You now have gained all of the basic skills needed to calculate the heat loss from a building. In Chapter 3, you learned where to find the appropriate design temperature data for both inside and outside conditions. In this chapter, you learned how to determine the U-factor through a wall or roof section. After looking up the R-values for each material in the cross-section, add all of the R-values to determine the total thermal resistance, R_T. Then take the reciprocal of R_T to find the U-factor. The final important step in determining the U-factor is to adjust it for the effect of the structural members.

You also learned how the insulating effect of an air cavity depends on its orientation, temperature and surface emissivities. Finally we described how a table of insulating package alternatives can be constructed to help designers compare their economic values. The only other data that we need to begin applying the $Q = U{\cdot}A{\cdot}\Delta T$ equation is the area of the wall or roof section. That information is available either from the drawings in new construction or through field measurements on existing structures.

After studying Chapter 4, you should be able to:

- Use the tabulated data in Chapter 24 of the 1997 *ASHRAE Handbook–Fundamentals*.
- For a given building section, calculate the effective R-value, and convert it to a U-factor.
- Determine the effective air film coefficient for a given geometry and surface property.

Bibliography

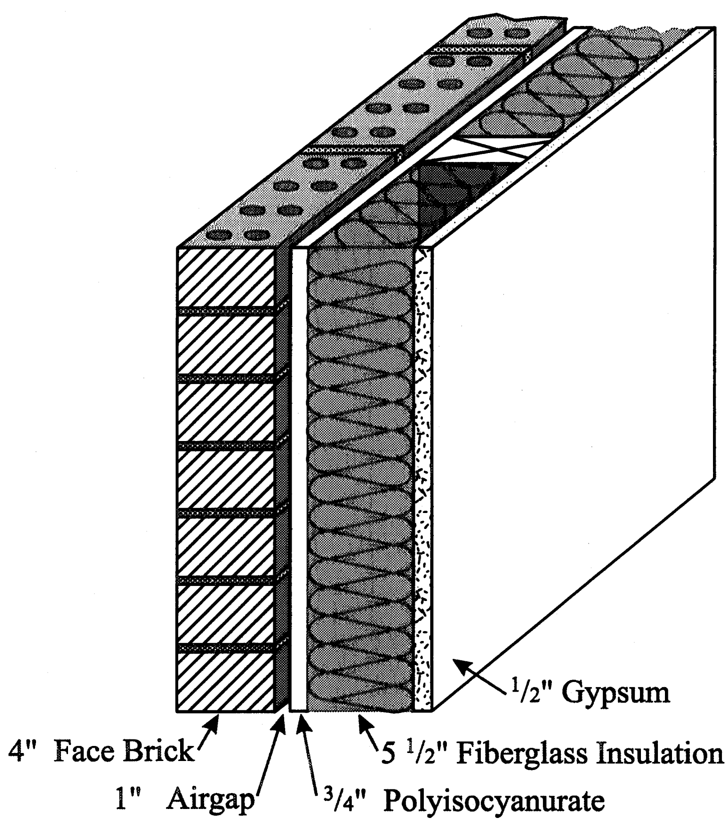
1. ASHRAE. 1997. "Thermal and water vapor transmission data." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 24.

2. ASHRAE. 1997. "Heat transfer." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 3.

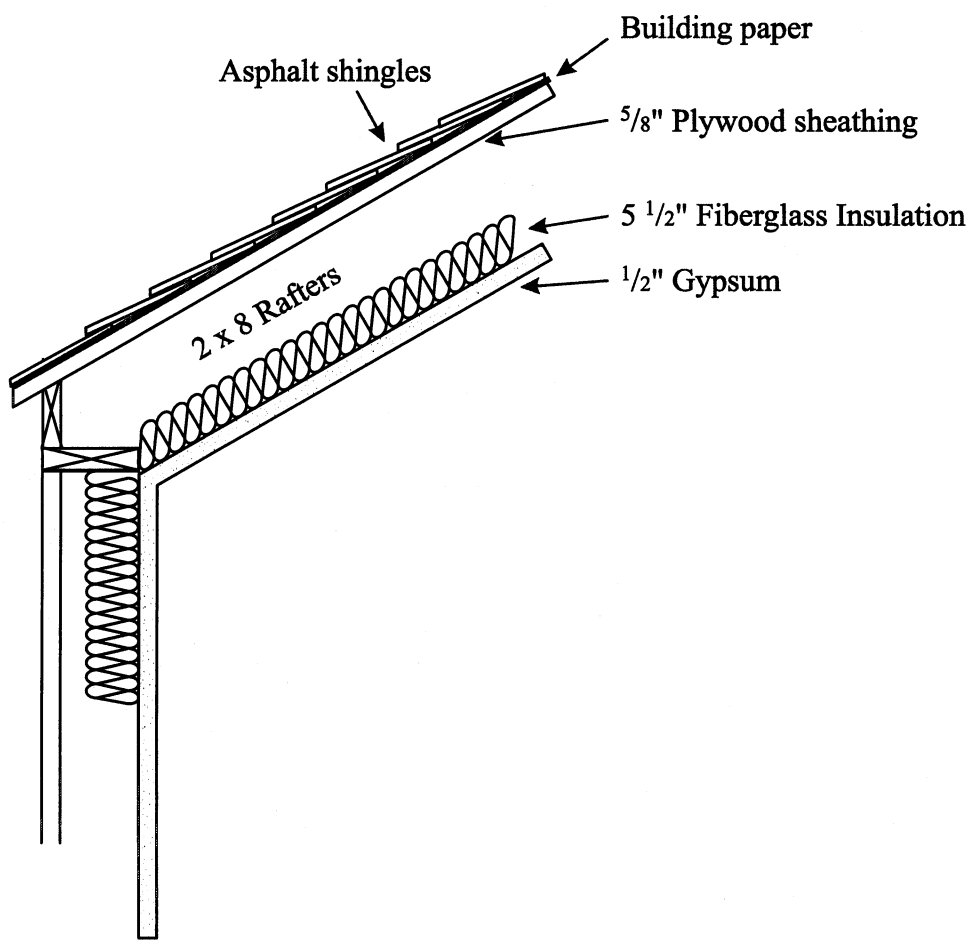
Skill Development Exercises for Chapter 4

Complete these questions by writing your answers on the worksheets at the back of this book.

4-01. The sample wall section shown below consists of 2×6 wood studs on 24 in. centers with R-19 insulation. Assuming 10% of the wall area is framing, calculate the effective U-factor.



4-02. For the roof detail section shown below, calculate the effective net U-factor, assuming a 20% framing factor.



4-03. Closing the drapes on a single-pane window effectively adds a 4 in. dead air space (assuming a perfect seal). If the emissivities of the drapery material and glass surface are 0.9 and 0.8 respectively, determine the difference in the rate of heat loss through a 5×9 ft single-pane window with the drapes open and closed. Assume negligible R-value for the glazing material itself, and a temperature difference of 60°F.

4-04. Explain why the air film coefficient (h_i) for horizontal surfaces is higher for upward heat flows than for downward heat flows.

Chapter 5
Heat Transfer Through Walls, Roofs and Floors

Contents of Chapter 5

Instructions

Read the material in Chapter 5. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 5

In this chapter, you will learn how to calculate the heat loss from a small residential building. We will also discuss thermal losses to unheated spaces, as well as losses through various floor types.

After studying Chapter 5, you should be able to:

- Estimate the heat loss rate through an unheated attached space.
- Estimate the heat loss through a slab-on-grade floor.
- Calculate the heat loss rates from various insulation systems in a crawlspace.
- Estimate the heat loss through a gabled roof or dormer.

5.1 *Building Description*

To demonstrate the process used to calculate the heating load, here is a design for a five-room house with an attached garage. The south elevation of the house is shown in *Figure 5-1*. Obviously, this example is very poorly laid out from an architectural viewpoint, but it will allow discussion of a variety of construction options encountered when calculating thermal loads.

Beginning at the far left (west), the garage (12×16 ft) is an unheated space. It shares an insulated wall with the kitchen (16×16 ft) which has a slab-on-grade floor. The dining room (20×16 ft) is built over a basement, and has a bedroom (20×16 ft) above it. The living room (22×16 ft) has a crawlspace below it, and the second bedroom (26×16 ft) is located above it.

To keep the problem relatively simple, each room is 8 ft high and 16 ft wide. Analysis of the external walls and ceilings yields U-factors of 0.06 Btu/h·ft^2·°F and 0.4 Btu/h·ft^2·°F, respectively. Assume each downstairs room has one 24×36 in. thermopane window with wood frame (U=0.5 Btu/h·ft^2·°F) on the north wall, and the kitchen and living room each have a 28×80 in. insulated metal door (U=0.3 Btu/h·ft^2·°F) on the south wall. Each bedroom has a 30×48 in. dormer window (U=0.5 Btu/h·ft^2·°F) and a gabled roof. The east bedroom has a 4 ft overhang on the east side.

Finally, we will assume that the house is located in Chicago, Illinois, where the winter design temperature is -4°F. The assumed inside design temperature is 65°F, and the average infitration into all rooms is 0.5 air changes per hour (ACH).

While all calculations can be done by hand, the calculation process lends itself quite nicely to the use of a spreadsheet. There are also several commercially available software packages that perform thermal load calculations. However, the comparison among these packages is beyond the scope of this course.

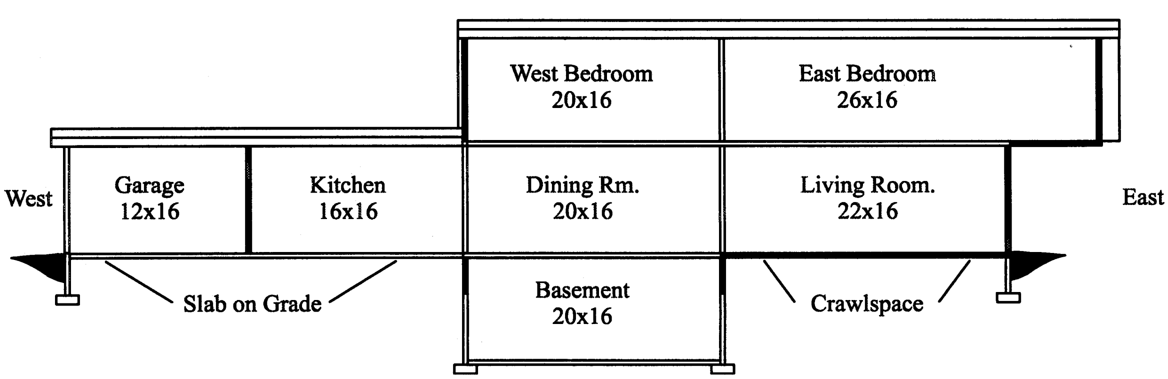


Figure 5-1. Example House Floorplan

5.2 *Zoning the Design*

The first step in performing a building thermal analysis is to consider how the building will be zoned. Because the energy transport system must be sized to ensure that each zone receives its fair share of the overall capacity, the energy needs of each zone must be determined individually. Usually the floor layouts are not available early in the design phase, and simplifying assumptions must be made to get started with mechanical equipment sizing and alternative comparisons. Perhaps each floor might be initially considered as a single zone, with the understanding that more details will be available later.

In this case, we will consider each room to be a separate zone, starting with the kitchen (see *Table 5-1*). Notice in the table that the door and window areas have been subtracted from the south wall and north wall net areas, respectively. The floor is slab-on-grade, and has an assumed U-factor of 0.1 Btu/h·ft²·°F and an assumed temperature difference of 20°F. (These assumptions will be discussed in Section 5.4.) There is no heat loss through the east side of this room, because it is adjacent to the dining room, and there is no temperature difference between the rooms. The west wall is adjacent to the unheated garage. The next section will discuss how to handle this situation, followed by a section discussing slab-on-grade floor heat loss calculations.

Table 5-1. Thermal Analysis of Example Kitchen

Section	Gross Area	Net Area	U = 1/R	$T_i - T_o$	$UA(T_i - T_o)$
North	16x8 - 2x3	122	0.06	69	505
East	heated space				0
West	16x8	128	0.06	66	507
South	16x8-28x80/144	112	0.06	69	464
Windows	2x3	6	0.5	69	207
Doors	28x80/144	16	0.3	69	331
Ceiling	16x16	256	0.04	69	707
Floor	16x16	256	0.1	20	512
Infiltration	16x16x8x0.5	1024	0.018	69	1272
			Total Heat Load =		**4505 Btu/h**

5.3 *Unheated Spaces*

Under steady-state conditions, the heat loss rate from the kitchen into the garage will equal the heat loss rate from the garage to the outside air. However, to determine either of these heat loss rates, it is first necessary to estimate the air temperature in the garage. This temperature will always be between the indoor and outdoor air temperatures. If the unheated space is well ventilated, uninsulated or includes large areas of glass (such as sunspaces and sleeping parlors), then the unheated space air temperature approaches that of the outdoor air. If the product of the wall areas and heat transfer coefficients (*UA*) happens to be equal between the unheated space and both the inside and outside (not true in this case), then the unheated space temperature can be assumed to be the mean of the indoor and outdoor air temperatures.

To calculate the air temperature, T_u, within an unheated space, equate the sum of heat loss rates from the unheated space with the sum of heat gains from the heated structure. In this case, the heat loss from the garage is due to both loss through the walls and to infiltration of cold outside air.

$$Q_{out} = Q_{in} \tag{5-1}$$

$$\left[\sum U_a A_a + (60 \times 0.018) Q_o\right](T_u - T_{out}) = \left(\sum U_1 A_1\right)(T_{in} - T_u)$$

where,

T_u = temperature in unheated space, °F

T_{in} = indoor design temperature of heated room, °F

$\Sigma U_I A_I$ = sum of *UA* products for surfaces between unheated space and heated space

T_{out} = outdoor design temperature, °F

$\Sigma U_a A_a$ = sum of *UA* products for surfaces between unheated space and outdoor air design temperature

60 × 0.018 = (minutes per hour) times (density times specific heat for standard air), Btu·min/h·ft³·°F

Q_o = rate of introduction of outside air into unheated space by infiltration and/or ventilation, cfm

The only unknown in *Equation 5-1* is the temperature of the unheated space, T_u. Algebraically solve for this unknown by putting all of the terms that include T_u on one side of the equation, factor out T_u, then divide both sides by the remaining term:

$$T_u\left[\left(\sum U_1 A_1\right)+\left(\sum U_a A_a+(60\times 0.018)Q_o\right)\right]=T_{in}\left(\sum U_1 A_1\right)+T_{out}\left(\sum U_a A_a+(60\times 0.018)Q_o\right)$$

$$T_u=\frac{T_{in}\left(\sum U_1 A_1\right)+T_{out}\left[\sum U_a A_a+(60\times 0.018)Q_o\right]}{\left(\sum U_1 A_1\right)+\left[\sum U_a A_a+(60\times 0.018)Q_o\right]}$$

In our kitchen example, assume the garage walls and roof have U-factors of U=0.09 and U=0.05, respectively. The area of the interior (U=0.06) wall is 16×8 = 128 ft², and the area of the three exposed garage walls is (12+16+12)(8) = 320 ft². We will assume that the area of each side of the 5:12 pitched roof is 12×8.67 = 104 ft², so the total roof area is 208 ft². We will also assume that the garage door leaks about 100 cfm. This rate translates to about 4 air changes per hour, as will be explained more fully in the next chapter. If the indoor and outdoor temperatures are 65°F and -4°F respectively, then the garage temperature is:

$$\begin{aligned}T_u&=\frac{65°\text{F}(0.06)(128)+(-4°\text{F})[(0.09)(320)+(0.05)(208)+(60\times 0.018)(100\,\text{cfm})]}{(0.06)(128)+(0.09)(320)+(0.05)(208)+(60\times 0.018)(100\,\text{cfm})}\\&=\frac{499-589}{7.7+148}\\&=-0.6°\text{F}\end{aligned}$$

This temperature is used to determine the 66°F shown in the temperature difference column of *Table 5-1* for the west wall of the kitchen. The garage temperature is only a few degrees above the outdoor air temperature. This is due to the larger surface exposed to the outside condition and to outside air leaking into the space. If the garage had been insulated, or if the rate of air exchange could be reduced (let Q_o approach 0), then the space temperature would increase another few degrees. (The importance of air infiltration will be discussed in the next chapter.)

5.4 Slab-on-Grade

Research conducted by Houghten *et al.*[1] and Dill *et al.*[2] indicates that heat flow is approximately 2.0 Btu/h·ft²·°F through an uninsulated concrete basement floor with a temperature difference of 20°F between the basement floor and the air 6 in. above it. As shown in *Table 5-1* for the kitchen, this data can be modeled as an effective U-factor of 0.1 Btu/h·ft² and a temperature difference of 20°F. This simple assumption is quite commonly used for residential slab-on-grade heat load calculations, but there are more accurate techniques available.

For concrete slab floors in contact with the ground at grade level, tests indicate that for small floor areas (equal to that of a 25×25 ft house), the heat loss can be calculated as proportional to the length of exposed edge rather than total area. This amounts to 0.81 Btu/h per linear foot of exposed edge per °F difference between the indoor air temperature and the average outdoor air temperature (Btu/h·ft·°F). Using this method in our kitchen example, which has (2×16=32) ft of exposed edge, the rate of heat transfer through the floor would be,

$$Q = (0.81 \text{ Btu/h·ft·°F})(32 \text{ ft})(69\text{°F}) = 1788 \text{ Btu/h}$$

instead of the 512 Btu/h shown in *Table 5-1* and determined using the above method. For very large floors, assume that a 10-ft width around the perimeter is controlled by loss to the outside air (second method), and the interior area loses energy at 2 Btu/h·ft².

Example 5-1

Problem: Determine the heat loss from a 100×80 ft warehouse slab-on-grade floor with a design temperature difference of 74°F.

Solution: The actual perimeter of the floor is 360 ft, which would yield a perimeter loss of:

$$Q = (0.81 \text{ Btu/h·ft·°F})(360 \text{ ft})(74\text{°F}) = 21{,}578 \text{ Btu/h}$$

Subtracting a 10-ft border leaves an interior area of 80×60 = 4,800 ft² which loses 2.0 Btu/h·ft² or (4,800 ft²)(2.0 Btu/h·ft²) = 9,600 Btu/h. Adding these two values together gives a total floor heat loss of 31,178 Btu/h or an average loss of about 3.9 Btu/h·ft².

This sizable heat loss rate can be reduced appreciably by installing insulation under the ground slab and along the perimeter between the floor and abutting walls. Depending on the construction details, as shown in *Figure 5-2*, there are several methods to accomplish this thermal break between the floor slab and the outside environment. This practice is strongly encouraged in new construction.

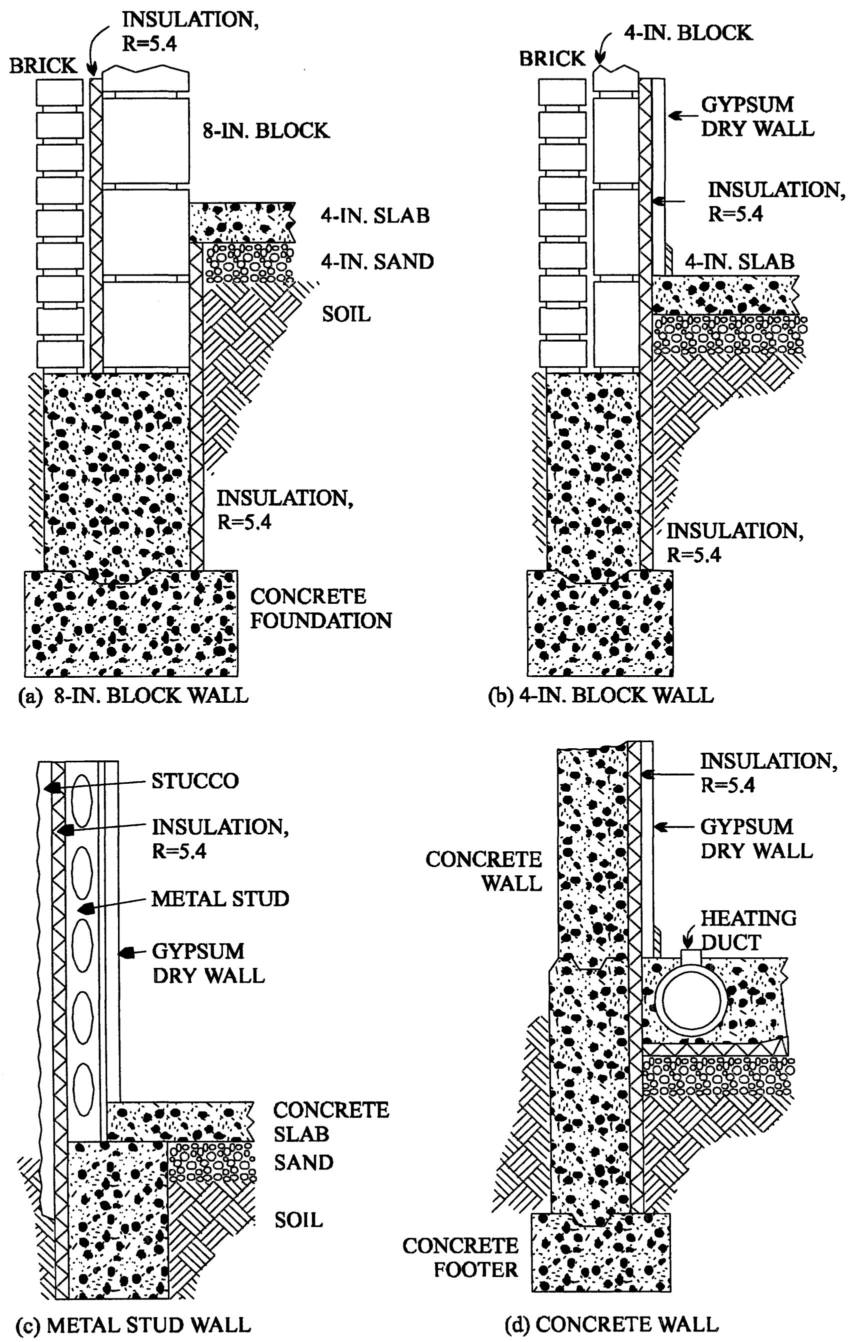


Figure 5-2. Slab-on-Grade Foundation Insulation

5.5 Basement

The basement interior is considered conditioned space if a minimum of 50°F is maintained over the heating season. Because the water heater and building heating plant with associated ducts or pipes are usually located in the basement, the basement temperature is often at or above 50°F.

In older buildings, the basement wall above grade is often not insulated. The rate of heat loss from this exposed area will be significant, because concrete and stone are relatively good thermal conductors. Standard practice in newer construction is to insulate the exterior portion of a basement wall both above grade plus a few feet below grade as shown in *Figure 5-3*.

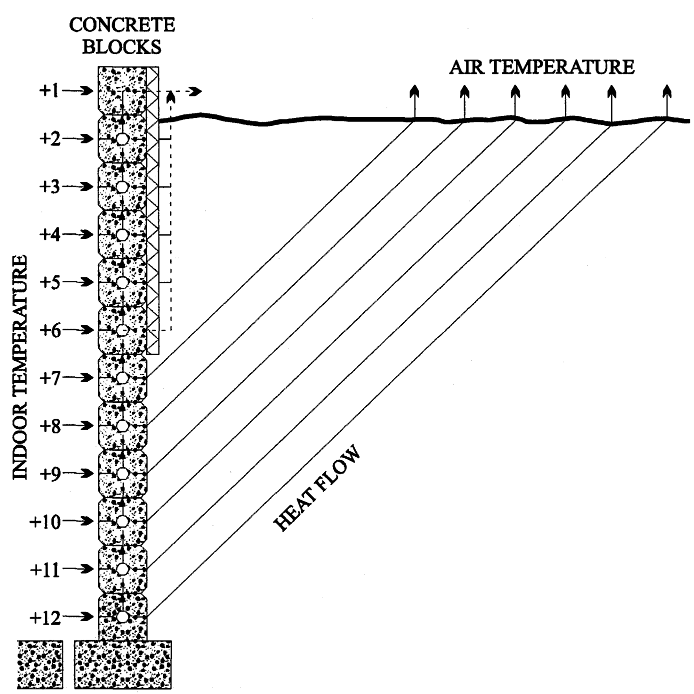


Figure 5-3. Heat Flow Path for Partially Insulated Basement Wall

The rate of heat loss from basement walls can be estimated using the data presented in *Table 5-2*. This table lists heat loss values at different depths for both uninsulated and insulated concrete walls.[3] For each one foot increment below grade, the heat loss is extracted from the appropriate column. The series of values for the wall are then added together and multiplied by the basement perimeter to determine the total basement wall heat loss.

The rate of heat loss from the basement floor can be estimated using *Table 5-3*, where the depth of the foundation wall and shortest width are used to determine the effective U-factor. Multiply this average value by the basement floor area to determine an estimate for the heat loss through the basement floor.

For both basement walls and basement floors, the effective temperature difference is not the same as the inside and outside air temperature difference. The heat capacity of the soil tends to buffer the temperature swings, which are represented by the amplitude value, *A*, on the map in *Figure 5-4*. To estimate the average soil temperature, look up the average winter air temperature in the meteorological records, then subtract the value of *A* at your location.

Table 5-2. Heat Loss Below Grade in Basement Walls[3]

Depth, ft	Path Length thru Soil, ft	Heat Loss*							
		Uninsulated		*R = 4.17*		*R = 8.34*		*R = 12.5*	
0-1	0.68	0.41	Sum to Depth	0.152	Sum to Depth	0.093	Sum to Depth	0.067	Sum to Depth
1-2	2.27	0.222	0.632	0.116	0.268	0.079	0.172	0.059	0.126
2-3	3.88	0.155	0.787	0.094	0.362	0.068	0.24	0.053	0.179
3-4	5.52	0.119	0.906	0.079	0.441	0.06	0.3	0.048	0.227
4-5	7.05	0.096	1.002	0.069	0.51	0.053	0.353	0.044	0.271
5-6	8.65	0.079	1.081	0.06	0.57	0.048	0.401	0.04	0.311
6-7	10.28	0.069	1.15	0.054	0.624	0.044	0.445	0.037	0.348

*Btu/h·ft²·°F

Table 5-3. Heat Loss Through Basement Floors*

Depth of Foundation Wall Below Grade, ft	Shortest Width of House, ft			
	20	24	28	32
5	0.032	0.029	0.026	0.023
6	0.03	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

*Btu/h·ft²·°F

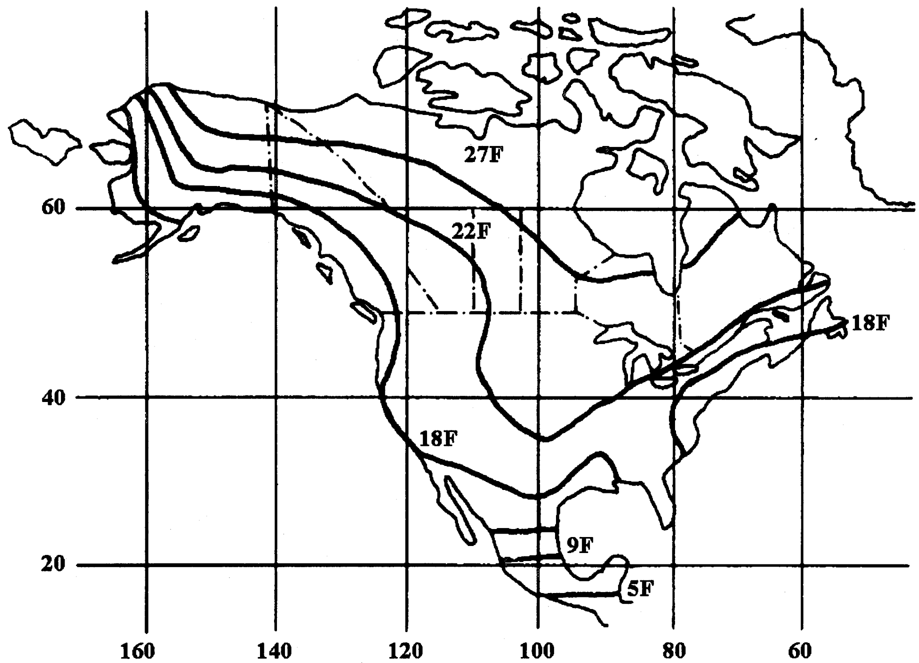


Figure 5-4. Lines of Constant Amplitude, *A*

EXAMPLE 5-2

Problem: Apply this method to determine the heat loss from the 20×16 ft basement under the dining room of the model home. The basement floor is 6 ft below grade, which in turn is 16 in. below the dining room floor. Foundation insulation rated at R-8.34 h·ft²·°F/Btu extends down the wall for the first 3 ft below grade. The inside temperature is 65°F, the outdoor design temperature is -4°F and the average winter temperature in Chicago is 27°F.

Solution: Three calculations are needed to determine the heat loss from this basement: the above-grade wall, the below-grade wall and the basement floor. Because the east and west walls adjoin heated spaces above, their losses are negligible. We are only concerned with the north and south walls, and we will begin at the top.

The top 16 in. on the north and south wall are exposed to outside air. The composite wall R-value (assuming 8 in. concrete block, the insulation and air films on both sides) is:

$$\begin{aligned} R_T &= 0.68 + 1.11 + 8.34 + 0.17 \\ &= 10.3 \text{ h·ft}^2\text{·°F/Btu} \end{aligned}$$

So, $U = 1/R_T = 0.097$ Btu/h·ft²·°F. The area is two walls at 20 ft × (16/12) ft = 53 ft², and ΔT = 65-(-4) = 69. Therefore:

$$\begin{aligned} Q_{exposed} &= UA\Delta T \\ &= (0.097 \text{Btu/h·ft}^2\text{·°F})(53 \text{ ft}^2)(69\text{°F}) \\ &= 355 \text{ Btu/h} \end{aligned}$$

For the rest of the wall below grade, we develop the following table based on data from *Table 5-2*. We use the R-8.34 column for the first 3 ft below grade, because they are insulated, and use the uninsulated column below that level.

First foot below grade	= 0.093 Btu/h·ft·°F
Second foot below grade	= 0.079 Btu/h·ft·°F
Third foot below grade	= 0.068 Btu/h·ft·°F (uninsulated)
Fourth foot below grade	= 0.119 Btu/h·ft·°F (uninsulated)
Fifth foot below grade	= 0.096 Btu/h·ft·°F
Sixth foot below grade	= 0.079 Btu/h·ft·°F
Total per foot length of wall	= 0.534 Btu/h·ft·°F

Because the length of the north and south basement walls totals 40 ft, the total wall heat loss rate through the basement walls below grade is (0.534 Btu/h·ft·°F)(40 ft) = 21 Btu/h·°F.

For the basement floor, we determine the average heat loss coefficient from *Table 5-3* (assuming 20 ft width) as 0.030 Btu/h·ft²·°F. The basement floor area is 16×20 = 320 ft², and so the total basement floor heat loss rate is (0.030 Btu/h·ft²·°F)(320 ft²) = 9.6 Btu/h·°F

To find the design temperature difference for the below-grade walls and basement floor, we start with the given mean winter temperature of 27°F. From *Figure 5-4*, we estimate the variation amplitude in Chicago to be A = 22°F. So the design temperature difference is given by:

$$\Delta T = 65\text{°F} - (27\text{°}-22\text{°}) = 60\text{°F}$$

Multiply this temperature difference by the sum of the basement wall and floor heat loss rates determined previously. The design heat loss from the basement is the sum of these three calculations:

$$Q_{Basement} = (21 + 9.6 \text{ Btu/h·°F})(60\text{°F}) + 355 \text{ Btu/h} = 2{,}191 \text{ Btu/h}$$

By comparison to the basement calculation, the dining room analysis in *Table 5-4* is very straightforward. The north wall has a window subtracted from it. The east and west walls adjoin heated spaces. The ceiling and floor adjoin the bedroom and basement, respectively, and have no heat loss. The infiltration is assumed at 0.5 air changes per hour, and the U-factors and temperature differences are as stated in the beginning.

Table 5-4. Thermal Analysis of Example Dining Room

Section	Gross Area	Net Area	U	$T_i - T_o$	$Q = UA(T_i - T_o)$
North	8x20 - 2x3	154	0.06	69	638
East	heated space			0	0
West	heated space			0	0
South	8x20	160	0.06	69	662
Windows	2x3	6	0.5	69	207
Doors	none				0
Ceiling	heated space				0
Floor	heated space			0	0
Infiltration	16x20x8x0.5	1280	0.018	69	1590
			Total Heat Loss =		**3097 Btu/h**

5.6 *Crawlspace*

Next we turn our attention to the living room, which is located over a crawlspace. *Table 5-5* below shows the results for this room. There is no heat loss from the ceiling or west walls, because they adjoin the bedroom and dining room respectively, and there is no temperature difference across the walls. There is an exterior door on the south wall of this space and one window on the north side. For simplicity, we will again assume 0.5 air change per hour for the infiltration rate. The major change is the heat loss through the crawlspace, as will be discussed below.

The heat loss to a crawlspace depends on how it is treated and vented. To minimize the transpiration of moisture from the ground, sheets of vapor retardant (such as polyethylene film) are used to cover the ground surface. Most codes require crawlspaces to be adequately vented all year round to minimize moisture problems. However, venting the crawlspace during the heating season causes substantial heat loss through the floor.

If the floor above is insulated between the floor joists (remember that the insulation's vapor retarder must be on top), then the vents should be kept open and the effective U-factor of the floor calculated, based on the materials used and heat flow in the downward direction. The temperature difference would be the same as for the walls.

Table 5-5. Thermal Analysis of Example Living Room

Section	Gross Area	Net Area	U	$T_i - T_o$	$Q = UA(T_i - T_o)$
North	22x8 - 2x3	170	0.06	69	704
East	16x8	128	0.06	69	530
West	heated space			0	0
South	22x8 - 28x80/144	160	0.06	69	662
Windows	2x3	6	0.5	69	207
Doors	28x80/144	16	0.3	69	331
Ceiling	heated space				0
Floor	22x16	352	0.07	69	1700
Infiltration	22x16x8x0.5	1408	0.018	69	1749
			Total Heat Loss =		5883 Btu/h

EXAMPLE 5-3

Problem: In our living room example, assume R-11 insulation is added between the 2×8 floor joists and under the R-3 allowance for dead air space and flooring; then calculate the rate of heat loss through the floor.

Solution: First calculate the effective U-factor assuming the joists represent 10% of the floor area; with an R-value of R-1.25 times the 7.5 in. thickness yields R-9.4 h·ft²·°F/Btu for the joists. Adding this value to the R-3 of the flooring allows us to determine an effective R-value as 0.9 (11 + 3) + 0.1 (9.4 + 3) = 13.8 h·ft²·°F/Btu or U=0.07 Btu/h·ft²·°F.

Assuming the air temperature in the crawlspace is the same as outside (-4°F), then the heat loss as shown for the floor loss in *Table 5-5* becomes:

$$Q = UA\Delta T = (0.07\ \text{Btu/h·ft}^2\text{·°F})(352\ \text{ft}^2)(65\text{°F} - [-4\text{°F}]) = 1700\ \text{Btu/h}$$

Another common design alternative is to insulate the perimeter walls. If these walls are insulated (either inside or outside), the vents should be kept closed during the heating season and open the remainder of the year. This is especially true if the building's furnace and/or ductwork are located in the crawlspace. The heat losses from these components will cause the crawlspace temperature to approach that of the indoor conditioned space.

The rate of heat loss through the floor to a crawlspace will equal the sum of the losses to the ground, due to air exchange through the vents, and through the perimeter walls. The temperature within the crawlspace will be somewhere between the outdoor and indoor temperatures. Under normal conditions, the crawlspace temperature will be close to 55°F, and losses to the ground (at about 50°F during the winter) become small. Using an effective U-factor of 0.1 Btu/h·ft²·°F for the ground as discussed in Section 5.4, the heat loss into the ground from the crawlspace becomes:

$$Q_{ground} = UA\Delta T = (0.1\ \text{Btu/h·ft}^2\text{·°F})\ (22\times16\ \text{ft}^2)(55°\text{-}50\text{°F}) = 176\ \text{Btu/h}$$

To determine the losses due to air exchange, Latta and Boileau estimate the exchange rate for an uninsulated basement at 0.67 air changes per hour under winter conditions.[3] The exchange rate in a crawlspace should be comparable.

Example 5-4

Problem: In our living room example, assume the crawlspace temperature is 55°F, and that the outside walls are 16-in. high concrete blocks (R-1.4 h·ft²·°F/Btu) and insulated with R-5.4 h·ft²·°F/Btu insulation. Determine the heat loss through the crawlspace.

Solution: There are three parts to solving this problem: the loss into the ground, the perimeter loss, and loss due to ventilation. From the calculation in the previous example, we know that the heat loss into the ground is 176 Btu/h. The second step is to calculate the rate of heat loss through the insulated perimeter walls above grade. The three exposed walls (north, east and south) have a total length of 60 ft. That value times the height of 16 in. gives an exposed area of 80 ft². The total R-value (including air films, concrete block and insulation) is 0.68+5.4+1.4+0.17=7.7 h·ft²·°F/Btu with a U-factor of 0.13 Btu/h·ft²·°F. The loss is from our assumed crawlspace temperature of 55°F to the outside design temperature of -4°F. The perimeter heat loss is given by:

$$Q_{perimeter} = UA\Delta T = (0.13\ \text{Btu/h·ft}^2\text{·°F})\ (80\ \text{ft}^2)\ (55\text{-}[-4]\ \text{°F}) = 614\ \text{Btu/h}$$

The third step is to calculate the heat loss due to air exchange. In this example, we will assume 0.67 air changes per hour (ACH) for the crawlspace. The volume is the floor area of the living room times an assumed height of 16 in. The temperature difference is the same as in the previous calculation. Using these values, the ventilation heat loss would be:

$$\begin{aligned} Q_{vent} &= \text{(ACH)(Volume per air change)(heat capacity per ft}^3\text{ of air)(Ti-To)} \\ &= (0.67\ \text{ACH})(16/12\times22\times16\ \text{ft}^3)(0.018\ \text{Btu/ft}^3\text{·°F})(55\text{-}[-4]\text{°F}) = 334\ \text{Btu/h} \end{aligned}$$

So, the total heat loss is the sum of the energy lost to the ground, the walls and through ventilation:

$$Q_{total} = 176 + 614 + 334 = 1124\ \text{Btu/h}$$

As a final check on our assumption of a 55°F temperature in the crawlspace, we should check that the total heat loss rate from the crawlspace matches the loss rate through the uninsulated R-3 h·ft²·°F/Btu floor of the living room:

$$Q_{floor} = UA\Delta T = (0.33\ \text{Btu/h·ft}^2\text{·°F})(16\times22\ \text{ft}^2)(65\text{-}55\ \text{°F}) = 1162\ \text{Btu/h}$$

Because the heat loss rate into the crawlspace through the floor (1162 Btu/h) is nearly the same as the heat loss from the crawlspace to the outside (1124 Btu/h), the temperature within the crawlspace will actually be close to the 55°F temperature that we assumed. The rate of heat loss into the floor from the living room using this design option would be lower than the 1700 Btu/h that we calculated above using the insulated floor method.

5.7 *Dormers, Gables and Overhangs*

Having completed the analysis of the first floor zones, we now turn our attention to the two bedrooms upstairs. The new features of interest are the gabled ceiling and the dormers in each bedroom. We will begin with the east bedroom, which overhangs the living room by 4 ft and is exposed on the north, east and south faces. The east bedroom calculations are summarized in *Table 5-6*. The vertical sections of the north and south walls are only 3 ft high due to the gabled roof as shown in *Figure 5-5*. The east wall can be visualized as a trapezoid with a height of 8 ft and top and bottom dimensions of 9 ft and 16 ft, respectively. There is no heat loss through the west wall because it adjoins the second bedroom.

Table 5-6. Thermal Analysis of East Bedroom

Section	Gross Area	Net Area	U	$T_i - T_o$	$Q = UA(T_i - T_o)$
North	26x3	78	0.06	69	323
East	16x8- 3.25x4.67	113	0.06	69	468
West	heated space				0
South	26x3	78	0.06	69	323
Dormer	7.5x4.67- 2.5x4+ 3.25x4.67	40	0.07	69	193
Windows	30x48/144	10	0.5	69	345
Doors	none	0			0
Flat Ceiling	26x9+ 3.25x7.5	258	0.04	69	712
Gable	2@26x5.67- 7.5x5.67	252	0.05	69	869
Floor	4x16 overhang	64	0.05	69	221
Infiltration	26x16x8x0.5	1664	0.018	69	2067
			Total Heat Loss =		**5521 Btu/h**

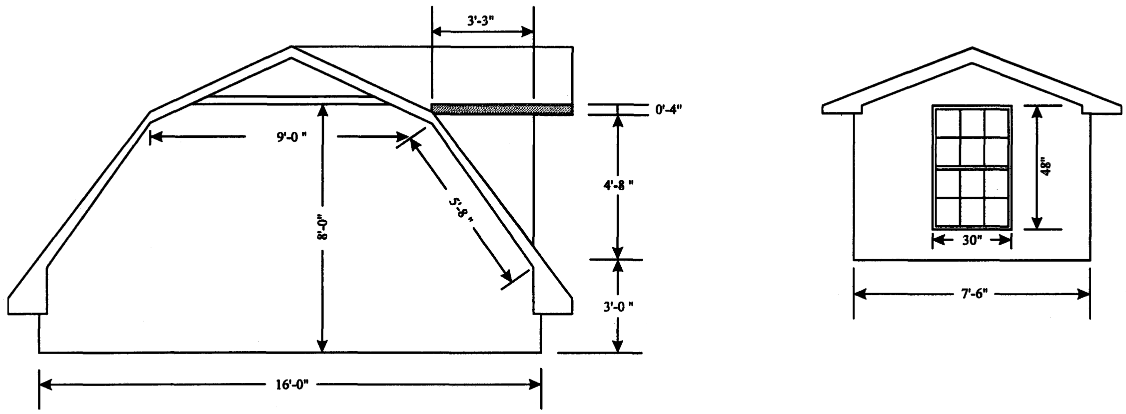


Figure 5-5. Dimensions of Wall and Dormer in Example House

The gabled roof simply adds several square feet to the ceiling area and possible adjustments to the ceiling U-factor because the construction details of the sloped section will be different than the flat portion of the ceiling. Moisture control within this cavity is very important, because wet insulation has little insulating value. Ventilation of the cavity on the unheated side of the insulation must be provided in such a way to prevent the entry of rain or snow through the vents themselves. The details of moisture control in structures is beyond the scope of this course but is a very important topic to be well informed about.

Example 5-5

Problem: Calculate the rate of heat loss from the gable roof in the east bedroom of the house.

Solution: The flat portion of dormer ceiling (3.25×7.5 ft) forms a tee with the flat portion of the bedroom ceiling (26×9 ft). This area has the same U-factor as the kitchen ($U = 0.04$ Btu/h·ft^2·°F). The north and south sloped ceiling areas (26×5.67 ft) minus the south-facing dormer area (5.67×7.5 ft) yields a net sloped area of: $147 + 147 - 42 = 252$ ft^2. We will assume that the effective U-factor for the sloped ceiling (assuming 20% structural members) is 0.05 Btu/h·ft^2·°F. The results are shown in *Table 5-6.*

The dormer design is another construction detail that requires special attention. There are usually several different insulation composites used in these small areas. Too often insulation contractors leave gaps and holes in these hard-to-insulate areas. Fortunately, these areas are small and do not have a large effect on the overall heat loss from the structure. Unfortunately, the zone around the dormer can be colder than it needs to be.

Example 5-6

Problem: Find the heat loss from the dormer in the east bedroom.

Solution: We will estimate the dimensions around the dormer as shown in *Figure 5-5*. The two areas to be considered are the 7.5×4.67 ft gable face (minus the 30×48 in. window) and the two 3.25×4.67 ft wing walls. Note that the two wing walls are triangles with a total area equal to one rectangle with the same dimensions. The assumed U-factor shown in *Table 5.6* has been increased to 0.07 Btu/h·ft^2·°F to account for the additional structural members required in this detail.

To calculate the heat loss from the exposed overhang section, it is assumed that the insulation under the floor consists of: downward surface resistance, 5/8-in. particleboard underlayment, 3/4-in. plywood, 5.5-in. fiberglass batt, and a 6-in. air gap down to the metal soffet. The corresponding R-values for these components, respectively, yield a total R-value of: 0.92+0.82+0.93+19+1.64 = 23.3 h·ft^2·°F/Btu. So U = 1/R = 0.04 Btu/h·ft^2·°F. Assuming that the floor framing members represent about 20% of the area at R-10 Btu/h·ft^2·°F, then the effective U-factor is: 0.8(0.04) + 0.2(0.1) = 0.05 Btu/h·ft^2·°F. The overhang area and temperature difference are shown in *Table 5-6*.

The west bedroom is very similar and slightly easier to detail because most of the numbers are available from our earlier calculation. The major difference is the room length and the lack of an overhang. The calculated values are presented in *Table 5-7*.

Table 5-7. Thermal Analysis of West Bedroom

Section	Gross Area	Net Area	U	$T_i - T_o$	$Q = UA(T_i - T_o)$
North	20x3	154	0.06	69	638
East	heated space				0
West	16x8-3.25x4.67	113	0.06	69	468
South	20x3	60	0.06	69	248
Dormer	7.5x4.67-2.5x4+3.25x4.67	40	0.07	69	193
Windows	30x48/144	10	0.5	69	345
Doors	none	0			0
Flat Ceiling	20x9+3.25x7.5	165	0.04	69	455
Sloped Ceiling	2@20x5.67-7.5x5.67	184	0.05	69	635
Floor	heated space				0
Infiltration	20x16x8x0.5	1280	0.018	69	1590
			Total Heat Loss =		**4572 Btu/h**

5.8 *Building Summary*

A summary of the calculated design heating loads for each room (or zone) is given in *Table 5-8*. This summary would be useful for the designer and heating contractor to know the total capacity of the heating system required. It also indicates how much energy must be supplied to each zone, which is needed to size the distribution system. Finally, the summary gives the designer an opportunity to see if any of the calculated values are out of line. As shown in the last column, designers can use the heat loss rate per square foot of zone floor area (Btu/h·ft²) as a benchmark or reality check. In this case, all of the values appear reasonable.

Table 5-8. Total Calculated Design Heating Loads

Zone	Area	Heat Loss Rate	Btu/h/ft²
Kitchen	256	4505	17.6
Dining Room	320	3097	9.7
Basement	320	2191	6.8
Living Room	352	5883	16.7
East Bedroom	416	5521	13.3
West Bedroom	320	4572	14.3
Totals	**1984**	**25,769**	**(aver. = 13.0)**

The Next Step

In all of the load calculations discussed so far, the rate of air infiltration has been modeled as a simple air change rate. In the next chapter, alternate methods of determining the rate of heat loss due to infiltration will be discussed along with several issues concerning ventilation.

Summary

In this chapter, you learned how to calculate the heat loss for a single-family house with several unique features. You applied the temperature data discussed in Chapter 3 and calculated U-factors based on your skills developed in Chapter 4. The example house included a wide range of construction details that are seldom all seen in the same structure. Floors are usually either slab-on-grade, over a crawlspace or over a basement, and you learned how to calculate heating loads from each of them. You also learned how to determine the temperature of unheated spaces, and how to calculate heat losses into them. Finally, you learned about the heat loss from special features such as dormers, gabled roofs and overhangs.

While the construction details in a commercial or industrial building vary significantly from this example house, the process used to calculate the rate of heat loss is identical, just larger and more complex:

- Identify the heating zones within the building.
- For each zone, identify the exposed surfaces by direction and type; and determine the net area of each surface.
- Calculate the effective U-factor for each surface, and look up or calculate the temperature difference across the surface.
- Multiply across the last three columns to get $Q = UA\Delta T$, and add down the last column to get the total heat loss rate for that zone.
- Finally, build a summary table showing the heat loss rates for each zone to compute the total heat loss rate for the building.

After studying Chapter 5, you should be able to:

- Estimate the heat loss rate through an unheated attached space.
- Estimate the heat loss through a slab-on-grade floor.
- Calculate the heat loss rates from various insulation systems in a crawlspace.
- Estimate the heat loss through a gabled roof or dormer.

Bibliography

1. Houghten, F., *et al.* 1942. "Heat loss through basement walls and floors." *ASHVE Transactions*. Atlanta, GA: ASHRAE. 48:369.

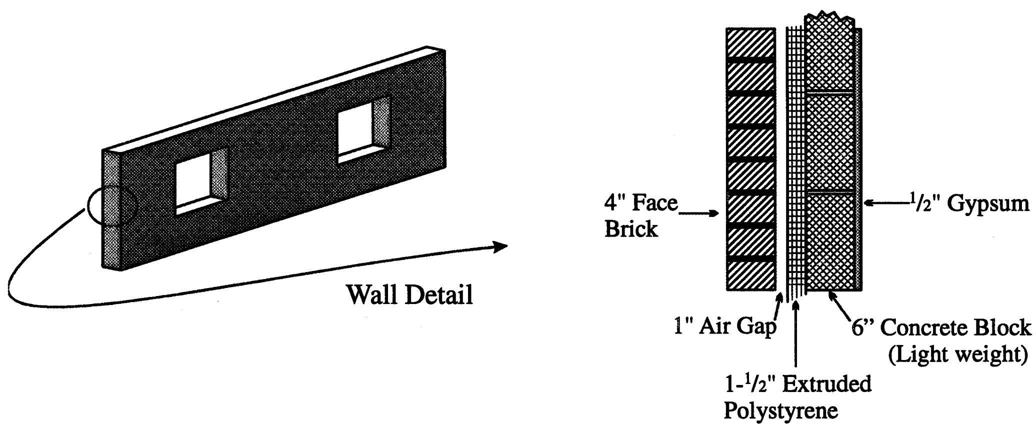
2. Dill, R., *et al.* 1945. *Measurements of Heat Losses from Slab Floors*. Washington, DC: US Department of Commerce, National Bureau of Standards. *Building Materials and Structures Report BMS 103.*

3. Latta, J., Boileau, G. 1969. "Heat losses from house basements." *Canadian Building.* 19(10):39.

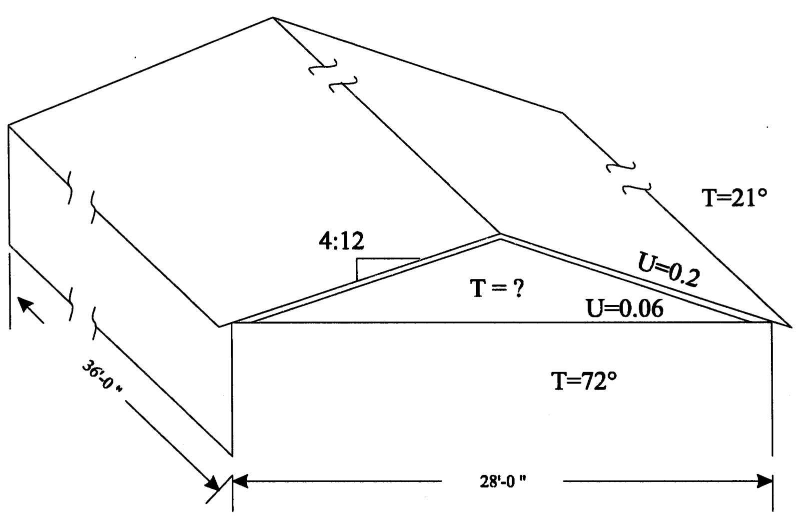
Skill Development Exercises for Chapter 5

Complete these questions by writing your answers on the worksheets at the back of this book.

5-01. Calculate the heat loss through the 24×8 ft wall section shown below (less the two 30×42 in. windows rated at U=0.6 Btu/h·ft²·°F each) when the inside temperature is 72°F and the outside design temperature is 21°F.



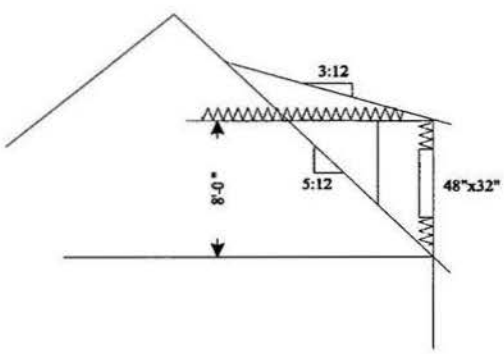
5-02. Determine the temperature in the 36×28 ft unheated attic shown below when the inside temperature is 72°F and the outside design temperature is 21°F. The attic floor and roof have effective U-factors of 0.06 Btu/h·ft²·°F and 0.2 Btu/h·ft²·°F respectively, and the roof pitch is 4:12. Assume 1.0 ACH through the attic.

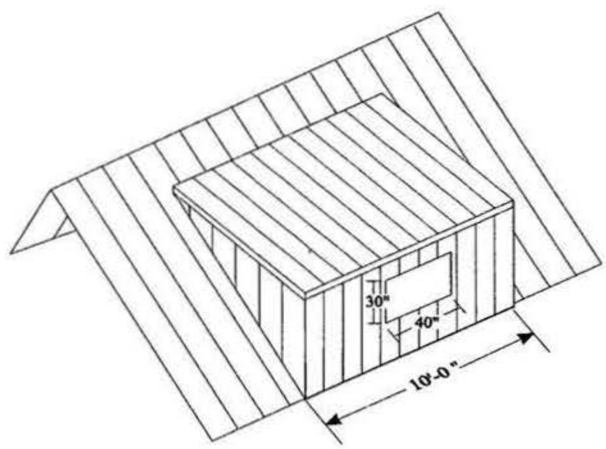


5-03. Determine the heat loss through a 26×38 ft slab-on-grade floor with R-5.4 h·ft²·°F/Btu in a cold climate. Assume a design temperature difference of 75°F.

5-04. Determine the rate of heat loss through the floor area in *Exercise 5-03* if it is located above an unvented crawlspace and the 24 in. of exposed wall is insulated down to 3 ft below grade with R-5.4 h·ft²·°F/Btu. Assume outside design temperature is -10°F.

5-05. Determine the rate of heat loss from the dormer shown below when the inside and outside temperatures are 74°F and 37°F, respectively. The 30×40 in. thermopane window is rated at U=0.6 Btu/h·ft²·°F. The effective U-factors for the dormer walls and ceiling are 0.07 and 0.05 Btu/h·ft²·°F, respectively.





Chapter 6
Infiltration and Ventilation

Contents of Chapter 6

Instructions

Read the material in Chapter 6. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 6

Infiltration and ventilation represent a significant fraction of the total thermal load on a building. Until now, we have used the simple assumption that the infiltration rate was always represented by 0.5 air changes per hour. In this chapter, we will discover the driving forces that cause infiltration and two different methods that can be used to estimate the thermal loss due to air infiltration. We will also discuss the basic need for, and effect of, providing ventilation air. Finally, some basic concepts related to humidity and moisture control within buildings will be discussed.

After studying Chapter 6, you should be able to:

- Describe the two basic infiltration sources.
- Given a space, estimate the rate of infiltration using the air change method.
- Given a space, estimate the rate of infiltration using the effective leakage area method.
- Describe the three methods that water enters a wall cavity.

6.1 Infiltration Sources

Infiltration is often the greatest single cause of heat loss in a residential building and a significant contributor to the thermal load of commercial buildings. There are two main forces driving infiltration: the prevailing wind and natural draft.

The prevailing wind causes a high pressure on one side of the structure and a slight negative pressure on the opposite side. These two different presures combine to force air into any opening on the upwind side and to pull air out of the building on the downwind side. These openings can be very difficult to locate and control, but are often found where building materials change (for example, at the sole plate in a frame building and around doors and windows) and at service entrances (electric, water and telephone). Providing an airlock at entrances can also help reduce the rate of air infiltration. Blocking the prevailing winter wind with the garage, outbuildings or shrubbery should also be considered.

The second driving force causing infiltration is natural draft, or the stack effect. Hot air rises through the building and escapes through cracks in the top ceiling. This causes cold outside air to be drawn in low (around the sole plate, basement windows or crawlspace access). While some outside air is necessary for fired equipment that is usually located in the basement (dryer, water heater, furnace, etc.), it is better to provide this air directly to the mechanical room. This helps to reduce drafts in the building caused by these devices. This stack effect becomes very pronounced in high-rise buildings, often causing noisy elevator and stair doors, where air is drawn into (or out of) these vertical shafts. While stack effect cannot be eliminated, it can be reduced through careful design and it is usually not dominant in buildings under four stories tall.

As a reference, the pressure difference at the top and bottom of a 40-ft-tall building with 70°F inside air and 32°F outside air is about 0.04 in. wg. The top of the building would be positively pressurized (air trying to escape), and the bottom would experience a negative pressure (outside air trying to enter the building). Similarly, a pressure of 0.04 in. wg can be produced by a 10 mph wind blowing against a building.

Two methods to estimate infiltration rates have been developed: the air change method and the effective leakage area method. Both methods will be discussed in this chapter, beginning with the simpler air change method.

6.2 Air Change Method

For residential and small commercial heating design work, the air change method is very simple and often accurate enough. The air filling the volume of the zone is assumed to be completely replaced with cold outside air a fixed number of times per hour. For example, in the kitchen of the house in Chapter 5, the room volume (16×16×8 ft) was assumed to undergo 0.5 air changes each hour (ACH). In the thermal analysis tables in Chapter 5, the units on the infiltration value of 0.018 in the U-column are really Btu/h·ft^3·°F instead of the units Btu/h·ft^2·°F shown for the rest of the column. This value is the product of the air density (0.075 lb$_m$/ft^3) times the air specific heat (0.24 Btu/lb$_m$·°F)· The temperature column does show the actual temperature difference between indoor and outdoor conditions, because the outside air entering the space must be heated up to room temperature.

Typical air change rates for new residential construction can be expected to be near 0.5 ACH, assuming good construction practices are used. This is the minimum value recommended in *ASHRAE Standard 62-1989* to maintain acceptable air quality within the space.[1] However, it is higher than comparable standards in Sweden and Canada. Under these tighter design constraints, an air-to-air heat exchanger is required to provide adequate fresh air without losing the energy contained within that air.

6.3 Effective Leakage Area Method

The second method to determine the rate of air infiltration is based on the effective leakage area of various construction components used in both residential and commercial buildings. The values shown in *Table 6-1* can be used to estimate the leakage area of a building. The values in the table present experimental results in terms of leakage area per component. The column labeled "Units" means the number of square inches either per component, per unit surface area, or per unit length of crack, whichever is appropriate.

To obtain the building's total leakage area, multiply the overall dimensions or number of occurrences of each building component by the appropriate table entry. The sum of the resulting products is the total building leakage area. Using the effective leakage area, the air flow rate due to infiltration is calculated according to:

$$Q = L\left(A\Delta T + BV^2\right)^{0.5} \tag{6-1}$$

Table 6-1. Effective Air Leakage Areas for Low-Rise Residential Applications[2]

	Units (see note)	Best Estimate	Minimum	Maximum
Ceiling				
General	in^2/ft^2	0.026	0.011	0.04
Drop	in^2/ft^2	0.0027	0.00066	0.003
Ceiling penetrations				
Whole-house fans	in^2 ea	3.1	0.25	3.3
Recessed lights	in^2 ea	1.6	0.23	3.3
Ceiling/Flue vent	in^2 ea	4.8	4.3	4.8
Surface-mounted lights	in^2 ea	0.13		
Chimney	in^2 ea	4.5	3.3	5.6
Crawl space				
General (area for exposed wall)	in^2/ft^2	0.144	0.1	0.24
8 in. by 16 in. vents	in^2 ea	20		
Door frame				
General	in^2 ea	1.9	0.37	3.9
Masonry, not caulked	in^2/ft^2	0.07	0.024	0.07
Masonry, caulked	in^2/ft^2	0.014	0.004	0.014
Wood, not caulked	in^2/ft^2	0.024	0.009	0.024
Wood, caulked	in^2/ft^2	0.004	0.001	0.004
Trim	in^2/lftc	0.05		
Jamb	in^2/lftc	0.4	0.3	0.5
Threshold	in^2/lftc	0.1	0.06	1.1
Doors				
Attic/crawl space, not weatherstripped	in^2 ea	4.6	1.6	5.7
Attic/crawl space, weatherstripped	in^2 ea	2.8	1.2	2.9
Attic fold down, not weatherstripped	in^2 ea	6.8	3.6	13
Attic fold down, weatherstripped	in^2 ea	3.4	2.2	6.7
Attic fold down, with insulated box	in^2 ea	0.6		
Attic from unconditioned garage	in^2 ea	0	0	0
Double, not weatherstripped	in^2/ft^2	0.16	0.1	0.32
Double, weatherstripped	in^2/ft^2	0.12	0.04	0.33
Elevator (passenger)	in^2 ea	0.04	0.022	0.054
General, average	in^2/lftc	0.015	0.011	0.021
Interior (pocket, on top floor)	in^2 ea	2.2		
Interior (stairs)	in^2/lftc	0.04	0.012	0.070
Mail slot	in^2/lftc	0.2		
Sliding exterior glass patio	in^2 ea	3.4	0.46	9.3
Sliding exterior glass patio	in^2/ft^2	0.079	0.009	0.22
Storm (difference between with and without)	in^2 ea	0.9	0.46	0.96
Single, not weatherstripped	in^2 ea	3.3	1.9	8.2
Single, weatherstripped	in^2 ea	1.9	0.6	4.2
Vestibule (subtract per each location)	in^2 ea	1.6		
Electrical outlets/Switches				
No gaskets	in^2 ea	0.38	0.08	0.96
With gaskets	in^2 ea	0.023	0.012	0.54
Furnace				
Sealed (or no) combustion	in^2 ea	0	0	0
Retention head or stack damper	in^2 ea	4.6	3.1	4.6
Retention head and stack damper	in^2 ea	3.7	2.8	4.6
Floors over crawl spaces				
General	in^2/ft^2	0.032	0.006	0.071
Without ductwork in crawl space	in^2/ft^2	0.0285		
With ductwork in crawl space	in^2/ft^2	0.0324		
Fireplace				
With damper closed	in^2/ft^2	0.62	0.14	1.3
With damper open	in^2/ft^2	5.04	2.09	5.47
With glass doors	in^2/ft^2	0.58	0.06	0.58
With insert and damper closed	in^2/ft^2	0.52	0.37	0.66
With insert and damper open	in^2/ft^2	0.94	0.58	1.3
Gas water heater	in^2 ea	3.1	2.3	3.9
Joints				
Ceiling-wall	in^2/lftc	0.070	0.0075	0.12
Sole plate, floor/wall, uncaulked	in^2/lftc	0.2	0.018	0.26
Sole plate, floor/wall, caulked	in^2/lftc	0.04	0.0035	0.056
Top plate, band joist	in^2/lftc	0.005	0.0035	0.018

	Units (see note)	Best Estimate	Minimum	Maximum
Piping/Plumbing/Wiring penetrations				
Uncaulked	in^2 ea	0.9	0.31	3.7
Caulked	in^2 ea	0.3	0.16	0.3
Vents				
Bathroom with damper closed	in^2 ea	1.6	0.39	3.1
Bathroom with damper open	in^2 ea	3.1	0.95	3.4
Dryer with damper	in^2 ea	0.46	0.45	1.1
Dryer without damper	in^2 ea	2.3	1.9	5.3
Kitchen with damper open	in^2 ea	6.2	2.2	11
Kitchen with damper closed	in^2 ea	0.8	0.16	1.1
Kitchen with tight gasket	in^2 ea	0.16		
Walls (exterior)				
Cast-in-place concrete	in^2/ft^2	0.007	0.0007	0.026
Clay brick cavity wall, finished	in^2/ft^2	0.0098	0.0007	0.033
Precast concrete panel	in^2/ft^2	0.017	0.0004	0.024
Lightweight concrete block, unfinished	in^2/ft^2	0.05	0.019	0.058
Lightweight concrete block, painted or stucco	in^2/ft^2	0.016	0.0075	0.016
Heavyweight concrete block, unfinished	in^2/ft^2	0.0036		
Continuous air infiltration barrier	in^2/ft^2	0.0022	0.0008	0.003
Rigid sheathing	in^2/ft^2	0.005	0.0042	0.006
Window framing				
Masonry, uncaulked	in^2/ft^2	0.094	0.082	0.148
Masonry, caulked	in^2/ft^2	0.019	0.016	0.03
Wood, uncaulked	in^2/ft^2	0.025	0.022	0.039
Wood, caulked	in^2/ft^2	0.004	0.004	0.007
Windows				
Awning, not weatherstripped	in^2/ft^2	0.023	0.011	0.035
Awning, weatherstripped	in^2/ft^2	0.012	0.006	0.017
Casement, weatherstripped	in^2/lftc	0.011	0.005	0.14
Casement, not weatherstripped	in^2/lftc	0.013		
Double horizontal slider, not weatherstripped	in^2/lftc	0.052	0.0009	0.16
Double horizontal slider, wood, weatherstripped	in^2/lftc	0.026	0.0070	0.081
Double horizontal slider, aluminum, weatherstripped	in^2/lftc	0.034	0.027	0.038
Double-hung, not weatherstripped	in^2/lftc	0.12	0.040	0.29
Double-hung, weatherstripped	in^2/lftc	0.031	0.009	0.089
Double-hung with storm, not weatherstripped	in^2/lftc	0.046	0.023	0.080
Double-hung with storm, weatherstripped	in^2/lftc	0.037	0.021	0.05
Double-hung with pressurized track, weatherstripped	in^2/lftc	0.023	0.018	0.026
Jalousie	in^2/louver	0.524		
Lumped	in^2/lfts	0.022	0.00042	0.097
Single horizontal slider, weatherstripped	in^2/lfts	0.031	0.009	0.097
Single horizontal slider, aluminum	in^2/lfts	0.04	0.013	0.097
Single horizontal slider, wood	in^2/lfts	0.021	0.013	0.047
Single horizontal slider, wood clad	in^2/lfts	0.030	0.025	0.038
Single-hung, weatherstripped	in^2/lfts	0.041	0.029	0.058
Sill	in^2/lftc	0.0099	0.0065	0.010
Storm inside, heat shrink	in^2/lfts	0.00085	0.00042	0.00085
Storm inside, rigid sheet with magnetic seal	in^2/lfts	0.0056	0.00085	0.011
Storm inside, flexible sheet with mechanical seal	in^2/lfts	0.0072	0.00085	0.039
Storm inside, rigid sheet with mechanical seal	in^2/lfts	0.019	0.0021	0.039
Storm outside, pressurized track	in^2/lftc	0.025		
Storm outside, 2-track	in^2/lftc	0.058		
Storm outside, 3-track	in^2/lftc	0.116		

Note: Air leakage areas are based on values found in the literature. The effective air leakage area (in square inches) is based on a pressure difference of 0.016 in. of water and $C_D = 1$.

Abbreviations: ft^2 = gross area in square feet; ea = each; lftc = linear foot of crack; lfts = linear foot of sash where,

Q = air flow rate, cfm

L = effective leakage area, in.^{2}

A = stack effect coefficient, cfm^2/(in.^{4}·°F)

ΔT = average indoor-outdoor temperature difference, °F

B = wind coefficient, cfm^2/(in.^{4}·mph^2)

V = average wind speed, mph

The infiltration rate of the building is obtained by dividing Q by the building volume. The value of B depends on the local shielding class of the building. Five different shielding classes are listed in *Table 6-2*. Stack effect coefficient values, A, for one-, two- and three-story houses are listed in *Table 6-3*. Wind coefficient values, B, for one-, two- and three-story houses in shielding classes one through five are listed in *Table 6-4*. The heights of the one-, two- and three-story buildings are 8, 16 and 24 ft, respectively

For large office buildings, typical air leakage values per unit exterior wall area have been given as 0.10, 0.30, and 0.60 cfm/ft^2 for tight, average and leaky walls, respectively. These values are for an assumed pressure difference across the wall of 0.30 in. wg.

Table 6-2. Local Shielding Classes

Class	Description
1	No obstructions or local shielding
2	Light local shielding; few obstructions, few tress, or small shed
3	Moderate local shielding; some obstructions within two house heights, thick hedge, solid fence, or one neighboring house
4	Heavy shielding; obstructions around most of perimeter, buildings or trees within 30 ft in most directions; typical suburban shielding
5	Very heavy shielding; large obstructions surrounding perimeter within two house heights; typical downtown shielding

Table 6-3. Stack Coefficient, *A*

	House Height (stories)		
	One	Two	Three
Stack Coefficient	0.0150	0.0299	0.0449

Table 6-4. Wind Coefficient, *B*

Shielding Class	House Height (stories)		
	One	Two	Three
1	0.0119	0.0157	0.0184
2	0.0092	0.0121	0.0143
3	0.0065	0.0086	0.0101
4	0.0039	0.0051	0.006
5	0.0012	0.0016	0.0018

Example 6-1

Problem: Estimate the infiltration at design conditions for a two-story house in Lexington, Kentucky. The house has an effective leakage area of 82 in.^{2}, a volume of 11,000 ft^3, and is located in a suburban development (Shielding Class 4).

Solution: The 99% heating dry-bulb temperature of 10°F is given in *Table 3-2* for Lexington. Assume a design wind speed of 15 mph and an inside temperature of 68°F. Choosing values for A (0.0313) from *Table 6-3* and B (0.0051) from *Table 6-4*, the air flow rate due to infiltration is:

$$Q = (82\ \text{in.}^2)[(0.0313\ \text{cfm}^2/\text{in.}^4\cdot°\text{F})(68°-10°\text{F}) + (0.0051\text{cfm}^2/\text{in.}^4\cdot\text{mph}^2)(15\ \text{mph})^2]^{0.5}$$
$$= 141\ \text{cfm}$$
$$= 8469\ \text{ft}^3/\text{h}$$

The infiltration rate I is equal to Q divided by the building volume:

$$I = (8469\ \text{ft}^3/\text{h})/(11{,}000\ \text{ft}^3)$$
$$= 0.77\ \text{ACH}$$

Because there are so many uncontrolled variables to consider, it has proven difficult to develop good empirical models for infiltration. When the entire building is modeled as a single cell, the error between calculated and measured performance averages close to 40%. However, progress has recently been made. The use of a multicell model has proven more accurate when all variables are known, especially the pressure differentials throughout the building, which determine the rate of air movement within the structure. Because these values are usually unknown during the design phase, a best guess estimate remains in the designer's tool kit. Also remember that for large buildings, the required ventilation rate is often several times larger than the estimated air infiltration rate.

6.4 Ventilation

Besides the uncontrolled ventilation discussed above as infiltration, there are two other types of ventilation available to the designer: natural ventilation and forced ventilation.

Before the advent of mechanical cooling, natural ventilation was the only method available to provide comfort in summer. It is still used in many residences and commercial facilities around the world. Opening windows will allow the prevailing winds to pass through the buildings. Roof ventilators and operable skylights make use of the stack effect to draw hot air out of the building during the months that require cooling. Architectural features from fountains to cupolas can also be used to enhance the cooling effect of natural ventilation.

While the comfort within naturally ventilated buildings can be enhanced through the proper location and operation of these devices, it is presently not possible to control the comfort within these spaces using these concepts alone. To control the comfort level, it is necessary to control the rate and location of ventilation air entering the building. This is accomplished through forced ventilation, where a fan provides a predictable and constant flow of outside air to the facility.

An even more important effect provided by this flow of outside air is the dilution of air contaminants generated within the building. Carbon dioxide exhaled by the occupants, odors and particles from processes that occur within the space, and even gaseous emissions from the furniture, floorcoverings and construction materials must be removed continuously from the building to keep the indoor air quality within acceptable limits.

ASHRAE Standard 62-1989 provides guidance on ventilation and indoor air quality in the form of two alternative procedures: the Ventilation Rate Procedure and the Indoor Air Quality Procedure.[1] In the Ventilation Rate Procedure, indoor air quality is assumed to be acceptable if the concentrations of six pollutants in the incoming outdoor air meet the US national ambient air quality standards and if the outside air supply rates meet or exceed values (which vary depending on the type of space) provided in a table. The minimum outside air supply per person for any type of space is 15 cfm. This minimum rate will maintain indoor carbon dioxide concentrations below 0.1% (1,000 parts per million).

For the purposes of this course, a 20 cfm per person minimum flow rate of outside air will be used, which is the current minimum standard for office space. Also, remember that air is usually being exhausted from the building as well. For example, restroom ventilation rates are typically 6 air changes per hour. There may also be exhaust fans in the kitchen/grill area or in the office photocopy center that must be included in the ventilation calculation. Finally, remember that these ventilation rates not only affect the temperature (or sensible loads) of the building but also the moisture (or latent loads) as well.

To calculate the sensible load caused by ventilation, use the equation:

$$q_s = 1.10\, Q\, \Delta T \tag{6-2}$$

where,

q_s = sensible heat load, Btu/h
1.10 = product of air density (0.075 lb/ft^3), specific heat (0.242 Btu/lb·°F) and 60 min/h
Q = air flow rate, cfm
ΔT = indoor-outdoor temperature difference, °F

To calculate the latent load caused by ventilation, use the equation:

$$q_l = 4840\, Q\, \Delta W \tag{6-3}$$

where,

q_l = latent heat load, Btu/h
4840 = product of air density (0.075 lb/ft^3), latent heat of vapor (1075 Btu/lb$_m$) and 60 min/h
Q = air flow rate, cfm
ΔW = humidity ratio of indoor air minus humidity ratio of outdoor air, lb$_m$ water/lb$_m$ dry air

EXAMPLE 6-2

Problem: An office building has an estimated summer population of 150 people. The outside summer design condition is an air temperature of 91°F at a humidity ratio of 0.014 lb_m water/lb_m dry air (about 45% relative humidity). The inside air is controlled to 76°F with a humidity ratio of 0.009 lb_m water/lb_m dry air (about 47% relative humidity). Calculate the sensible and latent heat loads caused by this ventilation air flow.

Solution: The ventilation flow rate required by 150 people at 20 cfm per person is 3,000 cfm. The sensible heat load is determined using the equation:

$$q_s = 1.10(3{,}000 \text{ cfm})(91°\text{-}76°) = 49{,}500 \text{ Btu/h}$$

The latent heat load is determined from the equation:

$$q_l = 4{,}840(3{,}000 \text{ cfm})(0.014 - 0.009 \text{ lb}_m \text{ water/lb}_m \text{ dry air}) = 72{,}600 \text{ Btu/h}$$

Notice in this ventilation example that the latent heat load is greater than the sensible load. This is often the case in humid climates, where the designer strives to have good indoor air quality (a high ventilation rate) as well as low operating energy costs (a low ventilation rate). The process for achieving a balance between these opposing goals is beyond the scope of this course.

6.5 Humidification and Moisture Control

While humidity control is generally a major issue in cooling design, it must also be considered in heating systems where good humidity control is required, when large volumes of outside air are introduced, or where extremely cold outside design temperatures require supplemental humidification of the indoor air. When outside air below 32°F is warmed to 70°F, the relative humidity drops below 30%, which is the generally accepted minimum comfort level as discussed in Chapter 3. Unless there are adequate sources of evaporation within the space (such as people, plants and processes), it will be necessary to add moisture. Industrial processes often move large volumes of outside air through their facilities, yet require close control of the minimum humidity levels during the heating season. Use the latent load equation above to calculate these latent loads.

Although not the main focus of this course, a basic understanding of the sources, effects and control of moisture within structures must be part of each designer's training. This section provides an introduction to these topics as they relate to the thermal envelope of a building. For additional information, read chapters 22-24 in the 1997 *ASHRAE Handbook–Fundamentals*.[3-5]

Moisture enters wall cavities through three basic mechanisms. Roof leaks and flashing leaks around penetrations can provide easy access to unwanted rain water and snow melt. Wind-driven moisture (liquid water) and humidity (water vapor) can penetrate any facade that is not airtight. Finally, water vapor can also migrate through the process of diffusion, which is driven by the difference in the partial pressures of the water vapor across a barrier.

The worst effect that can be caused by moisture trapped within the wall cavity is structural failure due to rot. Damage can also be caused by mold and mildew that cause discoloration and failure of wall surfaces and ceiling materials. Indoor air quality is often adversely affected by microbial growth that results from moisture leakage. Finally, the insulating value of most building materials is based on dry products; for example, wet fiberglass batts offer almost no insulating value. So it is important to keep moisture out of the wall cavity. It is also important to provide a method to remove any water that might get in.

Preventing leaks and keeping wind-driven moisture out of the building cavity are usually the responsibility of the architect and contractor. However, the installation of moisture retarders to minimize vapor migration is generally part of the building's insulation package.

Typical moisture retarders commonly used in construction include aluminum foil, asphalt-impregnated kraft paper and plastic sheeting. These materials should be free of gaps and tears when they are installed. Because the moisture-carrying capacity is higher for warmer air, always install the moisture retarder on the warm side of the insulation (inside in heating climates and outside in cooling climates). Avoid trapping moisture within the cavity, which can occur if a second layer of material is installed on the exterior of a heated building. It is generally good practice to ventilate the wall or cathedral ceiling cavity to the cooler side. Just ensure that the vents installed to get water vapor out do not themselves provide a means for water to get in.

The Next Step

In the next chapter, we will begin the final phase of our discussion of heating, ventilation and air-conditioning thermal load calculations. Air-conditioning load calculations require all of the basic concepts we have discussed so far, plus several additional internal energy sources that we have not yet discussed. You will also learn about several alternative methods used to calculate air-conditioning loads.

Chapter 7 will set the foundation for performing cooling load calculations by discussing the different concepts and models used. Some basic design constraints that must be considered will also be presented. In Chapter 8, you will learn how to select appropriate design temperature differences. Chapter 9 deals with the special cooling problems associated with windows, and Chapter 10 presents internal thermal loads that must be considered in a cooling design. All of these topics are pulled together in Chapter 11, where you will work through a complete set of heating and cooling calculations. Finally, Chapter 12 will discuss the future of load calculations and describe sophisticated mathematical models and simulations that computers use to accurately track energy flows on an hourly basis throughout the year.

Summary

This chapter has provided a background into the sources of infiltration, as well as an introduction into both natural and forced ventilation. However, to become a competent designer, you must learn much more about forced ventilation and its effect on indoor air quality. Similarly, this chapter provided an introduction into moisture control within building envelopes. After studying Chapter 6, you should be able to:

- Describe the two basic infiltration sources.
- Given a space, estimate the rate of infiltration using the air change method.
- Given a space, estimate the rate of infiltration using the effective leakage area method.
- Given the occupancy of a space, estimate the minimum required ventilation.
- Describe the three methods that water enters a wall cavity.

Bibliography

1. ASHRAE. 1989. *ANSI/ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: ASHRAE.

2. ASHRAE. 1997. "Ventilation and infiltration." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 25, Table 3.

3. ASHRAE. 1997. "Thermal and moisture control in insulated assemblies–Fundamentals." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 22.

4. ASHRAE. 1997. "Thermal and moisture control in insulated assemblies–Applications." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 23.

5. ASHRAE. 1997. "Thermal and water vapor transmission data." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 24.

Skill Development Exercises for Chapter 6

Complete these questions by writing your answers on the worksheets at the back of this book.

6-01. For the example house discussed in Chapter 5, determine the total infiltration rate (in ft^3/h) using the air change method, assuming 0.5 ACH for each room.

6-02. For the same house in Baltimore, MD, determine the total rate infiltration (in ft^3/h) using the effective leakage area method. Include five double-hung windows (with weatherstripping) with caulked wood framing, both doors (weatherstripped in caulked wood framing), 20 electrical outlets, gas water heater and dryer, kitchen and bathroom vents with dampers, and appropriate crawlspace (no ductwork) and caulked joint details. Discuss the difference between the calculated values from using both methods.

6-03. Convert both of the above air flow estimates to energy flows if the inside and outside temperatures are 75°F and 15°F, respectively.

6-04. Estimate the forced ventilation required in a 100-seat restaurant. If the grill and restroom exhaust fans remove 1,400 cfm and 400 cfm respectively, how much outside air must be brought into the building?

Chapter 7
Cooling Load Calculations

Contents of Chapter 7

Instructions

Read the material in Chapter 7. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 7

The process of calculating cooling loads is much more complex than the heating load method we have discussed so far. There are many interdependent variables needed to determine the cooling load, all of which we were able to ignore in the process of calculating the heating load. There are also several alternative methods that have been developed to make these cooling load calculations.

The purpose of this introductory chapter is to discuss the basic issues, concepts and methods used to determine cooling loads before we begin to actually crunch numbers. After studying Chapter 7, you should able to:

- Name several differences between cooling load calculations and heating load calculations.
- Explain the differences among the four basic building heat flows used in cooling load calculations.
- List the initial design considerations and why they are important.
- Describe three different methods used to calculate cooling loads and give the advantages and disadvantages of each.

7.1 Introduction

In determining the heating load, the winter design temperature is used. This condition typically occurs during the early morning hours when the sun is not shining, most lighting and internal equipment are turned off, and there is little human activity within the building. Any energy from these sources simply reduces the required thermal input from the heating system and adds to the design's margin of safety. However, the maximum cooling load almost always occurs in the middle of the afternoon, and the energy from all of these variables must be properly considered.

For example, when solar energy strikes the walls and roof of the building, it is either absorbed by or reflected from the building's surfaces. The color and texture of the outside skin has a strong affect on how much solar energy gets absorbed, with darker colors absorbing a higher percentage of the incident energy. The absorbed energy raises the outside surface temperature of the building. While this increased temperature allows some of the energy to convectively transfer back to the outside environment, it also raises the effective temperature difference across the building envelope, which in turn increases the conductive heat transfer into the space through the building shell.

Quite often there are differences in temperature within the structure. For example, an air-conditioned office might be located adjacent to an unconditioned warehouse. The thermal energy transfer through these walls can be determined using the method developed for unheated spaces discussed earlier.

The sunlight streaming through the windows contributes energy to the space. The quantity of solar energy available varies throughout each day and depends on the geographical location, the time of year, and the number of clouds on that day. The fraction of solar energy that actually enters the space depends on which direction the window is facing, how the glass surface is treated, and whether any curtains, blinds or other shading devices are being used.

If the quantity and quality of sunlight coming through the windows is inadequate, it must be supplemented by artificial light. Incandescent bulbs are extremely inefficient, with up to 98% of the rated wattage being emitted as heat to the space. Fluorescent tubes greatly reduce the rate of heat transfer into the space, but even that rate is affected by whether the lighting fixtures are ventilated. The thermal losses from the fluorescent lighting ballast must also be included in the calculations.

Identifying the type and capacity of electrical equipment and appliances within a building can be very difficult in the early design phases. The proliferation of computers and copying machines has made it difficult to determine how much energy these devices will contribute to the space.

Humidity additions must also be considered from these internal load sources, because humidity must be controlled in air-conditioned spaces. Not only is high humidity uncomfortable, it encourages the growth of molds and mildew which creates an indoor air quality problem. The office coffeemaker and decorative plants add moisture to the air. Specialized applications such as restaurants, laundromats and many industrial process facilities must also consider the large humidity and moisture loads that occur in these applications. As difficult as it seems to project each of these unknowns, reasonable values must be defined before the cooling load calculation can begin.

Finally, the human occupancy rate of the space must be considered. How many people are present and what they are doing both affect the rate of energy gain from this source. For example, a group of people dancing at a wedding reception will require more cooling than the same number of people listening to a lecture on William Shakespeare. People contribute both sensible and latent (moisture) energy to the space. Human activities such as cooking, washing and showering evaporate moisture into the air. Also the rate of ventilation with outside air required to maintain indoor air quality is usually based on the number of people. The energy that must be removed from this outside air as it enters the building represents a significant portion of the total cooling load.

The cooling load calculation methods that will be introduced later in this chapter all consider each of the above areas individually, then add the results of those calculations to determine the total load. This is because different fundamental principles and equations are used to calculate the different modes of energy transfer. However, there are also some other ways to group these energy transfers. Viewing the process from these directions as well will help you better understand the entire picture.

For example, heat gains can result from external, internal, ventilation and miscellaneous sources (see *Figure 7-1*). External heat gains enter the controlled space through walls, roofs and windows, and through interior partitions, ceilings and floors. Internal sources include people, lights and appliances. Energy transfer can also occur due to ventilation and infiltration, where it is the moving air that is transferring the energy and humidity. Miscellaneous sources include heat gains from sources within the cooling system itself, such as losses from the fan motor inside the air handling unit and heat gain to the supply ductwork or piping network.

Another way to dissect the problem is to consider both sensible and latent loads (see *Figure 7-2*). In the heating load calculation process, only temperature changes, or sensible loads, are usually important. But high humidity decreases our body's ability to lose heat through our sweat mechanism, and that has a major effect on human comfort. Thus it is necessary to account for both sensible and latent sources when calculating cooling loads. The three pri-

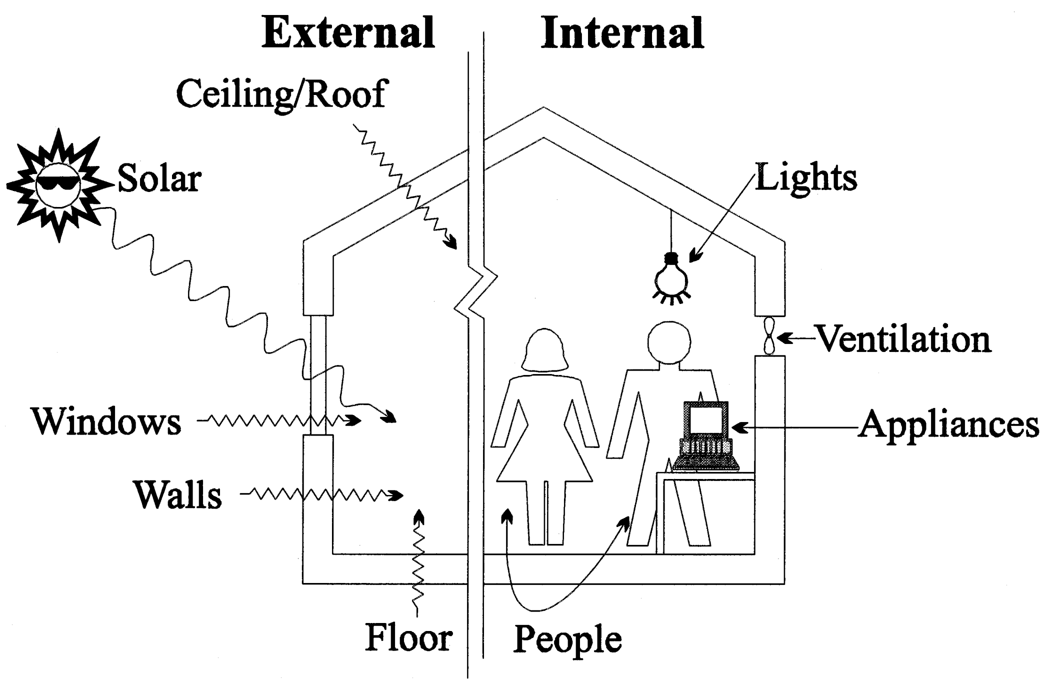


Figure 7-1. External and Internal Loads

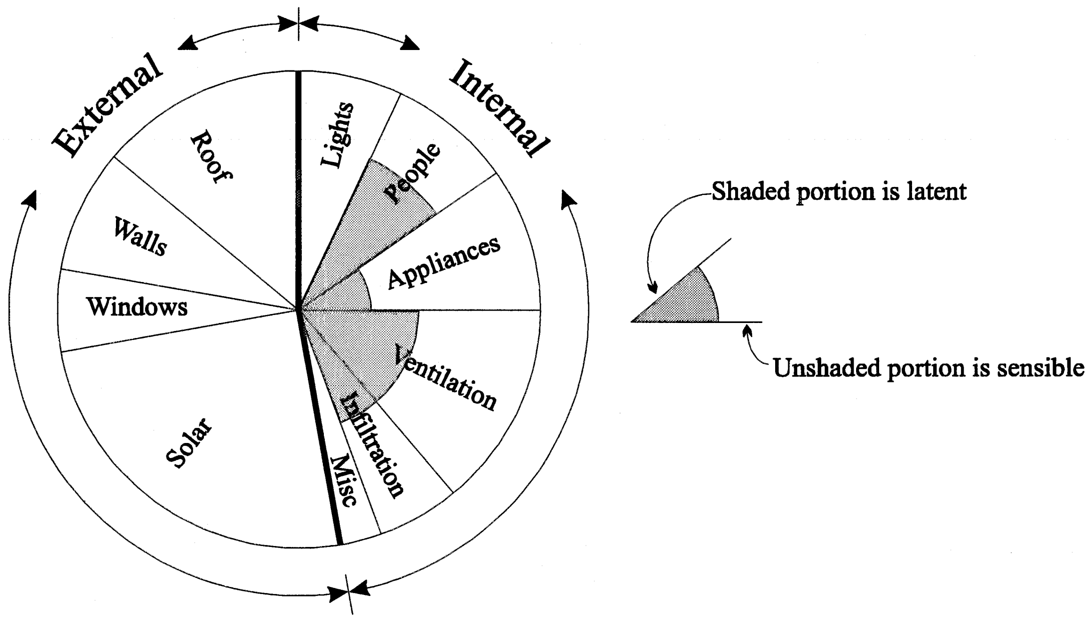


Figure 7-2. Sensible and Latent Loads

mary sources of humidity within buildings include people, processes and appliances, and outside air from ventilation and infiltration. To maintain a constant level of humidity within the space, the cooling system must remove moisture at a rate equal to the moisture addition.

Another parameter that plays a significant role in the determination of cooling loads is the building heat capacitance. If you put a full and an empty soda can into a refrigerator, the empty can will feel cold very quickly, because there is not as much mass to cool down. Buildings using light construction (such as wood frame or insulated metal walls) will also react more quickly to temperature changes than very massive structures built with concrete and bricks. It simply takes longer for a temperature front to pass through a massive wall section, which can dramatically shift the timing of the peak cooling load for the space.

The location of the insulation within the wall relative to the mass can also affect the cooling load. Conventional construction of a brick or concrete block wall calls for locating the insulation inside the facade. This protects the insulation from the elements. However, one popular retrofit project for older uninsulated buildings is to add the insulation to the exterior. Not only does this change the appearance of the building, it also affects the thermal loads of the building. A third popular construction method is to build a sandwich wall, with the insulation between the exterior facade and the interior wall. If each of these three wall sections had the same total R-value and the same total density, the thermal load profile would be different, as shown in *Figure 7-3*.

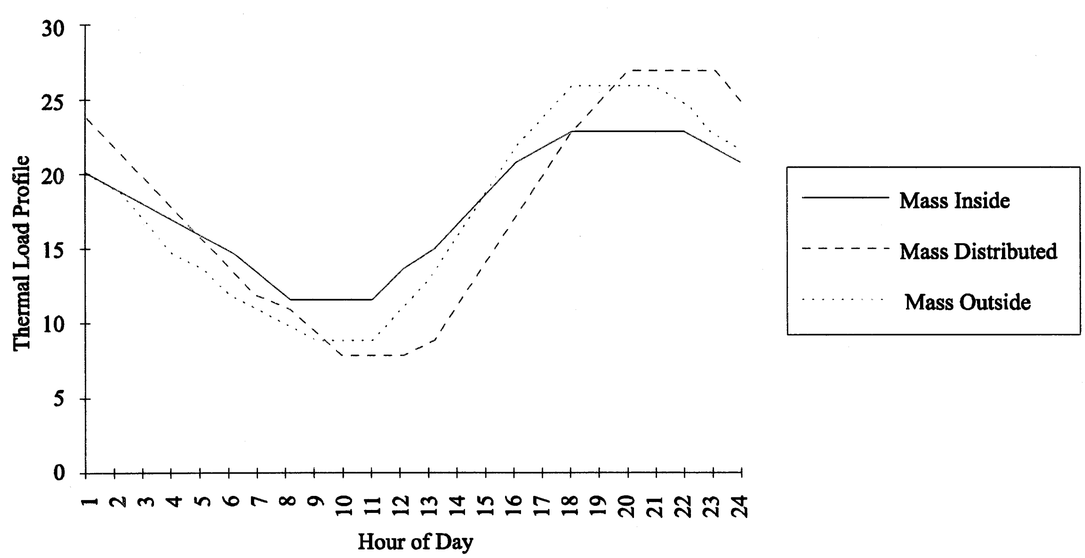


Figure 7-3. Thermal Load Profiles

What happens to sunlight streaming through a window can also be affected by the heat capacitance of the structure (see *Figure 7-4*). If the sunlight that passes through the glazing strikes a closed blind or drape just inside the window, part of the radiant energy will be immediately reflected back outside. The rest of the energy will be quickly transferred to the air in the room, creating an instantaneous heat gain. However, if the shading device is open, most of the solar energy is absorbed by the floor. A carpeted floor will quickly transfer the energy to the room air through convection and result in an instantaneous heat gain. However, a concrete floor will warm very slowly. The transfer to the room air will occur more slowly, but over an extended period of time.

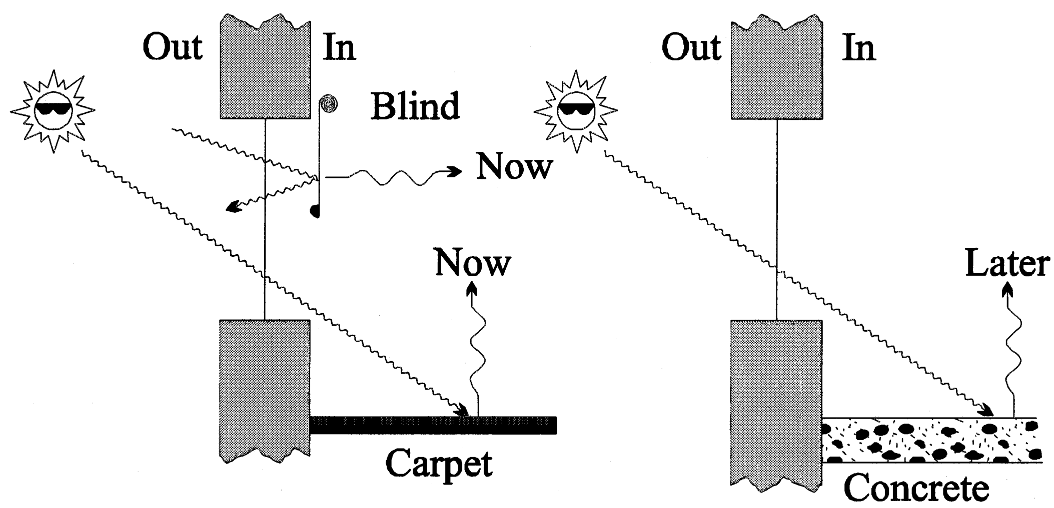


Figure 7-4. Window Heat Gains

The thermal effect of internal loads such as lighting, appliances and people is also influenced by the thermal storage effect of the building. Moreover, these loads can vary dramatically throughout the day. Imagine the cooling load from people in a fast food restaurant. As shown in *Figure 7-5*, there might be three large spikes at mealtimes and another minor increase late at night when the local movie theater closes. Therefore, to accurately calculate these effects, it is necessary to know the operating schedules for the lighting and equipment as well as the occupancy schedule for each zone within the building.

Trying to predict these schedules and usage profiles accurately is challenging. We all know that turning lights off when we leave a room saves energy. But in office buildings, that is not always possible; and in commercial buildings, bright lights attract customers. It is just as hard to predict how many times per day the conference room will be used and how many

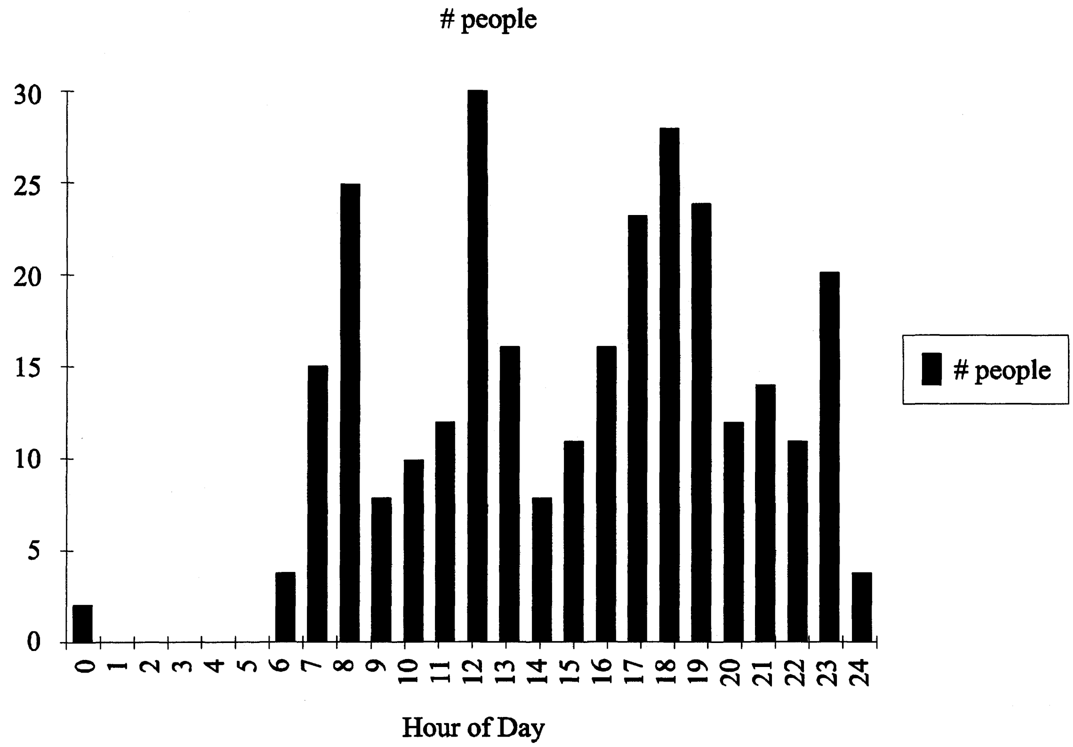


Figure 7-5. Example Cooling Loads in a Fast Food Restaurant

people will be in each group. Just because there are 500 chairs in the school library does not mean there will always be 500 people there. (That will probably only occur during finals week, and that is usually not the hottest month.) This diversity factor reduces the total cooling load required, because generally not everything is operating at full rated capacity.

7.2 Heat Flow Rates

There are four distinct but related heat flow rates used in the design of air-conditioning systems: space heat gain; space cooling load; space heat extraction rate; and cooling coil load (see *Figure 7-6*).

- Space heat gain, or instantaneous rate of heat gain, is the rate at which heat enters into and/or is generated within a space at a given instant. As noted above, these include internal, external, ventilation and miscellaneous sources. They can also be classified as sensible or latent sources.

- Space cooling load is the rate at which heat must be removed from the space to maintain a constant space air temperature. The thermal storage effect of the building's heat capacitance represents the primary difference between the space heat gain and the space cooling load. Any difference between the space heat gain and the space cooling load will cause the space temperature to "swing" above or below the desired set point. Stored radiant heat gains decrease the space cooling load, but are very difficult to calculate accurately.
- Space heat extraction rate is the rate at which heat is removed from the conditioned space. Only at summer design conditions is the space heat extraction rate equal to the space cooling load. Most of the time, the cooling equipment operates intermittently, and a small variation or swing of the space temperature occurs.
- Cooling coil load is the rate at which energy is removed at the cooling coil that serves one or more conditioned spaces in any central air-conditioning system. It is equal to the instantaneous sum of the space cooling load (or space heat extraction rate if the space temperature is assumed to swing) plus any external loads. Such external loads include the heat and moisture introduced by outside air for ventilation as well as energy gains to the distribution system between the cooling equipment and the individual spaces.

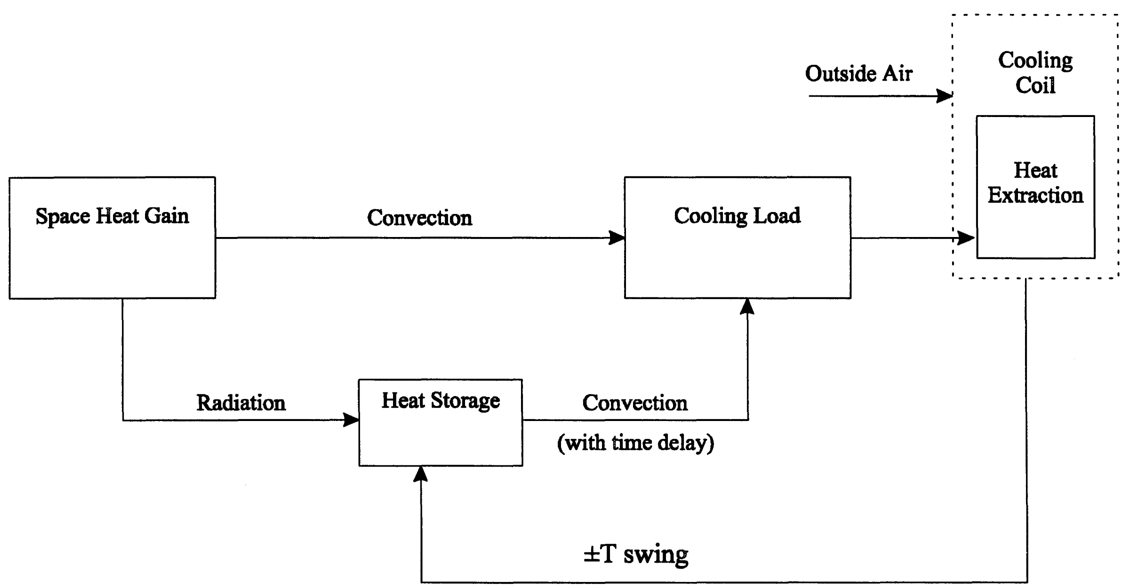


Figure 7-6. Loads on a Building

7.3 Initial Design Considerations

There are several steps required by the designer before beginning a space cooling load calculation. It is recommended that the initial contact with the client result in information on each of the following topics:

- Building characteristics. Characteristics of the building (such as building materials, component size, external surface colors and shape) can usually be obtained from building plans and specifications.
- Configuration. Determine the building location, orientation and external shading from plans and specifications (see *Figure 7-7*). Shading from adjacent buildings can be determined by a site plan or by visiting the proposed site. The probable permanence of shading should be evaluated before it is included in the calculations. Possible high ground-reflected solar radiation from adjacent water, sand or parking lots, or solar load from adjacent reflective building exteriors should not be overlooked.

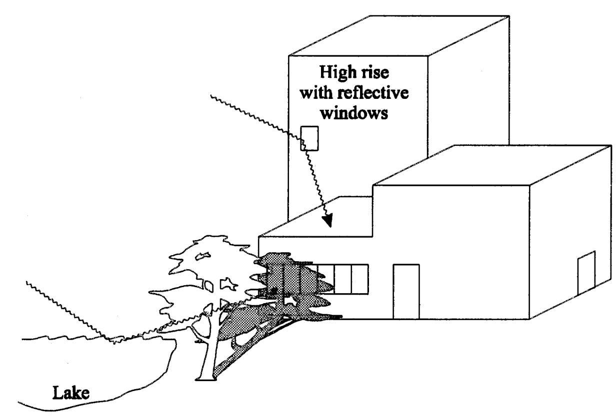


Figure 7-7. Example Site Plan

- Outdoor design conditions. As discussed in Chapter 2, obtain appropriate weather data and select outdoor design conditions. Consider the proximity of the weather station to the construction site, and adjust these conditions if necessary for the local microclimate. It is the designer's responsibility to ensure that project results are consistent with expectations, so use good judgment in selecting these design values. Finally, obtain information on the prevailing wind direction and velocity, which will be useful in locating your outside air inlets and exhausts.
- Indoor design conditions. Select the indoor design conditions such as indoor dry-bulb temperature and indoor relative humidity. Define the ventilation rate required by the occupancy rate and/or process equipment needs. Note any permissible variations to these criteria (such as 78°F ±2°F), as well as control limits (such as space air temperature not to exceed 82°F).

- Operating schedules. Obtain a proposed schedule for lighting, occupants, internal equipment, appliances and processes that will contribute to the internal thermal load. Determine the probability that the cooling equipment will be operated continuously or shut off during unoccupied periods (such as nights and/or weekends). The operating strategy dictates when the energy stored within the building structure will be removed.
- Date and time. Select the time of day and month to do the cooling load calculation. Occasionally, several hours of the day and several months must be analyzed to ensure the peak space cooling load is determined. The particular day and month are often dictated by the peak solar conditions. Note that zones on the east side of the building will peak in the morning and those on the west will peak in the afternoon. This diversity of load can often decrease the total capacity of the cooling system required, but the details of these energy analysis methods are beyond the scope of this course.
- Additional considerations. The performance of a space cooling system depends somewhat on the type of system used. Basic system selection and component sizing are required to calculate some of these miscellaneous gains. For example, a ceiling plenum return with vented light fixtures allows the heat gains from the roof and the lights to go directly to the cooling coil and contributes very little to the space cooling load. However, a system design using a wall return and unvented lights will add the energy from the roof and lights to the space cooling load as well as the cooling coil. The thermal losses from the fan motor of a blow-through system contribute only to the cooling coil load, while the motor losses of a draw-through system add to the space heat gain, the space cooling load and the cooling coil load (see *Figure 7-8*).

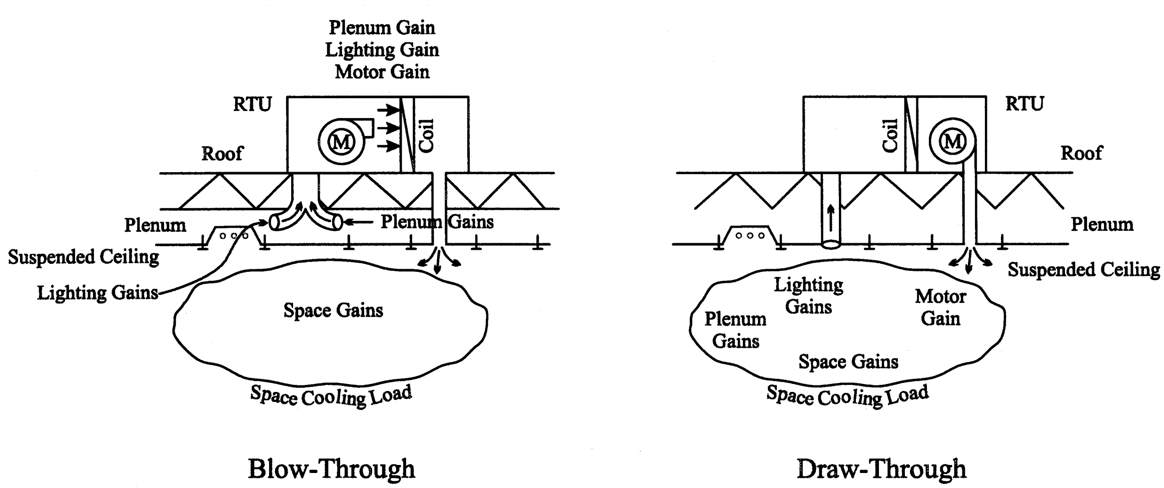


Figure 7-8. Air Handling Unit Comparison

7.4 Calculation Methods

Over the past 30 years, the process of determining building cooling loads has evolved from an art to more of a science. Lead by ASHRAE's efforts, the technical community has made tremendous strides in our understanding of these phenomena and in our ability to mathematically model the thermal performance of a wide variety of structures, with all of the variables mentioned in the previous section clearly defined. However, selecting the appropriate values for all of those input variables remains somewhat of an art. In this section, we will discuss the developmental evolution of four cooling load models and the strengths and problems of each.

Early research efforts recognized the importance of the interaction between two key variables: the sun and the building thermal heat capacitance. In 1967, an innovative method to account for the effects of these two variables on cooling loads was introduced in the *ASHRAE Handbook.*[1] This procedure used total equivalent temperature differential values and a system of time averaging (TETD/TA) to calculate cooling loads. This two-step method first calculates the heat gains from all sources to get an instantaneous space heat gain. This is then converted to a space cooling load through the use of weighting factors, which account for the influence of the building's thermal storage. It gives valid results to experienced users, but is tedious in practice and difficult for novice users to learn the manual calculation techniques. It is still applied by some computer programs. The time averaging method offers the experienced user the ability to quickly analyze the thermal storage effects, as well as visualize the effect of external shading on cooling load.

The transfer function method (TFM) was first introduced in the 1972 *ASHRAE Handbook*, and closely approximates the heat balance approach recognized as a fundamental concept in calculating cooling loads.[2] This computer-based procedure also occurs in two steps (space heat gain, then space cooling load). Not only does this method determine the space cooling load, it also evaluates both the rate at which heat is removed from the space and the temperature of the space when a specific size and type of cooling unit is used.

By allowing the space temperature to vary, the designer can evaluate the effects of different operating schedules and can use the entire width of the comfort zone in the design and selection of the equipment. For example, operating the cooling system at night to remove heat stored within the structure can reduce the peak space cooling load the next afternoon. The space temperature might be held at 75°F during the morning hours, then allowed to drift upward to 80°F by quitting time.

The penalty that must be paid for all of this accuracy and flexibility is the complexity of the model itself. The mathematical relationships used within the computer codes that use the TFM are beyond the experience of most novice designers. However, this methodology and the basic equations do provide the technical basis for a manual method that is relatively easy to understand and will be presented in the following chapters.

The third method is a one-step process that uses the cooling load temperature difference (CLTD) or the cooling load factors (CLF), or a combination of both, for each component of the space cooling load. First presented in the 1977 *ASHRAE Handbook*, it is applicable to several types of buildings for which data are available.[3]

Residential cooling systems represent one group of buildings with some unique and consistent design constraints. The specific CLTD/CLF procedures for calculating residential cooling loads are beyond the scope of this course. For more information on these procedures, refer to the 1997 *ASHRAE Handbook*.[4]

Research efforts are continuing to seek refinements of the computational methods. The development of new mathematical methods and tools promises even greater accuracy and flexibility. As a designer, you are encouraged to further develop your understanding of the state-of-the-art in cooling load calculations by learning to apply these new methods in your work as soon as possible.

The Next Step

In the next three chapters, we will present the CLTD/CLF load calculation in detail through the use of an example building. In this first example, all of the variables will be clearly defined, because it is the *process* that you will be learning. However, in practice, determining reasonable values for the variables will be much more challenging.

Chapter 8 will introduce the CLTD/CLF concept for walls, roofs and partitions. Chapter 9 will discuss solar gain through windows and the effects of various internal and external shading devices. Chapter 10 will cover internal gains from people lights, power and appliances. Chapter 11 will present an example problem combining all of these design activities into a complete process. Finally, Chapter 12 will present the procedure used to calculate cooling loads using the transfer function method.

Summary

So far, we have discussed in principle the many related variables that affect the cooling load on a building. Remember that we must account for both sensible and latent energy gains. These gains will depend on all of the variables described in section 7.3. It is especially important that we account for the effects of the solar energy, both that which is absorbed on the building skin as well as that which enters through the windows. The cooling load factor will assist us in accounting for the time delay caused by the thermal storage of the building envelope. Finally, the timing and capacity of all internal loads from people, equipment and lighting will also affect the building cooling load.

After studying Chapter 7, you should be able to:

- Name several differences between cooling load calculations and heating load calculations.
- Explain the differences among the four basic building heat flows used in cooling load calculations.
- List the initial design considerations and why they are important.
- Describe three different methods used to calculate cooling loads and give the advantages and disadvantages of each.

Bibliography

1. ASHRAE. 1967. "Air-conditioning cooling load." *ASHRAE Handbook of Fundamentals*. Atlanta, GA: ASHRAE. Chapter 28.

2. ASHRAE. 1972. "Air-conditioning cooling load." *ASHRAE Handbook of Fundamentals*. Atlanta, GA: ASHRAE. Chapter 22.

3. ASHRAE. 1977. "Air-conditioning cooling load." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 25.

4. ASHRAE. 1997. "Residential cooling and heating load calculations." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 27.

Skill Development Exercises for Chapter 7

Complete these questions by writing your answers on the worksheets at the back of this book.

7-01. Name several differences between cooling load calculations and heating load calculations.

7-02. Describe the four basic building heat flows used in cooling load calculations.

7-03. List six initial design considerations and explain how each can affect a cooling load calculation.

7-04. Describe three different methods used to calculate cooling loads and give the advantages and disadvantages of each.

Chapter 8
Air-Conditioning Loads on Walls, Roofs and Partitions

Contents of Chapter 8

Instructions

Read the material in Chapter 8. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 8

In the previous chapter, we discussed the general factors that make cooling load calculations more complex than heating load calculations. The first difference is that internal loads (such as people, lights and appliances) as well as external loads must be considered. Both sensible and latent loads for these sources must be determined. Sunlight entering the space through windows is a major contributor to cooling loads. Finally, the effect of thermal mass in delaying delivery of a portion of the space heat gain to the space cooling load must be addressed in the cooling load calculation.

The basic equation used for calculating air-conditioning loads is the same one used to calculate heating loads: $Q = U{\cdot}A{\cdot}\Delta T$, only in calculating cooling loads, the ΔT is usually replaced by the Cooling Load Temperature Difference (CLTD) that you will learn to look-up in this chapter.

The preliminary discussion in this chapter will focus on the process used to determine the sol-air temperature, which is the concept that was used in developing the CLTD/CLF method mentioned at the end of Chapter 7. In section 8.2, we will discuss in detail the process used to determine the CLTD for a typical roof section. A similar procedure presented in section 8.3 will be applied to wall sections, followed by a brief discussion of how to deal with interior walls between conditioned spaces. Finally, to demonstrate the use of this procedure, another sample building will be defined, and the heat gain through a sample roof and walls will be determined.

After studying Chapter 8, you should be able to:

- Estimate the sol-air temperature for a given application.
- Apply correction factors to the CLTD for a given application.
- Calculate the conduction heat transfer through a specified roof, wall or partition section.

8.1 Sol-Air Temperatures

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 outdoor air. As shown in *Figure 8-1*, the exterior surface experiences convective heat transfer and both infrared and visible radiant heat transfer with the environment. The sol-air temperature attempts to capture the thermal effect of all these variables as a single value. The convective heat transfer coefficient is assumed to remain fairly constant at h_o = 3.0 Btu/h·ft²·°F. This value represents the air film value discussed in Chapter 4.

The external surface will exchange long-wave radiation with its surroundings based on the relative temperatures between them. Because the radiant temperature of the sky is always several degrees cooler than the local air temperature, horizontal surfaces such as roofs tend to lose about 20 Btu/h·ft² through this mechanism. Assuming the roof to be an ideal absorber/emitter (a reasonable assumption for most building materials) and using the same convective heat transfer coefficient as above (h_o = 3.0 Btu/h·ft²·°F), then the roof surface temperature can be adjusted 7°F cooler due to this radiant transfer mechanism. There are specialized roof coatings that can have a significant impact on absorptance and emittance and, as a result, reduce roof temperature.

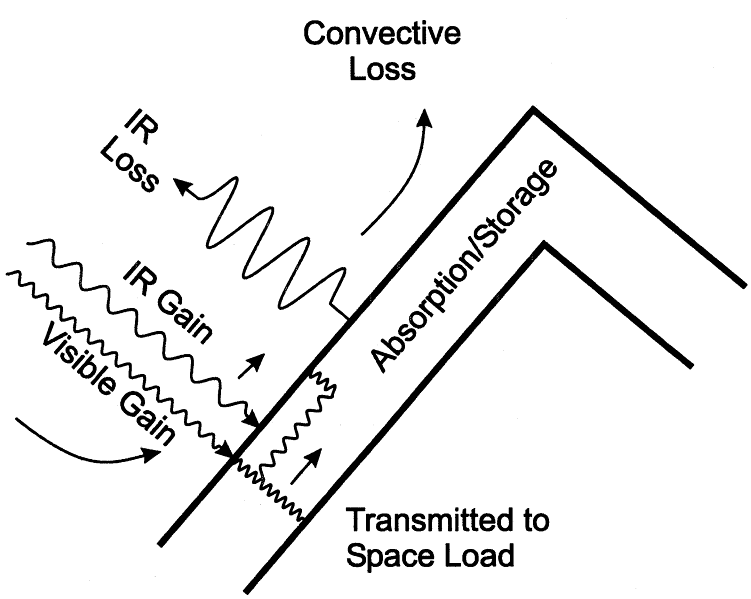


Figure 8-1. Roof Energy

The analysis of vertical surfaces is more difficult, because a wall is exposed to both warmer and cooler surfaces around it. A wall loses radiant energy to the lower sky temperature seen by the roof but gains radiant energy from surrounding surfaces that have been warmed by the sun. The model assumes that these two values cancel each other, and no temperature correction is made for radiant heat transfer on vertical surfaces.

The rate at which solar energy is absorbed by the external surface depends primarily on the color of that surface. Light colored surfaces ($\alpha \approx 0.45$) absorb less sunlight and remain cooler than darker surfaces ($\alpha \approx 0.90$). Values for both light ($\alpha/h_o = 0.15$) and dark ($\alpha/h_o = 0.30$) surfaces are presented in *Table 8-1.*

The values in this table are based on the above assumptions and on typical clear day solar inputs. The assumed daily variation in air temperature is shown in Column 2. The maximum temperature of 95°F occurs at 1500 hours (3:00 pm), and the minimum temperature of 74°F is assumed to occur at 0500 hours (5:00 am). The daily range or difference between these extreme temperatures is assumed to be 21°F. Sol-air temperatures can be adjusted to any other air temperature cycle by adding or subtracting the difference between the desired air temperature and the air temperature value given in Column 2. For example, if the local summer outdoor design temperature is 93°F instead of the 95°F maximum temperature used to develop the table, then all tabled values would be reduced by 2°F. Under this condi-

Table 8-1. Sol-Air Temperatures[1]

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

Time	Air Temp. t_o, °F	Light Colored Surface, $\alpha/h_o = 0.15$ 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, $\alpha/h_o = 0.30$ 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.

tion, the noon sol-air temperature for a north-facing wall would be 94°F instead of the 96°F shown in the table. For other corrections to the sol-air temperature, refer to Chapter 28 of the *ASHRAE Handbook–Fundamentals.*[1]

8.2 CLTD for Roofs

The CLTD for a roof will depend on the location of the mass relative to the insulation, the presence or absence of a suspended ceiling, and on the total R-factor and construction materials used. Based on these parameters, *Table 8-2* is used to translate typical roof constructions into a roof number from 1 to 14. Lower roof numbers typically represent roofs constructed using low-mass materials and including low roof insulation packages. This roof number is then used to determine the CLTD for any hour of the day using *Table 8-3*.

Table 8-2. Roof Numbers[1]

Mass Location**	Suspended Ceiling	R-Value, h·ft²·°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 8-3. July CLTD for Calculating Cooling Loads[1]

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·ft²·°F)/Btu
- With or without suspended ceiling but no ceiling plenum air return systems
- Inside surface resistance of 0.685 (h·ft²·°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

Example 8-1

Problem: A 2-in. heavyweight concrete roof has 2 in. of foam insulation (rated at R-5.4 h·ft²·°F/Btu per in.) on the top side and a suspended ceiling below. Determine the appropriate roof number and the greatest hourly CLTD.

Solution: The total R-value for the outside air film with a 7.5 mph wind (*Table 4-3*), insulation, concrete and inside air film is 0.25 + 2×5.4 + 0.2 + 0.92 = 12.2 h·ft²·°F/Btu. Because the mass is inside the insulation and a suspended ceiling is present, the roof number listed under the HW (heavyweight) concrete column (*Table 8-2*) is roof number 13. Entering *Table 8-3* on the roof number 13 line, the greatest CLTD for this roof is 49°F, which occurs in hour 19 (7 pm). As a comparison on the thermal load effects of different construction methods, notice that if the same level of insulation had been applied to the inside of the concrete, the resulting roof number would be 4, and the maximum CLTD of 78°F would occur during hour 18.

The assumptions used to calculate the CLTD values in *Table 8-3* are listed in Note 1 under the table. There are two adjustments that can be made to the table data as noted in Note 2. If the inside temperature (T_r) or the mean outdoor temperature (T_m) vary from the assumed values of 78°F and 85°F, respectively, then the CLTD can be corrected using the equation:

$$\text{Corr CLTD} = \text{CLTD} + (78°\text{F} - T_r) + (T_m - 85°\text{F})$$

where the mean outdoor temperature (T_m) is given by summer outdoor design temperature minus half of the daily range. These values can be located in *Figure 3-2* of Chapter 3. The tabled values were developed assuming a maximum outdoor temperature and a daily range of 95°F and 21°F, respectively.

EXAMPLE 8-2

Problem: The 0.4% cooling dry-bulb temperature for Boston, MA is given in *Figure 3-2* as 91°F with a mean daily range of 15.3°F. The indoor design temperature for the space is to be 75°F. Correct the CLTD value of 49°F found in the above example for this location.

Solution: The mean outdoor temperature will be one-half of the daily range (8°F) below the high temperature, or 91 - 8 = 83°F. Thus, the 49°F CLTD in the above example would be corrected to:

$$\begin{aligned} \text{CLTD} &= \text{CLTD} + (78 - T_r) + (T_m - 85) = 49 + (78 - 75) + (83 - 85) \\ &= 49 + 3 + [-2] = 50°\text{F} \end{aligned}$$

Table 8-3 shows CLTD values for July at 40° north latitude. These values can be adjusted for other months and latitudes by adding the appropriate value presented in *Table 8-4*. For example, a horizontal roof located at 32°N in September would require a temperature adjustment of -5°F and a corrected CLTD of 50-5 or 45°F.

Experience has shown that this adjustment factor is reasonably consistent during summer months, but much less realistic for early and late hours during traditional non-cooling load months. Research efforts to develop an improved model are ongoing. Until new procedures are available, apply the results from the current procedure with caution in making your design calculations and plan to update your skills with any new procedure as soon as it becomes available.

Also remember that the discussion in this section is focused on obtaining the correct CLTD for a specific roof. This is only the first step in the process of calculating the space cooling load. To obtain the heat gain through the roof, multiply this CLTD value by the appropriate U-factor for the roof and by the area calculated from the building plans or measured in the field.

Table 8-4. CLTD Correction for Latitude and Month[2]

Lat.	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	HOR
0	Dec	−3	−5	−5	−5	−2	0	3	6	9	−1
	Jan/Nov	−3	−5	−4	−4	−1	0	2	4	7	−1
	Feb/Oct	−3	−2	−2	−2	−1	−1	0	−1	0	0
	Mar/Sept	−3	0	1	−1	−1	−3	−3	−5	−8	0
	Apr/Aug	5	4	3	0	−2	−5	−6	−8	−8	−2
	May/Jul	10	7	5	0	−3	−7	−8	−9	−8	−4
	Jun	12	9	5	0	−3	−7	−9	−10	−8	−5
8	Dec	−4	−6	−6	−6	−3	0	4	8	12	−5
	Jan/Nov	−3	−5	−6	−5	−2	0	3	6	10	−4
	Feb/Oct	−3	−4	−3	−3	−1	−1	1	2	4	−1
	Mar/Sept	−3	−2	−1	−1	−1	−2	−2	−3	−4	0
	Apr/Aug	2	2	2	0	−1	−4	−5	−7	−7	−1
	May/Jul	7	5	4	0	−2	−5	−7	−9	−7	−2
	Jun	9	6	4	0	−2	−6	−8	−9	−7	−2
16	Dec	−4	−6	−8	−8	−4	−1	4	9	13	−9
	Jan/Nov	−4	−6	−7	−7	−4	−1	4	8	12	−7
	Feb/Oct	−3	−5	−5	−4	−2	0	2	5	7	−4
	Mar/Sept	−3	−3	−2	−2	−1	−1	0	0	0	−1
	Apr/Aug	−1	0	−1	−1	−1	−3	−3	−5	−6	0
	May/Jul	4	3	3	0	−1	−4	−5	−7	−7	0
	Jun	6	4	4	1	−1	−4	−6	−8	0	−7
24	Dec	−5	−7	−9	−10	−7	−3	3	9	13	−13
	Jan/Nov	−4	−6	−8	−9	−6	−3	9	3	13	−11
	Feb/Oct	−4	−5	−6	−6	−3	−1	3	7	10	−7
	Mar/Sept	−3	−4	−3	−3	−1	−1	1	2	4	−3
	Apr/Aug	−2	−1	0	−1	−1	−2	−1	−2	−3	0
	May/Jul	1	2	2	0	0	−3	−3	−5	−6	1
	Jun	3	3	3	1	0	−3	−4	−6	−6	1
32	Dec	−5	−7	−10	−11	−8	−5	2	9	12	−17
	Jan/Nov	−5	−7	−9	−11	−8	−15	−4	2	9	12
	Feb/Oct	−4	−6	−7	−8	−4	−2	4	8	11	−10
	Mar/Sept	−3	−4	−4	−4	−2	−1	3	5	7	−5
	Apr/Aug	−2	−2	−1	−2	0	−1	0	1	1	−1
	May/Jul	1	1	1	0	0	−1	−1	−3	−3	1
	Jun	1	2	2	1	0	−2	−2	−4	−4	2
40	Dec	−6	−8	−10	−13	−10	−7	0	7	10	−21
	Jan/Nov	−5	−7	−10	−12	−9	−6	1	8	11	−19
	Feb/Oct	−5	−7	−8	−9	−6	−3	3	8	12	−14
	Mar/Sept	−4	−5	−5	−6	−3	−1	4	7	10	−8
	Apr/Aug	−2	−3	−2	−2	0	0	2	3	4	−3
	May/Jul	0	0	0	0	0	0	0	0	1	1
	Jun	1	1	1	0	1	0	0	−1	−1	2
48	Dec	−6	−8	−11	−14	−13	−10	−3	2	6	−25
	Jan/Nov	−6	−8	−11	−13	−11	−8	−1	5	8	−24
	Feb/Oct	−5	−7	−10	−11	−8	−5	1	8	11	−18
	Mar/Sept	−4	−6	−6	−7	−4	−1	4	8	11	−11
	Apr/Aug	−3	−3	−3	−3	−1	0	4	6	7	−5
	May/Jul	0	−1	0	0	1	1	3	3	4	0
	Jun	1	1	2	1	2	1	2	2	3	2
56	Dec	−7	−9	−12	−16	−16	−14	−9	−5	−3	−28
	Jan/Nov	−6	−8	−11	−15	−14	−12	−6	−1	2	−27
	Feb/Oct	−6	−8	−10	−12	−10	−7	0	6	9	−22
	Mar/Sept	−5	−6	−7	−8	−5	−2	4	8	12	−15
	Apr/Aug	−3	−4	−4	−4	−1	1	5	7	9	−8
	May/Jul	0	0	0	0	2	2	5	6	7	−2
	Jun	2	1	2	1	3	3	4	5	6	1
64	Dec	−7	−9	−12	−16	−17	−18	−16	−14	−12	−30
	Jan/Nov	−7	−9	−12	−16	−16	−16	−13	−10	−8	−29
	Feb/Oct	−6	−8	−11	−14	−13	10	−4	1	4	−26
	Mar/Sept	−5	−7	−9	−10	−7	−4	2	7	11	−20
	Apr/Aug	−3	−4	−4	−4	−1	1	5	9	11	−11
	May/Jul	1	0	1	0	3	4	6	8	10	−3
	Jun	2	2	2	2	4	4	6	7	9	0

(1) Corrections in this table are in °F. The correction is applied directly to the CLTD for a wall or roof as given in Tables 29 and 31.

(2) The CLTD correction given in this table is *not* applicable to Table 33, Cooling Load Temperature Differences for Conduction through Glass.

(3) For South latitudes, replace Jan. through Dec. by July through June.

8.3 *CLTD for Walls*

A similar method is used to determine the CLTD for wall sections. The primary building material is selected from *Table 8-5* based on the code number. Next, using *Appendix B*, select the correct wall type, depending on whether the mass is located inside the insulation, evenly distributed, or outside the insulation. A secondary material on the outside of the building is then selected. The three choices of stucco and/or plaster, steel or other lightweight siding, and face brick represent medium, light and heavy construction, respectively. (For some construction details, it will be difficult to judge which model is most appropriate. Just take your best estimate, and make a mental note to check your assumptions later.) Next, the total R-value for the wall section is again used to determine the appropriate wall number. Finally, the wall number, hour of day, and facing direction are used in *Appendix C* to determine the correct CLTD.

Table 8-5. Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions[1]

Code Number	Layer Description	Thickness and Thermal Properties L	k	ρ	Cp	R	Mass
A1	1 in. Stucco	0.08	0.40	116	0.2	0.21	9.7
A2	4 in. Face brick	0.33	0.77	125	0.22	0.43	41.7
B7	1 in. Wood	0.08	0.07	37	0.6	1.20	3.1
B10	2 in. Wood	0.17	0.07	37	0.6	2.39	6.2
B9	4 in. Wood	0.33	0.07	37	0.6	4.76	12.3
C1	in. Clay tile	0.33	0.33	70	0.2	1.01	23.3
C2	4 in Lightweight concrete block	0.33	0.22	38	0.2	1.51	12.7
C3	4 in. Heavyweight concrete block	0.33	0.47	61	0.2	0.71	20.3
C4	4 in. Common brick	0.33	0.42	120	0.2	0.79	40.0
C5	4 in. Heavyweight concrete	0.33	1.00	140	0.2	0.33	46.7
C6	8 in. Clay tile	0.67	0.33	70	0.2	2.00	46.7
C7	8 in Lightweight concrete block	0.67	0.33	38	0.2	2.00	25.7
C8	8 in Heavyweight concrete block	0.67	0.60	61	0.2	1.11	40.7
C17	8 in. Lightweight concrete block (filled)	0.67	0.08	18	0.2	8.34	12.0
C18	8 in. Heavywight concrete block (filled)	0.67	0.34	53	0.2	1.96	35.4

L = thickness; k = thermal conductivity, Btu/h·ft·°F; ρ = density, lb/ft³

C_p = specific heat, Btu/lb·°F; R = thermal resistance, °F·ft²·h/Btu; Mass = unit mass, lb/ft³

EXAMPLE 8-3

Problem: A north wall section consists of 4-in. face brick on the outside, 1 in. of R = 5.4 h·ft²·°F/Btu per in. insulation, and 4-in. heavyweight concrete block on the inside. Find the maximum CLTD and when it would occur.

Solution: From *Table 8-5*, the primary wall material is C5 (concrete block) and the secondary material is face brick. These two masses are evenly distributed on both sides of the insulation. The total R-value is 0.25 + 0.43 + 5.4 + 0.33 + 0.68 = 7.09 h·ft²·°F/Btu. From *Appendix B*, this construction would represent a type 16 wall. Referring to *Appendix C* for a type 16 north-facing wall, the maximum CLTD of 19°F would occur during hours 22 through 24.

This value could again be adjusted for a different indoor temperature, different maximum outdoor temperature, and (with caution) for the latitude and time of year as outlined in the previous section on roofs. The details of this adjustment are given in Note 2 of *Appendix C*.

For comparison purposes, let us also calculate the CLTD for the same materials in two different sequences. If the brick and block are both located outside the insulation, then *Appendix B* yields a type 12 wall, and *Appendix C* indicates a maximum CLTD of 19°F occurs during hours 21 and 22. However, if the brick and block are both located inside the insulation, then *Appendix B* yields a type 13 wall, and *Appendix C* indicates that a maximum CLTD of 18°F occurs during hours 20 through 22.

Quite often the maximum space cooling load occurs in the late afternoon due to sunlight streaming through the west-facing windows. Suppose you wanted to find the CLTD for these same two wall constructions, only west-facing at hour 14. The values for types 13 and 16 walls at that hour are 15°F and 11°F, respectively. The 4°F difference represents the interaction between the insulation and the thermal storage effect of the mass.

For wall sections that are shaded throughout the day, use the CLTD listed for the north wall, where solar effects are minimal. For example, a high-rise office building with the lower floors on its south side shaded by buildings across the street would use the north CLTD for the lower floors and the south CLTD for the upper floors.

As noted with the roof CLTD process above, to determine the actual cooling load, you must multiply the CLTD determined using this process by the net area of the wall and by the effective U-factor determined by the methods in Chapter 4.

8.4 Interior Partitions

Interior partitions, floors and ceilings are relatively easy to include in the cooling load calculation. If both spaces are at the same controlled temperature, there is no cooling load between the two. However, if the spaces are at different temperatures, then use the formula:

$$Q = U{\cdot}A{\cdot}(T_1 - T_2) \qquad (8\text{-}1)$$

The composite U-factors for the partition are determined from the data in Chapter 4. The area, *A*, is calculated from the drawings or field measurements, and the temperatures are the assigned space air temperatures.

8.5 Sample Problem

Problem: An existing small sales building consists of a front office maintained at 76°F in the 36×24 ft west portion, and a stockroom maintained at 82°F in the 36×36 ft east portion (see *Figure 8-2*). Both portions share a flat roof that consists of 2 in. of R-5.4 h·ft²·°F/Btu per in. insulation over 2 in. of heavyweight concrete. The walls are 1 in. wood, 1 in. of R-5.4 h·ft²·°F/Btu per in. insulation, and 4 in. face brick on the outside. The structure is located in New Orleans. The interior partition wall between the office and stock room is 0.5 in. gypsum on both sides of 3.5 in. studs. The roof is 10 ft above the floor slab, with an 8-ft drop ceiling in the west portion only. The window areas are shown in *Figure 8-2*, and 34×80in. doors are located in both the west and the east ends of the building. Find the wall, partition, floor and roof heat gains at 3 pm (the 15th hour) in July.

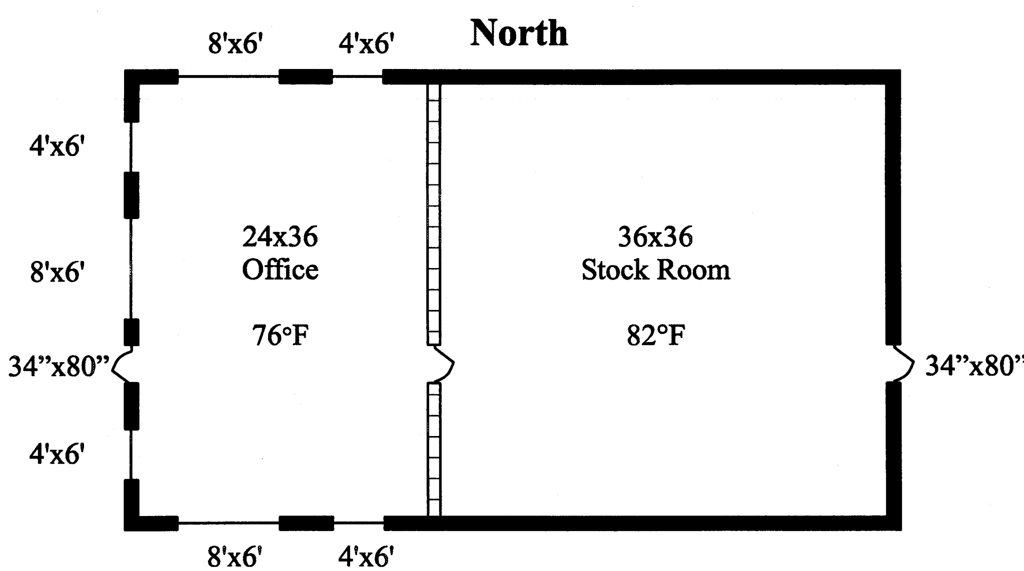


Figure 8-2. Sample Building

Solution: The first step is to divide the building into two zones (referred to here simply as West and East) which are maintained at the two different temperatures. Next, determine the net areas of the walls and roof for the structure as shown in the *Table 8-6*. The roof U-factor is determined from the total roof R-value using the data tables presented in Chapter 4:

0.25	Outside air film for horizontal surface
10.8	2 in. insulation at R-5.4 h·ft²·°F/Btu per in.
0.15	2 in. heavyweight concrete, 150 lb/ft³ at R-0.075 h·ft²·°F/Btu per in.
0.92	Inside air film for horizontal surface (non-reflective)
12.12 =	Total R-value $U = 1 / R_T = 0.083$ Btu/h·ft²·°F

For the east zone, roof number 4 is selected from *Table 8-2* for "Mass inside the insulation", "Without suspended ceiling" with C12 (heavyweight concrete) as the dominant mass and roof R-value between 10 and 15. For the west zone which has a suspended ceiling, the same table indicates roof number 13 should be selected. From *Table 8-3* for roof numbers 4 and 13 at 3 pm (1500 hr), the tabled CLTD values are 65°F and 38°F, respectively. A quick check of *Table 8-4* for latitude 32N indicates that a +1°F temperature correction is needed in July for horizontal surfaces like roofs. *Figure 3-2* indicates that for New Orleans (at International Airport), the 0.4% cooling dry-bulb temperature and mean daily range are 93°F and 15.5°F, respectively. These values along with the West and East room temperatures of 76°F and 82°F, respectively, yield corrected CLTDs for the roof of:

$$\text{West CLTD}_{corr} = (38 + 1) + (78\text{-}76) + ([93 - 16/2] - 85) = 38 + 2 + 0 = 41°\text{F}$$

$$\text{East CLTD}_{corr} = (65 + 1) + (78\text{-}82) + ([93 - 16/2] - 85) = 65 + (-4) + 0 = 62°\text{F}$$

Similarly the total R-value for the outside wall areas (see *Figure 8-3*) is also determined from the data in Chapter 4 and used to determine the wall U-factor:

0.68	Inside air film (non-reflective)
1.0	1 in. wood (assume Southern pine)
5.4	1 in. insulation at R-5.4 h·ft²·°F/Btu per in.
0.43	4 in. face brick
0.25	Outside air film
7.76 =	Total R-value $U = 1/R = 0.13$ Btu/h·ft²·°F

Table 8-6. Sample Problem Calculation Values

Section	Dimensions	Net A ft²	CLTD (Tabled)	CLTD (Corrected)	U-factor	Q=UA(CLTD) Btu/h·ft²·°F
West Zone (76°F)				CLTD+2°F		
North	24x10-6x8-6x4	168	17+1	20	0.13	437
Partition	36x10	360	- -	6	0.32	691
West	36x10-6x4-6x8-6x4-36x76/144	245	20	22	0.13	701
South	24x10-6x8-6x4	168	31-3	30	0.13	655
Roof	24x36	864	38+1	41	0.083	2940
Floor	24+36+24 LF	84	- -	9	0.81	612
					TOTAL =	6036 Btu/h
East Zone (82°F)				CLTD-4°F		
North	36x10	360	17+1	14	0.13	655
Partition	36x10	360	- -	-6	0.32	-691
East	36x10-36x76/144	341	38+1	35	0.13	1552
South	36x10	360	31-3	24	0.13	1123
Roof	36x36	1296	65+1	62	0.083	6669
Floor	36+36+36 LF	108	- -	3	0.81	262
					TOTAL =	9570 Btu/h

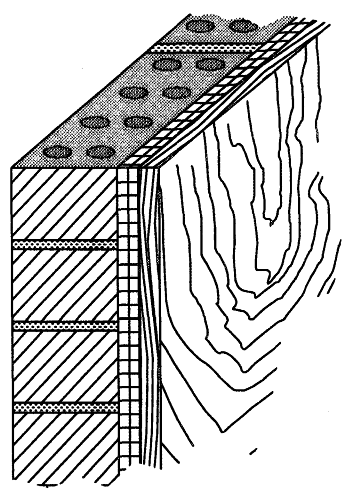


Figure 8-3. Outside Wall Area

The mass (brick) is located outside the wall insulation, so refer to *Appendix B:3*. The principle wall material (face brick) is in column A2, and the secondary material is lightweight siding (wood). Based on the calculated R-value of 7.76, we determine that this construction is modeled as a wall type 5. From *Appendix C* for wall type 5 at hour 15, we find the CLTD values for each wall facing. These tabled values must be corrected using Table 8-4 as shown in the first CLTD column of Table 8-6. As with the roof CLTD, these values for the West and East zones must be adjusted +2°F and -4°F, respectively, for the interior and ambient temperatures. The tabled and corrected values are shown in *Table 8-6* for each wall facing.

The floor slab actually contributes very little to the cooling load, because its average temperature is very close to the space air temperature. Using the method discussed in section 5.4, calculate the exposed floor perimeters for the east and west zones as 108 ft and 84 ft, respectively. Assume a heat loss rate of 0.81 Btu/h per linear foot of exposed edge per °F difference between the indoor air temperature and the average outdoor air temperature (85°F). The calculations are summarized in *Table 8-6*.

The interior cavity wall (see *Figure 8-4*) has an R-value as determined from Chapter 4 of:

0.68	Inside air film
0.32	0.5 in. gypsum (lightweight aggregate)
1.01	3.5 in. air space ($\varepsilon = 0.82$)
0.32	0.5 in. gypsum (lightweight aggregate)
<u>0.68</u>	Inside air film
3.01 =	Total R-value $U = 1 / R = 0.33$ (Btu/h·ft²·°F)

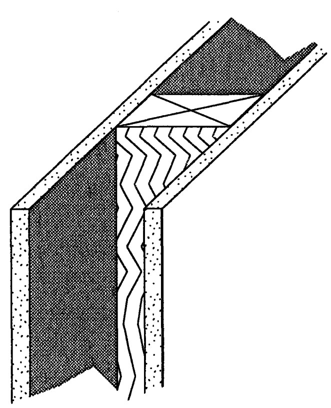


Figure 8-4. Interior Wall Cavity

Notice that the thermal energy flow is from east to west, because the controlled temperature of the east zone is 6°F warmer than the west zone. So, part of the cooling load for the east room is supplied by the west air-conditioning system and is transferred through this interior wall. Also remember in this example, we have only looked at the wall and roof areas. We did not consider the heat gains through the windows and doors, nor did we consider heat gains from ventilation, occupants and lights. These would have to be included to complete the heat gain calculation for this building. We will learn how to deal with those issues in the next chapter.

The Next Step

In the next chapter, the heat gains through windows will be considered. Not only do windows contribute a conduction heat load similar to that of walls and roofs, but they also provide access to the space for a large, complex and continuously moving source of radiant energy: the sun. Although the sun moves across the sky in a very predictable manner, its intensity varies widely throughout the day due primarily to unpredictable clouds. Designers also use a wide range of methods to mitigate the effects of the sun's power. These can range from awnings on the outside of the window, to shades and blinds on the inside, to special surface treatments on the window glass itself. In the next chapter, you will learn how to model these various features and how to calculate the thermal effects of the solar energy that enters the space.

Summary

Chapter 8 focused on the heat gains through roofs, walls, floors and interior partitions using the concepts of both sol-air temperature and CLTD. The application of these skills was demonstrated in an example problem. After studying Chapter 8, you should able to:

- Estimate the sol-air temperature for a given application.
- Apply correction factors to the CLTD for a given application.
- Calculate the conduction heat transfer through a specified roof, wall or partition.

Bibliography

1. ASHRAE. 1997. "Non-residential cooling and heating load calculations." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 28.

2. Sauer, H., Howell, J. 1990. *Principles of Heating, Ventilating and Air-Conditioning*. Atlanta, GA: ASHRAE.

Skill Development Exercises for Chapter 8

Complete these questions by writing your answers on the worksheets at the back of this book.

8-01. A building in Baltimore, MD, with identical dimensions as the above example has a different roofing detail and is rotated 90° counterclockwise (north becomes west). The new roof cross-section is a membrane roof on 2 in. of R-5.4 $h \cdot ft^2 \cdot °F/Btu$ per in. insulation, a steel deck, and 3.5 in. of fiberglass batts between the joists and without a suspended ceiling. Determine the appropriate roof number and heat gain through the roof at noon in July.

8-02. The rotated building in Baltimore, MD, used in *Exercise 8-01* also has a different wall detail, although the dimensions remain the same. The new wall cross-section includes (from the inside): 0.5 in. gypsum, 3.5 in. fiberglass between metal studs, 4 in. heavyweight concrete block, 1 in. air space, and 4 in. face brick. Determine the appropriate wall type and heat gain through the walls in July at noon.

Chapter 9
Cooling Loads from Windows

Contents of Chapter 9

Instructions

Read the material in Chapter 9. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 9

A sunny window offers aesthetic appeal to the occupant and a headache to the designer who must predict the effect the window will have on the cooling load. There are many variables that can affect that load. The quantity of sunlight reaching the window varies throughout the day, seasonally, and with the amount of cloud cover. Shade trees lose their leaves in the fall, grow taller each year, and eventually get cut down. Interior shading devices come in a wide variety of styles and colors, and often their use is at the unpredictable will of the occupant. More permanent features such as exterior overhangs block some of the solar gain. As shown in *Figure 9-1*, light shelves for daylighting will block solar gain on their lower side, but will reflect more light (and heat) through the upper portion of the window. Even the windows themselves come in a wide array of types, framing materials and special treatments. And of course there is always the problem of how the incoming solar energy interacts with the thermal mass of the structure.

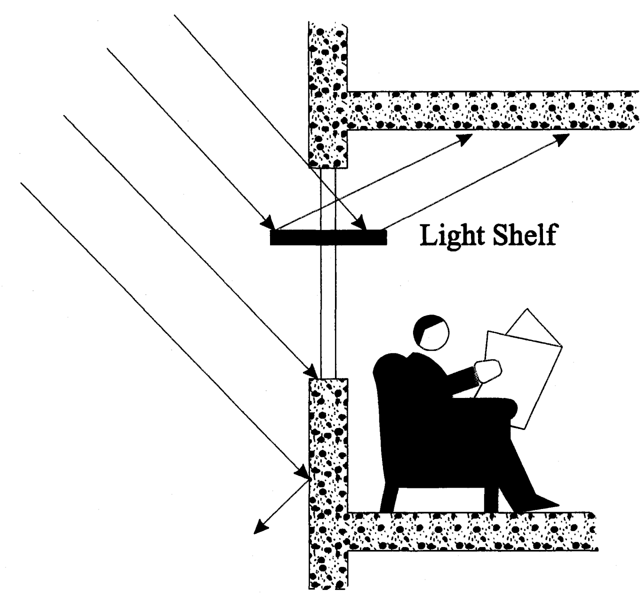


Figure 9-1. Light Shelf

This chapter will teach you how to sort through all of these variables and to predict the cooling load component from windows. We will begin with a general discussion on the various types of windows commonly used today. Heat gain through windows due to conduction will be presented first, because it is comparatively straightforward. You will learn how to determine the quantity of solar energy that is incident on a window, what fraction of that typically enters the space, and how that solar gain interacts with the interior surfaces to create a space cooling load. Finally, you will learn how to estimate the effect of shading devices, both inside and outside. In the last section, you will apply all of these skills to estimate the cooling load from windows in a sample problem.

After studying Chapter 9, you should be able to:

- Explain how various design parameters affect the rate of heat transfer through a window.
- Select appropriate design values (SHGC, SCL and U_o) for a given window.
- Determine the shaded portion for a given window condition.
- Estimate the cooling load for typical window applications.

9.1 Introduction

When we calculated the winter heating load for windows, only the conduction through the window was considered, because the highest heating load occurs at night. But the maximum cooling loads almost always occur during the day and are often driven by the solar gains coming through the windows.

Three new terms must be defined that will be needed in our discussion of windows. The *shading coefficient* (SC) is the ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar gain through a single pane of reference glass under the same conditions. To avoid the ambiguity associated with using a reference glass, this term is rapidly being replaced in the glazing industry by the *solar heat gain coefficient* (SHGC). The SHGC is the fraction of the total solar radiation (visible plus near-infrared) that passes through the glazing and becomes heat gain. Because 87% of the incident solar radiation passed through the reference glass, these two values are related through the expression:

$$SC = \frac{SHGC}{0.87} = 1.15(SHGC) \tag{9-1}$$

The third term is the *visible transmittance* (VT), which is the fraction of the available visible light as perceived by the human eye that is transmitted through a window system. In cooling situations, one design goal is to maximize the VT and minimize the SHGC. Because the visible portion of the spectrum represents 38% of the solar spectrum, the best ratio of VT to SHGC that can be accomplished is 1/0.38 or 2.6. This limit can be approached by using spectrally selective glazing. There are now commercially-available products with VT to SHGC ratios that exceed 2.0. Designers should look for a ratio of at least 1.0 and preferably 1.3 or more when selecting window assemblies for commercial buildings.

The radiant energy from the sun can be considered in three wavelength bands, as shown in *Figure 9-2*. Ultraviolet radiation (wavelengths less than 0.40 μm) represents less than 3% of the solar energy reaching windows. Because most of this energy is reflected back to the outside by glass, it can be ignored. The visible portion (0.4 to 0.7 μm) represents about 38% of the sunlight reaching the window. Transmission of these wavelengths through the glass is desirable to provide daylighting and visibility. The remaining 59% of the solar energy is in the near-infrared (0.7 to 2.2 μm) part of the spectrum. Keeping this infrared energy from entering the space will reduce the cooling load, but letting that energy into the space in winter can reduce the heating cost.

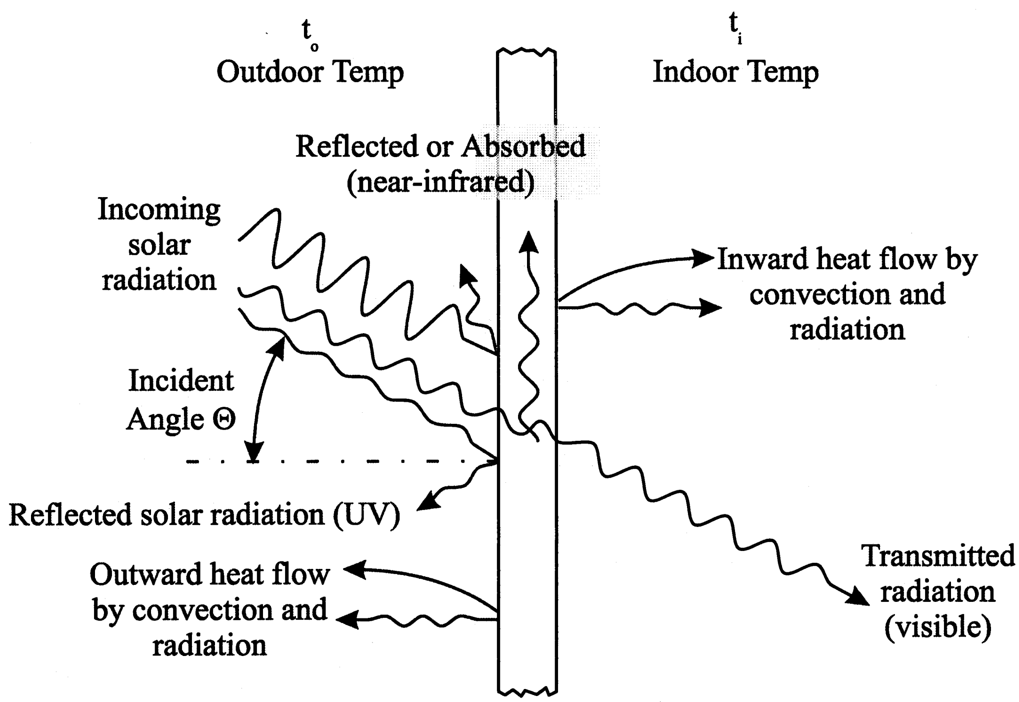


Figure 9-2. Interactions Between Glazings and Solar Radiation

There is a fourth band of wavelengths that plays a major role in heat transfer through windows. Long-wave infrared (5 to 15 μm) is emitted by objects at ambient temperatures. Glass is opaque to these wavelengths, creating what is commonly referred to as the greenhouse effect. Radiation at these wavelengths is absorbed by the glass, increasing its temperature relative to the air around it. The warm glass transfers this energy back to both the inside and the outside through a combination of convective and radiant methods.

The quantity of radiant energy that gets reradiated can be reduced through the application of a chemical coating that has a low emissivity for long-wave infrared radiation. Typical values for the emissivity of these surfaces range from 0.35 down to 0.05. Treating one side of the glass with a low emissivity (low-e) coating will minimize the rate at which long-wave infrared energy is transferred in that direction. Most of the radiant energy is released to the side away from the low-e coating.

Another common practice is to tint the window glazing, a product commonly known as heat-absorbing glass. While this process has little affect on the U-factor, it does decrease the quantity of radiant energy that passes through the window by absorbing it. This absorbed energy is then transferred by convection and radiation from both inside and outside surfaces. If only the outside glazing of a double- or triple-pane window is tinted, most of the absorbed energy is transferred to the outside of the building.

Several methods are available to improve the U-factor for windows. Multiple glazings provide non-convecting dead-air spaces to decrease the U-factor. Double-, triple- and quadruple-pane glazings are now commercially available. Because the middle glazings are protected by the outer panes, thin plastic films can be used. One or more of the glazing surfaces can be treated with a low-e coating. Increasing the spacing between the windows generally decreases the rate of conductive heat transfer, but raises the cost of the thicker framing. Inserting an inert gas such as argon or krypton between the glazings decreases the rate of conduction through a window.

Another variable that can have a strong effect on the conductive heat transfer through a window is the size and type of framing used. Low cost windows use a metal frame, which can easily transfer heat around the edge of a thermopane window. Adding a thermal break within the frame decreases the rate of heat transfer. Using alternate materials such as wood and vinyl can also decrease the rate of heat transfer through the frame.

Two additional factors that affect the rate of conductive heat transfer through windows are the orientation and operability. A skylight in a sloped roof will have a different rate of heat transfer than the same area and style mounted in a vertical wall. Permanently sealed windows are also slightly more energy efficient than operable windows, which must rely on movable seals to prevent air movement and infiltration.

As a general rule, window manufacturers will be able to provide specific design values for their product lines. This chapter contains values on generic types of windows. While these values are useful during the initial phase of a design, always verify the assumed values with those of the specified materials as the project progresses and those values become known.

9.2 Window Gains by Conduction

The basic equation for calculating the rate of conductive heat gain through a window is identical to that used for roofs and walls:

$$q_{conduction} = UA(\mathrm{CLTD}) \tag{9-2}$$

The U-factors for typical window assemblies are given in *Table 9-1*. The "Glass Only" columns do not include losses around the perimeter, due to the framing, which can increase the effective U-factor significantly. There are four types of vertical windows and two types of sloped installation presented. Under each type of window are several framing methods, generally listed from highest U-factor to lowest U-factor for each type. For low-e applications, the surfaces are numbered from the outside as shown in *Figure 9-3*. For example, surface 3 is the outside of the inside glass for a double-pane unit).

Table 9-1. U-Factors for Various Fenestration Products[1]

ID	Product Type / Frame Type / Glazing Type	Glass Only: Center of Glass	Glass Only: Edge of Glass	Vertical Installation — Operable (including sliding and swinging glass doors): Aluminum without Thermal Break	Operable: Aluminum with Thermal Break	Operable: Reinforced Vinyl/ Aluminum Clad Wood	Operable: Wood/ Vinyl	Operable: Insulated Fiberglass/ Vinyl	Fixed: Aluminum without Thermal Break	Fixed: Aluminum with Thermal Break	Fixed: Reinforced Vinyl/ Aluminum Clad Wood	Fixed: Wood/ Vinyl	Fixed: Insulated Fiberglass/ Vinyl
	Single Glazing												
1	1/8 in. glass	1.04	1.04	1.27	1.08	0.90	0.89	0.81	1.13	1.07	0.98	0.98	0.94
2	1/4 in. acrylic/polycarb	0.88	0.88	1.14	0.96	0.79	0.78	0.71	0.99	0.92	0.84	0.84	0.81
3	1/8 in. acrylic/polycarb	0.96	0.96	1.21	1.02	0.85	0.83	0.76	1.06	1.00	0.91	0.91	0.87
	Double Glazing												
4	1/4 in. airspace	0.55	0.64	0.87	0.65	0.57	0.55	0.49	0.69	0.63	0.56	0.56	0.53
5	1/2 in. airspace	0.48	0.59	0.81	0.60	0.53	0.51	0.44	0.64	0.57	0.50	0.50	0.48
6	1/4 in. argon space	0.51	0.61	0.84	0.62	0.55	0.53	0.46	0.66	0.59	0.53	0.52	0.50
7	1/2 in. argon space	0.45	0.57	0.79	0.58	0.51	0.49	0.43	0.61	0.54	0.48	0.48	0.45
	Double Glazing, e = 0.60 on surface 2 or 3												
8	1/4 in. airspace	0.52	0.62	0.84	0.63	0.55	0.53	0.47	0.67	0.60	0.54	0.53	0.51
9	1/2 in. airspace	0.44	0.56	0.78	0.57	0.50	0.48	0.42	0.60	0.53	0.47	0.47	0.45
10	1/4 in. argon space	0.47	0.58	0.81	0.59	0.52	0.50	0.44	0.63	0.56	0.50	0.49	0.47
11	1/2 in. argon space	0.41	0.54	0.76	0.55	0.48	0.46	0.40	0.58	0.51	0.45	0.44	0.42
	Double Glazing, e = 0.40 on surface 2 or 3												
12	1/4 in. airspace	0.49	0.60	0.82	0.61	0.53	0.51	0.45	0.64	0.58	0.51	0.51	0.49
13	1/2 in. airspace	0.40	0.54	0.75	0.54	0.48	0.45	0.40	0.57	0.50	0.44	0.44	0.41
14	1/4 in. argon space	0.43	0.56	0.78	0.57	0.50	0.47	0.41	0.59	0.53	0.46	0.46	0.44
15	1/2 in. argon space	0.36	0.51	0.72	0.52	0.45	0.43	0.37	0.53	0.47	0.41	0.40	0.38
	Double Glazing, e = 0.20 on surface 2 or 3												
16	1/4 in. airspace	0.45	0.57	0.79	0.58	0.51	0.49	0.43	0.61	0.54	0.48	0.48	0.45
17	1/2 in. airspace	0.35	0.50	0.71	0.51	0.44	0.42	0.36	0.53	0.46	0.40	0.39	0.37
18	1/4 in. argon space	0.38	0.52	0.74	0.53	0.46	0.44	0.38	0.55	0.48	0.42	0.42	0.40
19	1/2 in. argon space	0.30	0.46	0.67	0.47	0.41	0.39	0.33	0.48	0.41	0.36	0.35	0.33
	Double Glazing, e = 0.10 on surface 2 or 3												
20	1/4 in. airspace	0.42	0.55	0.77	0.56	0.49	0.47	0.41	0.59	0.52	0.46	0.45	0.43
21	1/2 in. airspace	0.32	0.48	0.69	0.49	0.42	0.40	0.35	0.50	0.43	0.37	0.37	0.35
22	1/4 in. argon space	0.35	0.50	0.71	0.51	0.44	0.42	0.36	0.53	0.46	0.40	0.39	0.37
23	1/2 in. argon space	0.27	0.44	0.65	0.45	0.39	0.37	0.31	0.46	0.39	0.33	0.33	0.31
	Double Glazing, e = 0.05 on surface 2 or 3												
24	1/4 in. airspace	0.41	0.54	0.76	0.55	0.48	0.46	0.40	0.58	0.51	0.45	0.44	0.42
25	1/2 in. airspace	0.30	0.46	0.67	0.47	0.41	0.39	0.33	0.48	0.41	0.36	0.35	0.33
26	1/4 in. argon space	0.33	0.48	0.70	0.49	0.43	0.41	0.35	0.51	0.44	0.38	0.38	0.36
27	1/2 in. argon space	0.25	0.42	0.63	0.44	0.38	0.36	0.30	0.44	0.37	0.32	0.31	0.29
	Triple Glazing												
28	1/4 in. airspaces	0.38	0.52	0.72	0.51	0.44	0.43	0.38	0.55	0.48	0.42	0.41	0.40
29	1/2 in. airspaces	0.31	0.47	0.67	0.46	0.40	0.39	0.34	0.49	0.42	0.36	0.35	0.34
30	1/4 in. argon spaces	0.34	0.49	0.69	0.48	0.42	0.41	0.35	0.51	0.45	0.39	0.38	0.36
31	1/2 in. argon spaces	0.29	0.45	0.65	0.44	0.38	0.37	0.32	0.47	0.40	0.34	0.34	0.32
	Triple Glazing, e = 0.20 on surface 2,3,4, or 5												
32	1/4 in. airspaces	0.33	0.48	0.69	0.47	0.41	0.40	0.35	0.50	0.44	0.38	0.37	0.36
33	1/2 in. airspaces	0.25	0.42	0.62	0.41	0.36	0.35	0.30	0.43	0.37	0.31	0.30	0.29
34	1/4 in. argon spaces	0.28	0.45	0.65	0.44	0.38	0.37	0.32	0.46	0.40	0.34	0.33	0.32
35	1/2 in. argon spaces	0.22	0.40	0.60	0.39	0.34	0.33	0.28	0.41	0.34	0.29	0.28	0.27
	Triple Glazing, e = 0.20 on surfaces 2 or 3 and 4 or 5												
36	1/4 in. airspaces	0.29	0.45	0.65	0.44	0.38	0.37	0.32	0.47	0.40	0.34	0.34	0.32
37	1/2 in. airspaces	0.20	0.39	0.58	0.38	0.32	0.31	0.27	0.39	0.33	0.27	0.26	0.25
38	1/4 in. argon spaces	0.23	0.41	0.61	0.40	0.34	0.33	0.29	0.42	0.35	0.30	0.29	0.28
39	1/2 in. argon spaces	0.17	0.36	0.56	0.36	0.30	0.29	0.25	0.37	0.30	0.25	0.24	0.23
	Triple Glazing, e = 0.10 on surfaces 2 or 3 and 4 or 5												
40	1/4 in. airspaces	0.27	0.44	0.64	0.43	0.37	0.36	0.31	0.45	0.39	0.33	0.32	0.31
41	1/2 in. airspaces	0.18	0.37	0.57	0.36	0.31	0.30	0.25	0.37	0.31	0.25	0.25	0.23
42	1/4 in. argon spaces	0.21	0.39	0.59	0.39	0.33	0.32	0.27	0.40	0.34	0.28	0.27	0.26
43	1/2 in. argon spaces	0.14	0.34	0.54	0.33	0.28	0.27	0.23	0.34	0.28	0.22	0.21	0.20
	Quadruple Glazing, e = 0.10 on surfaces 2 or 3 and 4 or 5												
44	1/4 in. airspaces	0.22	0.40	0.60	0.39	0.34	0.33	0.28	0.41	0.34	0.29	0.28	0.27
45	1/2 in. airspaces	0.15	0.35	0.54	0.34	0.29	0.28	0.24	0.35	0.28	0.23	0.22	0.21
46	1/4 in. argon spaces	0.17	0.36	0.56	0.36	0.30	0.29	0.25	0.37	0.30	0.25	0.24	0.23
47	1/2 in. argon spaces	0.12	0.32	0.52	0.32	0.27	0.26	0.22	0.32	0.26	0.20	0.20	0.19
48	1/4 in. krypton spaces	0.12	0.32	0.52	0.32	0.27	0.26	0.22	0.32	0.26	0.20	0.20	0.19

Notes:

1. All heat transmission coefficients in this table include film resistances and are based on winter conditions of 0 °F outdoor air temperature and 70 °F indoor air temperature, with 15 mph outdoor air velocity and zero solar flux. With the exception of single glazing, small changes in the indoor and outdoor temperatures will not significantly affect overall U-factors. The coefficients are for vertical position except skylight and sloped glazing values, which are for 20° from horizontal with heat flow up.

2. Glazing layer surfaces are numbered from the outdor to the indor. Double, triple and quadruple refer to the number of glazing panels. All data are based on 1/8 inch glass, unless otherwise noted. Thermal conductivities are: 0.53 Btu/(h·ft·°F) for glass, and 0.11 Btu/(h·ft·°F) for acrylic and polycarbonate.

3. Standard spacers are metal. Edge-of-glass effects assumed to extend over the 2 1/2 inch band around perimeter of each glazing unit as in Figure 3.

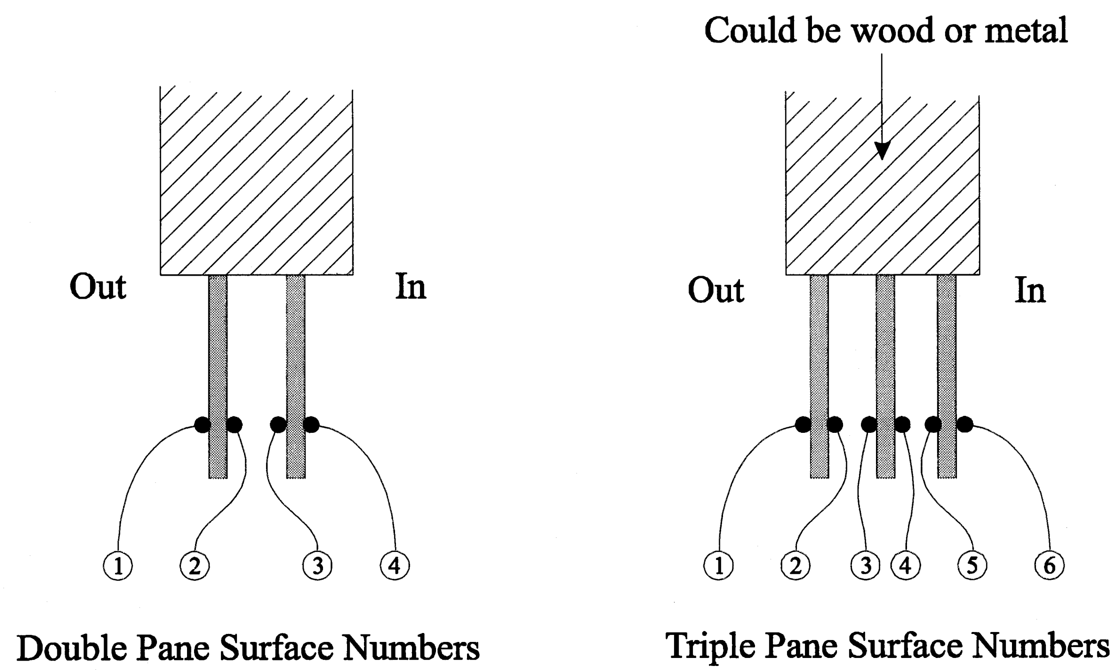


Figure 9-3. Window Cross-Sections

The area, *A*, used in this calculation is the gross area of the fenestration product, including the frame and the glazing. The CLTD for each hour of the day is given in *Table 9-2*. As with the roof and wall CLTDs discussed in Chapter 8, this value can be adjusted if the indoor temperature differs from 78°F, or if the outdoor daily average temperature is not equal to 85°F. For more detailed discussion on the assumptions made to obtain these U-factors, or how to determine the U-factors of other construction details, see Chapter 29 of the *ASHRAE Handbook–Fundamentals.*[1]

Table 9-2. CLTD for Conduction Through Glass[2]

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.

9.3 Solar Heat Gains

Three values are required to estimate the space cooling loads due to solar radiation gains through windows. The gross window area A in square feet and the window orientation are the most easily obtained either from the drawings or through field measurements.

The second required value is the fraction of the incident radiation that is actually transmitted through the glazing and enters a space, which is given by the SHGC. The third required value is the intensity of solar radiation intercepted by a surface in the given orientation. This value is a function of latitude, month and time of day. The thermal storage of the space has also been incorporated into the determination of the value called Solar Cooling Load (SCL) in units of Btu/h·ft^2.

The methodology used here to estimate space cooling loads due to solar radiation gains through windows is a product of these three values as given by the equation:

$$q_{rad} = A(1.15 \cdot \mathrm{SHGC})(\mathrm{SCL}) \tag{9-3}$$

where,

q_{rad} = cooling load caused by solar radiation, Btu/h
A = net glass area of fenestration, ft^2
SHGC = solar heat gain coefficient, for combination of fenestration and shading device
SCL = solar cooling load, Btu/(h·ft^2)

The SHGC is a function of the incident angle and spectral properties such as low-e and tinted glass. *Table 9-3* gives SHGC values for frequently used fenestrations. This value can be used to represent a wide range of glazing combinations from single glazing treated with solar-reflective films or coatings to double and triple glazing with low-emittance coatings and a range of incident angles. For example, if a 30% reflective film is added to a single-pane clear window in a fixed aluminum frame (ID 1o), then the resulting SHGC is about 0.36. In other words, this window will admit to the space about 36% of the solar energy that would be incident on the glazing.

To investigate the effects of both tinting and low-e coatings, let us examine the data for double strength (0.25 in.), double-pane windows in fixed aluminum frames. *Table 9-3* indicates the SHGC values for clear uncoated glass (ID 5b), green tinted outside and clear inside (5f), and clear with a low-e coating on surface 3 (ID 17d) are 0.64, 0.43 and 0.59, respectively. Combining the low-e coating with the green tinting (ID 17h) results in a value for SHGC of 0.39. The VT to SHGC ratio for all of these selections is greater than 1.0, so they would be acceptable selections.

Table 9-3. VT, SC and SHGC at Normal Incidence for Single-Pane Glass and Insulating Glass[1]

ID	Glass Thick, in.	Glazing System	Center Glazing VT	Center Glazing SC	Glazing SHGC at Specified Incidence Angles: Normal 0°	40°	50°	60°	70°	Hemis. (Diffuse)	Total Window SHGC at Normal Incidence: Aluminum Operable	Aluminum Fixed	Other Frames Operable	Other Frames Fixed	Total Window VT at Normal Incidence, All Frames: Operable	Fixed
		Uncoated Single Glazing														
1a	1/8	Clear	0.90	1.00	0.86	0.85	0.83	0.78	0.67	0.78	0.75	0.78	0.63	0.75	0.65	0.78
1b	1/4	Clear	0.89	0.94	0.81	0.80	0.77	0.73	0.62	0.73	0.71	0.74	0.60	0.71	0.65	0.78
1c	1/8	Bronze	0.68	0.85	0.73	0.71	0.69	0.64	0.55	0.65	0.64	0.67	0.54	0.64	0.49	0.59
1d	1/4	Bronze	0.55	0.73	0.62	0.60	0.58	0.54	0.46	0.55	0.55	0.57	0.46	0.54	0.40	0.48
1e	1/8	Green	0.82	0.82	0.71	0.68	0.66	0.62	0.53	0.63	0.62	0.65	0.53	0.62	0.60	0.71
1f	1/4	Green	0.74	0.68	0.58	0.56	0.54	0.51	0.44	0.52	0.51	0.53	0.43	0.51	0.54	0.64
1g	1/8	Gray	0.62	0.82	0.70	0.68	0.66	0.61	0.53	0.63	0.61	0.64	0.52	0.61	0.45	0.54
1h	1/4	Gray	0.43	0.65	0.56	0.53	0.51	0.48	0.41	0.49	0.50	0.51	0.42	0.49	0.31	0.37
1i	1/4	Bluegreen	0.75	0.72	0.62	0.59	0.57	0.54	0.46	0.55	0.55	0.57	0.46	0.54	0.54	0.65
		Reflective Single Glazing														
1j	1/4	SS on CLR 8%	0.08	0.22	0.19	0.19	0.18	0.17	0.15	0.17	0.18	0.18	0.15	0.17	0.06	0.07
1k	1/4	SS on CLR 14%	0.14	0.29	0.25	0.25	0.24	0.23	0.20	0.23	0.23	0.24	0.19	0.22	0.10	0.12
1l	1/4	SS on CLR 20%	0.20	0.36	0.31	0.30	0.30	0.28	0.24	0.28	0.28	0.29	0.24	0.27	0.15	0.17
1m	1/4	SS on GRN 14%	0.12	0.29	0.25	0.25	0.24	0.23	0.20	0.23	0.23	0.24	0.19	0.22	0.09	0.10
1n	1/4	TI on CLR 20%	0.20	0.34	0.29	0.29	0.28	0.26	0.23	0.27	0.27	0.27	0.22	0.26	0.15	0.17
1o	1/4	TI on CLR 30%	0.30	0.45	0.39	0.38	0.37	0.35	0.30	0.35	0.35	0.36	0.29	0.34	0.22	0.26
		Uncoated Double Glazing														
5a	1/8	CLR CLR	0.81	0.87	0.75	0.73	0.70	0.63	0.49	0.65	0.66	0.68	0.55	0.66	0.59	0.71
5b	1/4	CLR CLR	0.78	0.81	0.70	0.68	0.65	0.58	0.45	0.60	0.61	0.64	0.52	0.61	0.57	0.68
5c	1/8	BRZ CLR	0.62	0.72	0.62	0.59	0.57	0.51	0.39	0.53	0.55	0.57	0.46	0.54	0.45	0.54
5d	1/4	BRZ CLR	0.48	0.59	0.50	0.47	0.45	0.40	0.31	0.42	0.45	0.46	0.37	0.44	0.35	0.42
5e	1/8	GRN CLR	0.74	0.70	0.60	0.57	0.55	0.49	0.38	0.51	0.53	0.55	0.45	0.53	0.54	0.64
5f	1/4	GRN CLR	0.66	0.54	0.47	0.44	0.42	0.38	0.30	0.40	0.42	0.43	0.35	0.41	0.48	0.57
5g	1/8	GRY CLR	0.56	0.69	0.59	0.57	0.54	0.48	0.37	0.50	0.52	0.54	0.44	0.52	0.41	0.49
5h	1/4	GRY CLR	0.40	0.51	0.44	0.42	0.40	0.35	0.28	0.38	0.39	0.41	0.33	0.39	0.29	0.35
5i	1/4	BLUGRN CLR	0.67	0.58	0.50	0.47	0.45	0.40	0.32	0.43	0.45	0.46	0.37	0.44	0.49	0.58
5j	1/4	HI-P GRN CLR	0.59	0.46	0.39	0.37	0.35	0.31	0.25	0.33	0.35	0.36	0.29	0.34	0.43	0.51
		Reflective Double Glazing														
5k	1/4	SS on CLR 8%,CLR	0.07	0.15	0.13	0.13	0.12	0.12	0.10	0.12	0.13	0.13	0.10	0.12	0.05	0.06
5l	1/4	SS on CLR 14%, CLR	0.13	0.20	0.17	0.17	0.16	0.15	0.12	0.15	0.17	0.16	0.13	0.15	0.09	0.11
5m	1/4	SS on CLR 20%, CLR	0.18	0.26	0.22	0.21	0.21	0.19	0.16	0.19	0.21	0.21	0.17	0.20	0.13	0.16
5n	1/4	SS on GRN 14%, CLR	0.11	0.18	0.16	0.16	0.15	0.14	0.12	0.14	0.16	0.16	0.13	0.14	0.08	0.10
5o	1/4	TI on CLR 20%, CLR	0.18	0.24	0.21	0.20	0.20	0.18	0.15	0.19	0.20	0.20	0.16	0.19	0.13	0.16
5p	1/4	TI on CLR 30%, CLR	0.27	0.33	0.29	0.28	0.27	0.25	0.20	0.25	0.27	0.27	0.22	0.26	0.20	0.24
		Low-e Double Glazing, e = 0.2 on Surface 2														
17a	1/8	LE CLR	0.76	0.76	0.65	0.63	0.61	0.55	0.43	0.57	0.57	0.59	0.48	0.57	0.55	0.66
17b	1/4	LE CLR	0.73	0.70	0.60	0.58	0.56	0.51	0.40	0.52	0.53	0.55	0.45	0.53	0.53	0.64
		Low-e Double Glazing, e = 0.2 on Surface 3														
17c	1/8	CLR LE	0.76	0.81	0.70	0.68	0.65	0.59	0.46	0.61	0.61	0.64	0.52	0.61	0.55	0.66
17d	1/4	CLR LE	0.73	0.75	0.65	0.63	0.60	0.54	0.42	0.56	0.57	0.59	0.48	0.57	0.53	0.64
17e	1/8	BRZ LE	0.58	0.66	0.57	0.54	0.52	0.46	0.36	0.48	0.50	0.52	0.42	0.50	0.42	0.51
17f	1/4	BRZ LE	0.45	0.52	0.45	0.42	0.40	0.35	0.27	0.37	0.40	0.41	0.34	0.40	0.33	0.39
17g	1/8	GRN LE	0.70	0.63	0.55	0.52	0.50	0.44	0.34	0.46	0.49	0.50	0.41	0.48	0.51	0.61
17h	1/4	GRN LE	0.61	0.48	0.42	0.39	0.37	0.33	0.25	0.35	0.38	0.39	0.32	0.37	0.44	0.53
17i	1/8	GRY LE	0.53	0.63	0.54	0.51	0.49	0.43	0.33	0.46	0.48	0.50	0.40	0.47	0.38	0.46
17j	1/4	GRY LE	0.37	0.46	0.39	0.36	0.34	0.31	0.24	0.33	0.35	0.36	0.29	0.34	0.27	0.32
17k	1/4	BLUGRN LE	0.62	0.52	0.45	0.42	0.40	0.35	0.27	0.37	0.40	0.41	0.34	0.40	0.45	0.54
17l	1/4	HI-P GRN LE	0.55	0.40	0.34	0.31	0.29	0.26	0.20	0.28	0.31	0.32	0.26	0.30	0.40	0.48
		Low-e Double Glazing, e = 0.1 on Surface 2														
21a	1/8	LE CLR	0.75	0.62	0.54	0.52	0.49	0.44	0.34	0.46	0.48	0.50	0.40	0.47	0.54	0.65
21b	1/4	LE CLR	0.72	0.59	0.51	0.49	0.47	0.42	0.32	0.44	0.45	0.47	0.38	0.45	0.52	0.63
21l	1/4	HI-P GRN W/LE CLR	0.57	0.36	0.31	0.30	0.29	0.26	0.21	0.27	0.28	0.29	0.24	0.27	0.41	0.50
		Low-e Double Glazing, e = 0.1 on Surface 3														
21c	1/8	CLR LE	0.75	0.69	0.60	0.58	0.56	0.51	0.41	0.53	0.53	0.55	0.45	0.53	0.54	0.65
21d	1/4	CLR LE	0.72	0.66	0.56	0.54	0.52	0.47	0.38	0.49	0.50	0.51	0.42	0.49	0.52	0.63
21e	1/8	BRZ LE	0.57	0.56	0.48	0.46	0.43	0.39	0.31	0.41	0.43	0.44	0.36	0.42	0.41	0.50
21f	1/4	BRZ LE	0.45	0.45	0.39	0.37	0.34	0.31	0.24	0.33	0.35	0.36	0.29	0.34	0.33	0.39
21g	1/8	GRN LE	0.68	0.57	0.49	0.47	0.44	0.40	0.31	0.42	0.44	0.45	0.37	0.43	0.49	0.59
21h	1/4	GRN LE	0.61	0.45	0.39	0.36	0.34	0.30	0.24	0.33	0.35	0.36	0.29	0.34	0.44	0.53
21i	1/8	GRY LE	0.52	0.53	0.46	0.44	0.41	0.37	0.29	0.39	0.41	0.42	0.34	0.41	0.38	0.45
21j	1/4	GRY LE	0.37	0.40	0.35	0.33	0.31	0.28	0.22	0.29	0.32	0.33	0.26	0.31	0.27	0.32
21k	1/4	BLUGRN LE	0.62	0.48	0.42	0.39	0.37	0.33	0.26	0.35	0.38	0.39	0.32	0.37	0.45	0.54

Table 9-3. VT, SC and SHGC at Normal Incidence for Single-Pane Glass and Insulating Glass (cont.)

ID	Glass Thick, in.	Glazing System	Center Glazing VT	Center Glazing SC	Glazing SHGC at Specified Incidence Angles: Normal 0°	40°	50°	60°	70°	Hemis. (Diffuse)	Total Window SHGC at Normal Incidence: Aluminum Operable	Aluminum Fixed	Other Frames Operable	Other Frames Fixed	Total Window VT at Normal Incidence: All Frames Operable	All Frames Fixed
Low-e Double Glazing, e = 0.05 on Surface 2																
25a	1/8	LE CLR	0.72	0.48	0.41	0.38	0.34	0.26	0.14	0.35	0.37	0.38	0.31	0.36	0.52	0.63
25b	1/4	LE CLR	0.70	0.43	0.37	0.34	0.31	0.24	0.13	0.32	0.33	0.34	0.28	0.33	0.51	0.61
25c	1/4	BRZ W/LE CLR	0.42	0.30	0.26	0.24	0.22	0.18	0.10	0.23	0.24	0.24	0.20	0.23	0.31	0.37
25d	1/4	GRN W/LE CLR	0.60	0.35	0.30	0.28	0.25	0.20	0.11	0.26	0.28	0.28	0.23	0.27	0.44	0.52
25e	1/4	GRY W/LE CLR	0.35	0.27	0.24	0.22	0.20	0.16	0.10	0.20	0.22	0.23	0.18	0.21	0.25	0.30
25f	1/4	BLUE W/LE CLR	0.45	0.32	0.27	0.25	0.23	0.18	0.10	0.23	0.25	0.25	0.21	0.24	0.33	0.39
25g	1/4	HI-P GRN W/LE CLR	0.53	0.31	0.27	0.26	0.25	0.23	0.18	0.24	0.25	0.25	0.22	0.25	0.38	0.46
Triple Glazing																
29a	1/8	CLR CLR CLR	0.74	0.78	0.67	0.65	0.61	0.53	0.39	0.57	0.59	0.61	0.50	0.59	0.54	0.64
29b	1/4	CLR CLR CLR	0.70	0.71	0.61	0.58	0.55	0.48	0.35	0.51	0.54	0.56	0.45	0.54	0.51	0.61
29c	1/4	HI-P GRN CLR CLR	0.53	0.39	0.34	0.31	0.29	0.25	0.19	0.27	0.31	0.32	0.26	0.30	0.38	0.46
Triple Glazing, e = 0.2 on Surface 2																
32a	1/8	LE CLR CLR	0.68	0.69	0.60	0.58	0.55	0.48	0.35	0.51	0.53	0.55	0.45	0.53	0.49	0.59
32b	1/4	LE CLR CLR	0.64	0.62	0.53	0.50	0.47	0.41	0.30	0.44	0.47	0.49	0.39	0.47	0.46	0.56
Triple Glazing, e = 0.2 on Surface 5														0.00	0.00	
32c	1/8	CLR CLR LE	0.68	0.72	0.62	0.60	0.56	0.49	0.36	0.52	0.55	0.57	0.46	0.54	0.49	0.59
32d	1/4	CLR CLR LE	0.64	0.65	0.56	0.53	0.50	0.44	0.32	0.47	0.50	0.51	0.42	0.49	0.46	0.56
Triple Glazing, e = 0.1 on Surface 2 and 5																
40a	1/8	LE CLR LE	0.62	0.52	0.45	0.43	0.40	0.36	0.26	0.38	0.40	0.41	0.34	0.40	0.45	0.54
40b	1/4	LE CLR LE	0.59	0.47	0.41	0.39	0.37	0.32	0.24	0.34	0.37	0.38	0.31	0.36	0.43	0.51
Triple Glazing, e = 0.05 on Surface 2 and 4								0.00	0.00							
40c	1/8	LE LE CLR	0.58	0.37	0.32	0.30	0.29	0.26	0.19	0.27	0.29	0.30	0.24	0.28	0.42	0.51
40d	1/4	LE LE CLR	0.55	0.36	0.31	0.29	0.28	0.25	0.19	0.26	0.28	0.29	0.24	0.27	0.40	0.48

KEY:

CLR = clear, GRN = green, GRY = gray, SS = stainless steel reflective coating, TI = titanium reflective coating
Reflective coating descriptors include percent visible transmittance as x%.
Hi-P GRN = high performance green tinted glass, LE = glass with a low-emissivity coating with an emittance of e = 0.xx

Low-e coating with an emittance of 0.2 is a pyrolytic coating. Other low-e coatings are sputtered coatings.
VT is Visible Transmittance, SC is Shading Coefficient, SHGC, is Solar Heat Gain Coefficient, and HEMIS is the hemispherical SHGC
ID numbers refer to U-factors in Table 5
SHGC at 90° is 0.

The Solar Cooling Load (SCL) depends on a particular combination of conditions defining the space, or zone, under consideration. Extensive research has identified 14 design parameters that affect the rate at which sunlight streaming through a window is absorbed by a surface in the room, converted to sensible energy, and released into the air. A room with greater storage will generally have a smaller space cooling load for a longer period of time.

To determine the most appropriate SCL table for a zone, refer to *Tables 9-4a* and *9-4b*, where zone types (A, B, C or D) are given as functions of some of the more dominant of the 14 zone parameters known to affect how quickly entering solar energy is converted to the space cooling load. Based on the number of exposed walls, type of floor covering, partition type and presence of an inside shade, a zone type is selected from this table. Note that this table also indicates zone types for people and equipment, and for lights. These parameters will be used in the next chapter to determine the internal loads from those sources. The last two columns give a percentage error band between the measured value and the calculated value that can be expected when making the above assumptions.

Table 9-4a. Zone Types for Use With SCL and CLF Tables, Single-Story Building[2]

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 selected to achieve the minimum error band shown in the righthand column for Solar Cooling Load (SCL). The error band for Lights and People and Equipment is approximately 10%.
[b]The effect of inside shade is negligible in this case.

Table 9-4b. Zone Types for Use With CLF Tables, Interior Rooms[2]

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.

For each zone type defined above, the SCLs for sunlit glass at 40°N latitude and one month, July, are tabulated in *Table 9-5*. For each hour of the day and any given orientation, the solar flux through the window is given. For example, at noon on July 21, a south-facing zone type A window will transmit 97 Btu/h·ft², but a zone type B window will transmit 86 Btu/h·ft². In the second case, more of the solar energy is being stored in the building mass, shifting the space cooling rate to later in the day. Referring back to the first three lines of *Table 9-4a*, this difference might represent either a change in partition type (gypsum to concrete block) or floor covering (carpet to vinyl). Either change allows more of the radiant energy to be stored in the building mass.

The *Cooling and Heating Load Calculation Manual* includes additional data for multi-story buildings and for other latitudes, months and zone types.[3] Interpolation between latitudes can be performed with some loss of accuracy. Because northern windows are never directly exposed to the sun, values from that column can also be used for windows that are completely shaded. These solar gains come from diffuse and reflected sunlight that reaches the window even when it is shaded. Expect some loss of accuracy from using these values at latitudes lower than 24°N.

There is another table of values related to solar energy gain through windows that will be required in Chapter 12. The Solar Heat Gain Factor (SHGF) is similar to the SCL because it represents the rate of solar energy incident on the surface in units of Btu/h·ft²·°F. However, the SHGF represents the actual instantaneous solar flux and does not include any thermal storage effects incorporated into the determination of the SCL. *Table 9-6* presents values for the SHGF at 40°N latitude, depending on month, time of day and orientation. Because the data are symmetrical around solar noon, notice that morning values are read from the top down, and the afternoon values are read from the bottom up. Values for other latitudes can be found in the *ASHRAE Handbook–Fundamentals*.[1]

Example 9-1

Problem: Compare the SHGF values in March at 40°N for a SE facing with values for a SW facing at solar times of 0800, 1100, 1400 and 1700.

Solution: The values (in Btu/h·ft²·°F) are determined from *Table 9-6* as shown in the following table:

Hour	0800	1100	1400	1700
SE	211	198	29	8
SW	16	77	229	135

Table 9-5. July Solar Cooling Load for Sunlit Glass, 40° North Latitude[2]

Zone Type A

Glass Face	Hour 1	2	3	4	5	6	7	8	9	10	11	Solar Time 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 1	2	3	4	5	6	7	8	9	10	11	Solar Time 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 1	2	3	4	5	6	7	8	9	10	11	Solar Time 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 1	2	3	4	5	6	7	8	9	10	11	Solar Time 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·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.

Table 9-6. Solar Irradiance and SHGF for 40° North Latitude[1]

Date	Solar Time	Direct Normal Btu/(h·ft²)	Solar Heat Gain Factors, Btu/(h·ft²)																	Solar Time
			N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Hor.	
Jan	0800	142	5	5	17	71	111	132	133	114	75	22	6	5	5	5	5	5	14	1600
	0900	239	12	12	13	74	154	205	224	209	160	82	13	12	12	12	12	12	55	1500
	1000	274	16	16	16	31	124	199	241	246	213	146	51	17	16	16	16	16	96	1400
	1100	289	19	19	19	20	61	156	222	252	244	198	118	28	19	19	19	19	124	1300
	1200	294	20	20	20	20	21	90	179	234	254	234	179	90	21	20	20	20	133	1200
	HALF DAY TOTALS		61	61	73	199	452	734	904	932	813	561	273	101	62	61	61	61	354	
Feb	0700	55	2	3	23	40	51	53	47	34	14	2	2	2	2	2	2	2	4	1700
	0800	219	10	11	50	129	183	206	199	160	94	18	10	10	10	10	10	10	43	1600
	0900	271	16	16	22	107	186	234	245	218	157	66	17	16	16	16	16	16	98	1500
	1000	294	21	21	21	49	143	211	246	243	203	129	38	21	21	21	21	21	143	1400
	1100	304	23	23	23	24	71	160	219	244	231	184	103	27	23	23	23	23	171	1300
	1200	307	24	24	24	24	25	86	170	222	241	222	170	86	25	24	24	24	180	1200
	HALF DAY TOTALS		84	86	152	361	648	916	1049	1015	821	508	250	114	85	84	84	84	548	
Mar	0700	171	9	29	93	140	163	161	135	86	22	8	8	8	8	8	8	8	26	1700
	0800	250	16	18	91	169	218	232	211	157	74	17	16	16	16	16	16	16	85	1600
	0900	282	21	22	47	136	203	238	236	198	128	40	22	21	21	21	21	21	143	1500
	1000	297	25	25	27	72	153	207	229	216	171	95	29	25	25	25	25	25	186	1400
	1100	305	28	28	28	30	78	151	198	213	197	150	77	30	28	28	28	28	213	1300
	1200	307	29	29	29	29	31	75	145	191	206	191	145	75	31	29	29	29	223	1200
	HALF DAY TOTALS		114	139	302	563	832	1035	1087	968	694	403	220	132	114	113	113	113	764	
Apr	0600	89	11	46	72	87	88	76	52	18	5	5	5	5	5	5	5	5	11	1800
	0700	206	16	71	140	185	201	186	143	75	16	14	14	14	14	14	14	14	61	1700
	0800	252	22	44	128	190	224	223	188	124	41	22	21	21	21	21	21	21	123	1600
	0900	274	27	29	80	155	202	219	203	156	83	29	27	27	27	27	27	27	177	1500
	1000	286	31	31	37	92	152	187	193	170	121	56	32	31	31	31	31	41	217	1400
	1100	292	33	33	34	39	81	130	160	166	146	102	52	35	33	33	33	33	243	1300
	1200	293	34	34	34	34	36	62	108	142	154	142	108	62	36	34	34	34	252	1200
	HALF DAY TOTALS		154	265	501	758	957	1051	994	782	488	296	199	157	148	147	147	147	957	
May	0500	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1900
	0600	144	36	90	128	145	141	115	71	18	10	10	10	10	10	10	10	11	31	1800
	0700	216	28	102	165	202	209	184	131	54	20	19	19	19	19	19	19	19	87	1700
	0800	250	27	73	149	199	220	208	164	93	29	25	25	25	25	25	25	25	146	1600
	0900	267	31	42	105	164	197	200	175	121	53	32	30	30	30	30	30	30	195	1500
	1000	277	34	36	54	105	148	168	163	133	83	40	35	34	34	34	34	34	234	1400
	1100	283	36	36	38	48	81	113	130	127	105	70	42	38	36	36	36	36	257	1300
	1200	284	37	37	37	38	40	54	82	104	113	104	82	54	40	38	37	37	265	1200
	HALF DAY TOTALS		215	404	666	893	1024	1025	881	601	358	247	200	180	176	175	174	175	1083	
Jun	0500	22	10	17	21	22	20	14	6	2	1	1	1	1	1	1	1	2	3	1900
	0600	155	48	104	143	159	151	121	70	17	13	13	13	13	13	13	13	14	40	1800
	0700	216	37	113	172	205	207	178	122	46	22	21	21	21	21	21	21	21	97	1700
	0800	246	30	85	156	201	216	199	152	80	29	27	27	27	27	27	27	27	153	1600
	0900	263	33	51	114	166	192	190	161	105	45	33	32	32	32	32	32	32	201	1500
	1000	272	35	38	63	109	145	158	148	116	69	39	36	35	35	35	35	35	238	1400
	1100	277	38	39	40	52	81	105	116	110	88	60	41	39	38	38	38	38	260	1300
	1200	279	38	38	38	40	41	52	72	89	95	89	72	52	41	40	38	38	267	1200
	HALF DAY TOTALS		253	470	734	941	1038	999	818	523	315	236	204	191	188	187	186	188	1126	
Jul	0500	2	1	2	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	1900
	0600	138	37	89	125	142	137	112	68	18	11	11	11	11	11	11	11	12	32	1800
	0700	208	30	102	163	198	204	179	127	53	21	20	20	20	20	20	20	20	88	1700
	0800	241	28	75	148	196	216	203	160	90	30	26	26	26	26	26	26	26	145	1600
	0900	259	32	44	106	163	193	196	170	118	52	33	31	31	31	31	31	31	194	1500
	1000	269	35	37	56	106	146	165	159	129	81	41	36	35	35	35	35	35	231	1400
	1100	275	37	38	40	50	81	111	127	123	102	69	43	39	37	37	37	37	254	1300
	1200	276	38	38	38	40	41	55	80	101	109	101	80	55	41	40	38	38	262	1200
	HALF DAY TOTALS		223	411	666	885	1008	1003	858	584	352	248	204	186	181	180	180	181	1076	
Aug	0600	81	12	44	68	81	82	71	48	17	6	5	5	5	5	5	5	5	12	1800
	0700	191	17	71	135	177	191	177	135	70	17	16	16	16	16	16	16	16	62	1700
	0800	237	24	47	126	185	216	214	180	118	41	23	23	23	23	23	23	23	122	1600
	0900	260	28	31	82	153	197	212	196	151	80	31	28	28	28	28	28	28	174	1500
	1000	272	32	33	40	93	150	182	187	165	116	56	34	32	32	32	32	32	214	1400
	1100	278	35	35	36	41	81	128	156	160	141	99	52	37	35	35	35	35	239	1300
	1200	280	35	35	35	36	38	63	106	138	149	138	106	63	38	36	35	35	247	1200
	HALF DAY TOTALS		164	273	498	741	928	1013	956	751	474	296	205	166	157	156	156	156	946	
Sep	0700	149	9	27	84	125	146	144	121	77	21	9	9	9	9	9	9	9	25	1700
	0800	230	17	19	87	160	205	218	199	148	71	18	17	17	17	17	17	17	82	1600
	0900	263	22	23	47	131	194	227	226	190	124	41	23	22	22	22	22	22	138	1500
	1000	280	27	27	28	71	148	200	221	209	165	93	30	27	27	27	27	27	180	1400
	1100	287	29	29	29	31	78	147	192	207	191	146	77	31	29	29	29	29	206	1300
	1200	290	30	30	30	30	32	75	142	185	200	185	142	75	32	30	30	30	215	1200
	HALF DAY TOTALS		119	142	291	534	787	980	1033	925	672	396	222	137	119	118	118	118	738	
Oct	0700	48	2	3	20	36	45	47	42	30	12	2	2	2	2	2	2	2	4	1700
	0800	204	11	12	49	123	173	195	188	151	89	18	11	11	11	11	11	11	43	1600
	0900	257	17	17	23	104	180	225	235	209	151	64	18	17	17	17	17	17	97	1500
	1000	280	21	21	22	50	139	205	238	235	196	125	38	22	21	21	21	21	140	1400
	1100	291	24	24	24	25	71	156	212	236	224	178	101	28	24	24	24	24	168	1300
	1200	294	25	25	25	25	27	85	165	216	234	216	165	85	27	25	25	25	177	1200
	HALF DAY TOTALS		88	89	152	351	623	878	1006	974	791	493	247	117	89	88	88	88	540	
Nov	0800	136	5	5	18	69	108	128	129	110	72	21	6	5	5	5	5	5	14	1600
	0900	232	12	12	13	73	151	201	219	204	156	80	13	12	12	12	12	12	55	1500
	1000	268	16	16	16	31	122	196	237	242	209	143	50	17	16	16	16	16	96	1400
	1100	283	19	19	19	20	61	154	218	248	240	194	116	28	19	19	19	19	123	1300
	1200	288	20	20	20	20	21	89	176	231	250	231	176	89	21	20	20	20	132	1200
	HALF DAY TOTALS		63	63	75	198	445	721	887	914	798	551	269	101	63	63	63	63	354	
Dec	0800	89	3	3	8	41	67	82	84	73	50	17	3	3	3	3	3	3	6	1600
	0900	217	10	10	11	60	135	185	205	194	151	83	13	10	10	10	10	10	39	1500
	1000	261	14	14	14	25	113	188	232	239	210	146	55	15	14	14	14	14	77	1400
	1100	280	17	17	17	17	56	151	217	249	242	198	120	28	17	17	17	17	104	1300
	1200	285	18	18	18	18	19	89	178	233	253	233	178	89	19	18	18	18	113	1200
	HALF DAY TOTALS		52	52	56	146	374	649	822	867	775	557	276	94	53	52	52	52	282	
			N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE	Hor.	PM

Notes: 1. Clearness number = 1.00; Ground reflectance = 0.20. 2. Figures shown are for 21st day of each month.

9.4 *Internal and External Shading Devices*

Most windows have some type of internal shading to provide privacy and for aesthetic effects. These shading devices also give varying degrees of sun control. Typical SC values for insulating glass with venetian blinds or roller shades are given in *Table 9-7*. The SC depends on the type and color of the shading device and on the surface treatment of the glass. (Recall that the shading coefficient is equal to 1.15×SHGC.) Additional tables for single-glass and between-glass shading, as well as a variety of drape colors, weaves and yarns, can be found in Chapter 29 of the *ASHRAE Handbook–Fundamentals*.[1]

The most effective way to reduce the solar load on fenestration is to intercept direct radiation from the sun before it reaches the glass. Windows that are fully shaded from the outside will reduce solar heat gain by as much as 80%. This shading can be provided by roof overhangs, vertical and horizontal architectural projections, awnings, louvers or screens.

To calculate the fraction of the window that is shaded at any given time, it is first necessary to determine the location of the shadow line caused by the external projection. This process requires some three dimensional geometry, two angles and some basic trigonometry. The geometry is shown in *Figure 9-4*, where both horizontal and vertical projections help shade the window from the sun.

Table 9-7. Shading Coefficients[1]

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

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

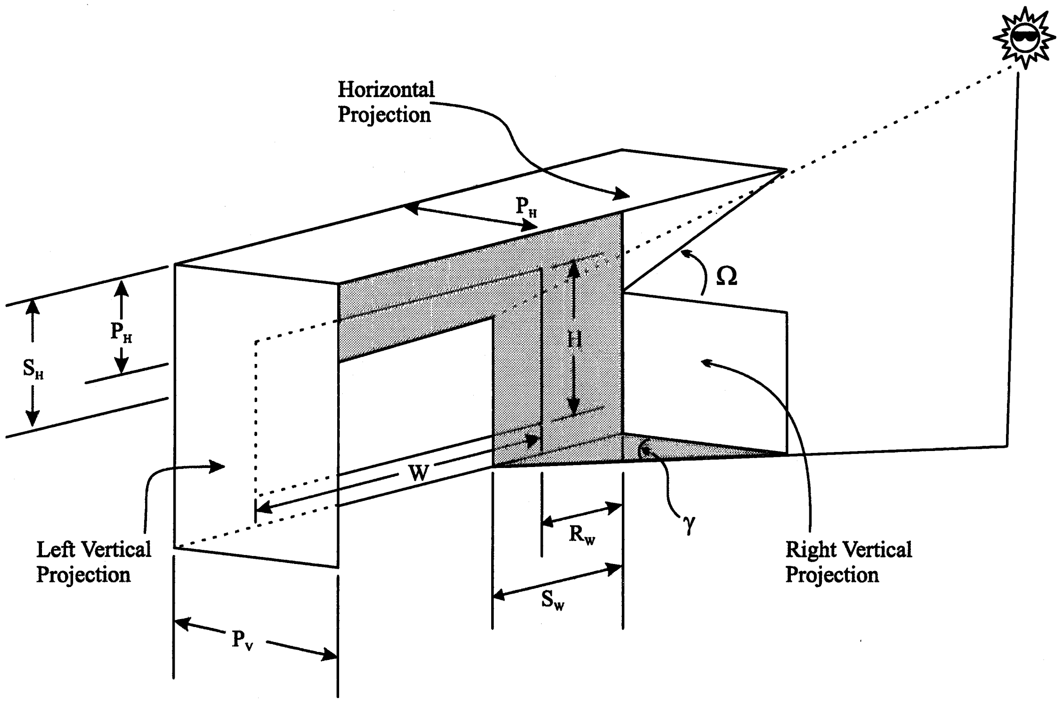


Figure 9-4. Projections and Profile Angles for Fenestration System

The two angles locate the position of the sun relative to an imaginary line perpendicular to the plane of the glass. The horizontal profile angle, Ω, measures how far the sun is above the horizon at that time, date and latitude. The solar azimuth, γ, measures the concurrent horizontal angle to the sun-earth plane relative to due south. To correct the solar azimuth for a non-south facing window, add the value from the table below to the given solar azimuth.

Table 9-8. Solar Azimuth Correction Factors

Orientation	N	NE	E	SE	S	SW	W	NW
Surface Azimuth	180	-135	-90	-45	0.0	45	90	135

These angles can be calculated for any given latitude, date, time and window direction. *Table 9-9* gives a sample data set for 40°N latitude. The horizontal profile angle is called altitude (ALT) is this table. Note that because of symmetry around solar noon and around the spring equinox (March 21) and fall equinox (September 21), the table has been condensed, morning hours have a positive value and afternoon hours have a negative value. Also, remember that solar noon occurs at least one hour later than clock noon when daylight savings time is in effect.

Table 9-9. Solar Position and Profile Angles for 40° North Latitude[4]

DATE	Solar Time	Solar Time ALT	AZ	Profile (Shadow Line) Angles N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	Angles of Incidence Vertical Surfaces N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	HOR	Solar Time
DEC	0800	5	53			35	11	7	6	6	6	9	21					82	60	37	16	10	31	53	76			65	1600
	0900	14	42				37	20	15	14	15	18	30	78					71	50	39	14	24	44	65	87		76	1500
	1000	21	29				72	38	26	21	21	23	41	54					84	62	43	26	22	15	35	75		69	1400
	1100	25	15					66	37	28	25	26	31	43	75					76	56	38	26	29	44	63	83	65	1300
	1200	27	0					90	53	35	28	27	28	35	53					90	70	51	34	27	34	51	70	63	1200
JAN – NOV	0800	8	55			38	15	10	8	8	10	14	34					80	58	36	15	13	34	56	75			82	1600
	0900	17	44				40	24	18	17	18	23	37	67					70	48	29	17	27	46	68	89		73	1500
	1000	24	31				72	41	29	24	24	27	36	61					82	62	43	27	25	38	57	77		66	1400
	1100	28	16					63	41	32	29	29	35	48	78					76	57	40	29	32	47	65	84	62	1300
	1200	30	0					90	56	39	33	30	32	39	56					90	71	52	37	30	37	52	71	60	1200
FEB + OCT	0700	4	72		43	9	6	4	4	5	7	34					85	63	41	18	6	27	50	72				56	1700
	0800	15	62			43	23	17	15	15	19	29	69					74	52	32	16	22	41	63	84			75	1600
	0900	24	50			80	45	31	25	24	27	33	56					86	65	46	30	25	36	54	74			66	1500
	1000	32	35				70	47	36	32	33	38	40	75					79	61	44	33	36	46	63	82		58	1400
	1100	37	19					67	49	40	37	39	45	60	85					75	58	45	37	41	53	69	87	53	1300
	1200	39	0					90	65	49	41	39	41	49	65					90	73	57	44	39	44	57	73	51	1200
MAR + SEP	0700	11	80		43	13	13	12	12	14	21	50					78	56	34	15	37	37	58	80				79	1700
	0800	23	70		85	45	29	24	23	25	31	50					88	67	47	30	24	33	51	71				67	1600
	0900	33	57			72	48	37	33	33	38	50	75					80	61	45	34	35	46	63	81			57	1500
	1000	42	42				69	53	45	42	43	50	64	87					76	60	48	42	45	56	71	88		48	1400
	1100	48	23				90	71	57	50	48	50	57	71					90	73	62	52	48	53	62	75		42	1300
	1200	50	0					90	72	59	52	50	52	59	72					90	76	63	54	50	54	63	76	40	1200
APR + AUG	0600	7	99	40	14	9	8	9	9	12	29					81	59	37	15	12	32	54	77					83	1800
	0700	19	89		42	26	20	19	20	26	41	88					69	48	29	19	29	46	68	89				71	1700
	0800	30	79		71	46	35	31	31	35	47	72					80	61	44	32	32	44	62	81				60	1600
	0900	41	67			67	51	44	41	43	51	66	90					74	58	46	41	46	58	73	90			49	1500
	1000	51	51			85	69	58	52	51	55	63	77					86	72	61	53	51	57	67	80			39	1400
	1100	59	29				86	73	64	60	59	62	69	81					87	75	66	60	59	61	71	82		31	1300
	1200	62	0					90	78	69	63	62	63	69	78					90	80	70	64	62	64	70	80	28	1200
MAY + JUL	0500	2	115	5	3	2	2	2	3	6						65	41	28	3	25	47	78						88	1900
	0600	13	106	40	20	15	13	13	16	25	62					75	53	32	14	20	40	61	83					77	1800
	0700	24	97	73	42	30	25	24	27	36	58					84	64	44	28	25	37	55	76					66	1700
	0800	35	87		65	47	38	35	37	44	59	86					74	57	43	36	40	53	70	88				55	1600
	0900	47	76		82	64	53	48	47	51	61	77					84	69	57	48	47	54	66	80				43	1500
	1000	57	61			80	68	61	58	58	63	73	86					82	70	62	58	59	65	75	86			33	1400
	1100	66	37				84	75	69	66	67	71	77	87					84	76	70	66	67	71	78	87		24	1300
	1200	70	0					90	82	76	71	70	71	76	82					90	82	76	72	70	72	76	82	20	1200
JUN	0500	4	117	9	6	4	4	3	7	14						63	40	18	6	28	50	72						86	1900
	0600	15	108	40	23	16	15	16	19	31	75					72	51	30	15	23	43	64	86					75	1800
	0700	26	100	71	42	31	27	26	30	40	66					81	61	41	29	26	40	59	79					64	1700
	0800	37	91	89	65	47	39	37	40	48	64					89	72	53	42	37	43	56	73					53	1600
	0900	49	80		79	63	54	49	50	54	65	82					82	68	56	50	50	57	69	84				41	1500
	1000	60	66			78	68	62	60	61	67	77	89					80	70	63	60	62	68	78	89			30	1400
	1100	69	42				83	76	71	69	70	74	81	89					83	76	71	69	70	75	81	89		21	1300
	1200	73	0					90	84	78	74	73	75	78	84					90	84	78	75	73	75	78	84	17	1200
				N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	HOR	

Dates vary year to year within plus or minus two days of the twenty-first day of the month.

EXAMPLE 9-2

Problem: Find the horizontal profile angle and the solar azimuth angle for a vertical window facing southwest at 4:00 pm on July 21.

Solution: First look up the orientation correction for southwest in *Table 9-8* to find +45°. Next use *Table 9-9* to determine values for the angles in July at 1600 hours (same as May at 0800) as $\Omega = 35°$ and $\phi = -87°$ (negative in the afternoon and almost due west). Add the orientation correction to the latter value: $\gamma = -87 + 45 = -42°$. The negative result indicates that the left side of the window will be shaded.

Any azimuth angle greater than ±90° indicates that the sun is behind the window, and the glass is completely shaded. For the above example at 1000 hour, the given solar azimuth is $\phi = 61°$. Adding 45° yields $\gamma = 106°$, and the sun will not be shining on this southwestern window at that time.

To calculate the shadow height (S_H) produced by a horizontal projection such as a roof or recess, multiply the depth of the projection (P_H) by the tangent of the horizontal profile angle, Ω, found in *Table 9-9*:

$$S_H = P_H \cdot \tan\Omega$$

Similarly, to calculate the shadow width (S_W) produced by a vertical projection such as a wing wall, multiply the depth of the projection (P_V) by the absolute value of the tangent of the solar azimuth angle, γ:

$$S_W = P_V |\tan\gamma|$$

Example 9-3

Problem: Determine the effect that a 2 ft roof overhang would have on a window at the same conditions as in the previous example (facing southwest at 4:00 pm on July 21). The sill of the window is 5 ft below the overhang, and the dimensions are 36 in. wide by 48 in. high, as shown in *Figure 9-5.*

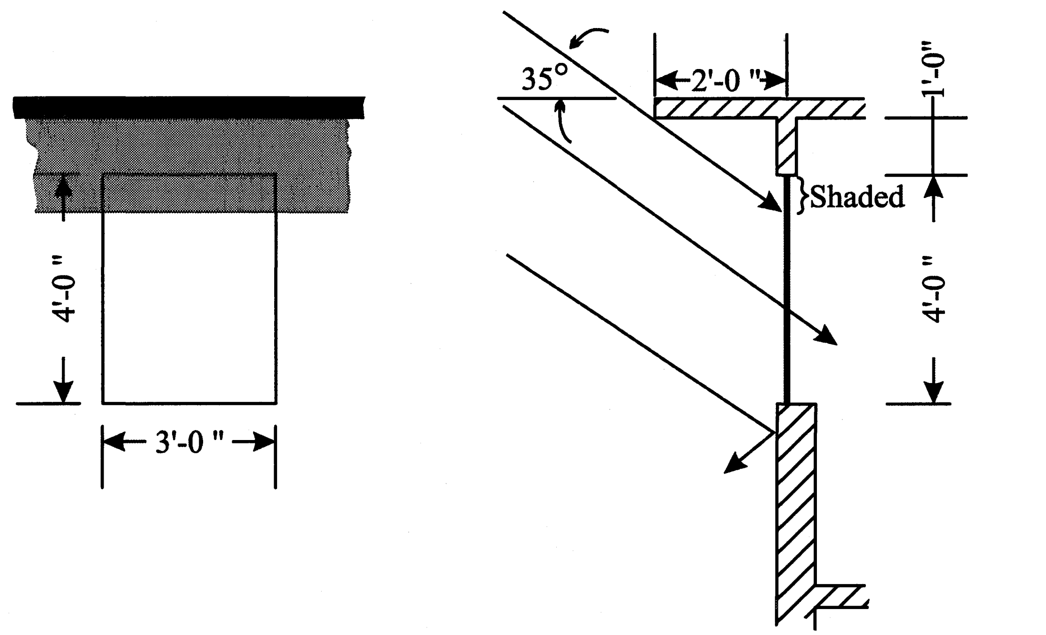


Figure 9-5. Window Geometry for *Example 9-3*

Solution: We know from the previous problem that the horizontal profile angle $\Omega = 35°$, and the horizontal projection (P_H) is 2 ft. So the equation becomes:

$$S_H = P_H \cdot \tan\Omega = (2\,\text{ft}) \cdot \tan(35°) = 2\,\text{ft} \cdot (0.7) = 1.4\,\text{ft} = 1\,\text{ft}\,5\,\text{in.}$$

Because the top of the window is 12 in. below the overhang, only the top 5 in. of the window glass are shaded, which is about 5/48 = 0.10 or 10% of the total area. In calculating the solar load for these conditions, assume that an area of 36 × 5 /144 = 1.25 ft² is totally shaded (using north window SCL), and the rest of the window area (36 × 43 /144=10.75 ft²) is exposed (using southwest SCL).

9.5 *Example Calculations*

Learning to deal with all of these new variables, tables and charts can be very confusing. The first example will be presented in four segments; the second example will start with a totally integrated problem statement. In each case, however, we will need to determine the parameters of the glass (U_o, SHGC), the heat gain by conduction, the fraction that is externally shaded and the solar cooling load.

Example 9-4.1

Problem: A vertical window has double-pane glazing with a 0.5 in. air space between the two 0.25 in. thick glazings. The outside glazing is tinted gray. The aluminum frame has a thermal break and is fixed and insulated. Find the appropriate values for U_o, SHGC and VT. Calculate the ratio of VT to SHGC.

Solution: Referring to *Table 9-1*, Line 5 identifies the correct glazing type. Moving over to the "Aluminum with Thermal Break" column, under "Fixed," the table yields a value of U_o = 0.57 Btu/h·ft²·°F. To determine the Solar Heat Gain Coefficient for this window, refer to *Table 9-3*, (ID 5h) where the value of SHGC = 0.41 appears under "Fixed Aluminum" frame. The VT listed in the last column is 0.35. The ratio VT / SHGC = 0.35 / 0.41 = 0.85 indicates that this window would not be a good product for daylighting because it transmits more heat than light. The green glass in Line 5f has a VT / SHGC = 0.57 / 0.43 = 1.33 and would have been a better choice for daylighting.

Example 9-4.2

Problem: The window in *Example 9-4.1* measures 4 ft high by 5 ft wide. The inside space temperature is 74°F, and the local outside design temperature is 96°F with a 16° outdoor daily range. Find the conductive heat gain through the glass at 11 am daylight savings time.

Solution: Three values are required for this calculation of the equation:

$$q = U_o A(\text{CLTD})$$

The U_o = 0.57 Btu/h·ft²·°F was determined in the previous step. The area in square feet is given by the window dimensions ($A = 4 \times 5 = 20$ ft²). The cooling load temperature difference is determined from *Table 9-2* at the 1000 hour, because daylight savings time is one hour ahead of solar time. The tabled value (CLTD = 4°F) must be corrected for the given inside and outside design conditions as discussed in Chapter 8:

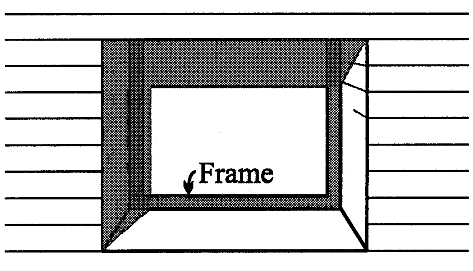
$$\begin{aligned} CLTD_{corr} &= 4 + (78 - 74) + ([96 - 16/2] - 85) \\ &= 4 + 4 + 3 \\ &= 11°\text{F} \end{aligned}$$

These values can now be substituted into the equation:

$$\begin{aligned} q &= U_o A(CLTD) \\ &= (0.57\ \text{Btu/h}\cdot\text{ft}^2\cdot°\text{F})(20\ \text{ft}^2)(11°\text{F}) \\ &= 125\ \text{Btu/h} \end{aligned}$$

EXAMPLE 9-4.3

Problem: The window below faces east and is recessed 12 in. on all sides, with a 3 in. framing allowance. Find the horizontal profile angle, solar azimuth angle, and the areas of the shaded and unshaded glass at 11 am daylight savings time on July 21 at 40° north latitude.



Solution: Table 9-9 gives the horizontal profile and solar azimuth angles for July at 1000 hours (standard time) as $\Omega = 57°$ and $\phi = +61°$ (positive in morning hours) respectively. Use *Table 9-8* to find the angle correction for an east facing window is -90°, so the horizontal profile angle γ is -29° (negative means the left side of the window is shaded).

The shadow line for the horizontal overhang is given by:

$$S_H = P_H \cdot \tan\Omega = (1\ \text{ft})\tan 57° = 1.5\ \text{ft}$$

Because the top 3 in. or 0.25 ft is framing, the top 1.25 ft of glass is shaded, or a net glass height of 4 - 1.25 = 2.75 ft is exposed to the sun.

Part of the bottom of the glass is also shaded by the side. The shadow line for the vertical wall is given by:

$$S_W = P_V \cdot |\tan\gamma| = (1\text{ ft}) \cdot \tan -29° = 0.6\text{ ft}$$

Again the first 0.25 ft is framing, so a glass width of 0.35 ft is shaded, leaving a net glass width of 5 - 0.35 = 4.65 ft is exposed to the sun. The net area exposed to the sun is therefore 4.65 × 2.75 = 12.8 ft² out of a possible 20 ft². The shaded glass area is 7.2 ft².

EXAMPLE 9-4.4

Problem: The interior space has two exposed walls, terrazzo floor and gypsum walls with minimum inside shading. Find the Solar Cooling Loads for both unshaded and shaded, and the solar load for this window at the given time, date, and latitude.

Solution: Refer to *Table 9-4a* assuming vinyl flooring and "Half to None" inside shade to find zone type C. Next use *Table 9-5* for zone type C at Solar Time = 10 and East glass facing to find the SCL = 124 Btu/h·ft². For the same conditions, a north or shaded glass has a SCL = 30 Btu/h·ft². The SHGC value was determined in the first example problem of this section.

The solar load is given by the sum of the gain through the shaded and unshaded windows plus the conduction gain determined earlier:

$$q_{shaded} = A(1.15\times\text{SHGC})(\text{SCL}) = 7.2\text{ ft}^2(1.15\times0.41)(30) = 102\text{ Btu/h}$$
$$q_{unshaded} = A(1.15\times\text{SHGC})(\text{SCL}) = 12.8\text{ ft}^2(1.15\times0.41)(124) = 748\text{ Btu/h}$$
$$q_{conduction} = U_oA(\text{CLTD}) = (0.57\text{ Btu/h·ft}^2\text{·°F})(20\text{ ft}^2)(11\text{°F}) = \underline{125\text{ Btu/h}}$$
$$\text{Total window gain (shaded + unshaded + conduction)} = 975\text{ Btu/h}$$

EXAMPLE 9-5

Problem: Consider a double-glazed window with a 0.5 in. air space between the two 0.25 in. thick glazings and a low-e (ε = 0.2) film on the inside surface of the outside glass. The insulated fiberglass/vinyl frame has operable insulated vinyl casements. The window dimensions are 4 ft high by 8 ft wide. The inside space temperature is 80°F, and the local outside design temperature is 94°F with a 22°F outdoor daily range.

The window faces southwest and is recessed 6 in. on all sides with a 4 in. framing allowance. The interior space has one exposed wall, carpet floor and concrete walls. Find the total heat gain through this window at 2 pm EDT on July 21 at 40° north latitude.

Solution: To determine the design parameters for the glazing, refer to line 17 on *Table 9-1*. For this style of operable metal frame, the U_o equals 0.36 Btu/h·ft²·°F. To determine the SHGC for this glass, refer to *Table 9-3* on line 17b, to find SHGC = 0.45. Note that for that window, VT = 0.53, and the VT/SHGC ratio of 1.2 means this window is a good selection.

The CLTD from *Table 9-2* at 1300 hour (which is 2 pm EDT corrected for daylight savings time) is 12°F, which must be corrected for the specified inside and outside conditions to:

$$CLTD_{corr} = 12 + (78 - 80) + ([94 - 22/2] - 85) = 12 - 2 - 2 = 8°\text{F}$$

The conduction gain can be determined by:

$$q_{conduction} = UA(CLTD) = 0.36\ \text{Btu/h}\cdot\text{ft}^2\cdot°\text{F}(32\ \text{ft}^2)(8°\text{F}) = 92\ \text{Btu/h}$$

The shading angles must be determined next. *Table 9-9* gives the horizontal profile angle and the solar azimuth angle for July at 1300 hour as 66° and -37° (negative in afternoon) respectively.

$$S_H = P_H \cdot \tan\Omega = (0.5\ \text{ft})\tan 66° = 1.1\ \text{ft}$$

The shade line is down about 13 in. from the top, but the first 4 in. (0.33 ft) is framing, so the exposed glass height is 4 - (1.1-0.33) = 3.23 ft.

Table 9-9 indicates a +45° correction for a southwest facing window, so the horizontal profile angle, γ, is -37 + 45 = 8°

$$S_W = P_V|\tan\gamma| = (0.5\ \text{ft})\cdot\tan 8° = 0.07\ \text{ft}$$

Because the shadow line falls on the framing under these conditions, no additional calculations are required. The net unshaded area is 3.23 × 8 = 25.8 ft², and the shaded area is 32 - 25.8 = 6.2 ft².

The next step is to determine the correct SCL values. Refer to *Table 9-4a* to find a zone type B construction. *Table 9-5* at hour 13 for southwest and north glass indicates 89 and 38 Btu/h·ft², respectively. Combining these values with the SHGC determined earlier yields the total gains through this window:

$$\begin{aligned}
q_{shaded} &= \text{A}(1.15\times\text{SHGC})(\text{SCL}) = 6.2\ (1.15\times0.45)(38) &&= 122\ \text{Btu/h}\\
q_{unshaded} &= \text{A}(1.15\times\text{SHGC})(\text{SCL}) = 25.8\ (1.15\times0.45)(89) &&= 1188\ \text{Btu/h}\\
q_{conduction} &= \text{UA(CLTD)} = 0.36\ \text{Btu/h}\cdot\text{ft}^2\cdot°\text{F}(32\ \text{ft}^2)(8°\text{F}) &&= \underline{92\ \text{Btu/h}}\\
&\text{Total window gain (conduction + solar)} &&= 1402\ \text{Btu/h}
\end{aligned}$$

In this second example, more window glass area is exposed, and the window gain is significantly higher.

The Next Step

In the next chapter, we will complete our detailed look at cooling load calculations by considering internal loads such as people, lighting, appliances and equipment. Because the ventilation requirements are generally based on the building occupancy, the cooling load requirements due to ventilation and infiltration will also be discussed. The major new wrinkle that these elements add to the puzzle is the latent loads that are caused by moisture. Until now, all of the loads have only had a sensible load component. You will learn how to correctly account for these latent loads as part of your load calculation process.

Summary

After studying Chapter 9, you should be able to:

- Explain how various design parameters affect the rate of heat transfer through a window.
- Select appropriate design values (U_o, SHGC and VT) for a given window.
- Determine the shaded portion for a given window condition.
- Estimate the cooling load for typical window applications.

Bibliography

1. ASHRAE. 1997. "Fenestration." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 29.

2. ASHRAE. 1997. "Nonresidential Cooling and Heating Load Calculations." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 28.

3. McQuiston, F., Spitler, J. 1992. *Cooling and Heating Load Calculation Manual*. Atlanta, GA: ASHRAE.

4. ASHRAE. 1985. "Fenestration." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 27.

Skill Development Exercises for Chapter 9

Complete these questions by writing your answers on the worksheets at the back of this book.

9-01. For a fixed window in a vinyl frame with double glazing, 0.5 in. air space, and two 0.25 in. panes of glass, determine the total window SHGC and VT for: bronze glass, low-e of 0.2 on surface 3; and high performance green, low-e of 0.2 on surface 3. Discuss which is better for reducing solar gain, and which is better for daylighting.

9-02. Determine the solar cooling load at 10:00 am EDT in July through a southeast-facing retail store window (clear double 0.25 in. pane and 0.5 in. air space with fixed aluminum frame) that is 12 ft tall and 40 ft wide and has a continuous 6 ft overhang for weather protection located 12 in. above the window. Local latitude is 40°N.

9-03. If the overhang in *Exercise 9-02* was increased to 10 ft wide, explain how the solar heat gain would be affected throughout the day in July and again in January. Show your calculations.

9-04. For a one-story carpeted office with gypsum walls and vertical blinds, determine the solar cooling load and conduction heat gain through a 10 ft wide by 6 ft high window (clear double 0.25 in. pane and 0.5 in. air space with low-e of 0.1 on surface 3) in July at 9 am, noon and 3 pm. The window faces south-southeast.

Chapter 10
Internal Loads

Contents of Chapter 10

Instructions

Read the material in Chapter 10. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 10

In this chapter, we will discuss the topic of internal gains, which are thermal sources contained within the space. When calculating the heating load, these sources could be ignored, because any thermal contribution that they made would help to reduce the demand on the heating plant. However, during the cooling season, these sources are often what drives the space cooling requirements.

There are five basic types of sources that we will discuss: lighting, power, appliances, people and cooling system. The location, type and intensity of the lighting system will greatly affect the significant heat contribution from this source. Electric motors operating within the conditioned space will also contribute heat to the space. These sources will be discussed in the power section.

A variety of appliances, ranging from computers to refrigerators and process ovens, might be located within a space. These devices can produce sensible energy (which is the only type that we have dealt with so far), and also latent energy due to evaporative processes. Examples might include a steam table in a restaurant and the coffeepot in your office. People can also contribute both sensible and latent loads to the space. The thermal quantities will vary with the number and activity level of those present. Finally, internal heat gains can come from the cooling system itself. Heat gains into the cooling system ductwork and from the supply air fan of a draw-through AHU can contribute to the space cooling load and must be accounted for.

After studying Chapter 10, you should be able to:

- Calculate the sensible heat gain from lighting, power, appliances and people, given the design details of a space.
- Calculate the latent heat gain from appliances and people, given the design details of a space.
- Compare the heat gain from three different lighting systems.
- Propose some alternative methods to deal with a typical internal load source.

10.1 Lighting

Only a small fraction of the electricity that enters a lighting device is converted to visible radiation. Typical conversion efficiencies range from about 1% for an incandescent light bulb to over 25% for a new high efficiency fixture. The remainder of the entering electricity is wasted as heat to the local environment through a combination of convective and radiant transfer. The convective losses contribute immediately to the space heat gain. The radiant losses (in the form of long wave radiation) must first be absorbed by the walls, floors and furniture, and only contribute to the space load when they are convectively released by these surfaces. Thus, the cooling system feels the thermal effect of the lighting system long after the lights have been switched off.

The primary source of heat from lighting comes from the light-emitting elements (lamps), although additional heat may be generated from associated components in the light fixtures housing such as the ballast in fluorescent fixtures.

At any time, the space cooling load from lighting can be estimated as:

$$q_{el} = HG_{el}(CLF_{el}) \tag{10-1}$$

where,

q_{el}	= cooling load from lighting, Btu/h
HG_{el}	$= 3.41 \times W \times F_{ul} \times F_{sa}$ = heat gain from lighting, Btu/h
W	= total lamp wattage
F_{ul}	= lighting use factor
F_{sa}	= lighting special allowance factor
CLF_{el}	= lighting cooling load factor

The total lamp wattage is obtained from the ratings of all lamps installed, both for general illumination and for display use. The factor 3.41 converts the units from watts to Btu/h. The lighting use factor (F_{ul}) is the ratio of the wattage actually in use at the time that 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 (F_{sa}) is used to account for conditions such as the ballast required by fluorescent fixtures. This value can be as high as 2.19 for a single 32-W lamp high-output fixture on a 277 V circuit. A value of 1.0 is recommended for 34-W T-8 lamps with electronic starters, and 1.2 for rapid start 40-W lamp fixtures with magnetic starters. This value can range in general applications from as low as 1.18 for two lamps at 277 V to a high of 1.30 for one lamp at 118 V. Industrial fixtures (such as sodium lamps) may also have a special allowance factor varying from 1.04 to 1.37, depending on the manufacturer. These situations should be dealt with individually.

The type of lighting fixture can also affect the fraction of lighting energy that enters the conditioned space. Ventilated and recessed fixtures transfer much of their heat to the ceiling plenum above the space. Manufacturer's data must be sought to determine the fraction of the total wattage that may be expected to enter the conditioned space directly (and subject to time lag effect). The remainder of the heat that is released to the plenum must be picked up by the return air or in some other appropriate manner.

Some lighting fixtures are designed to allow return air to pass through the fixture into the ceiling plenum, thus minimizing the space cooling load and increasing the temperature of the return air. These "heat-to-return" fixtures send 40% to 60% of their total wattage directly to the ceiling return. Unventilated fixtures usually direct only 15% to 25% to the plenum.

The CLF_{el} data used in the lighting equation above are given in *Table 10-1*. The zone type is the same one determined in Chapter 9 from *Table 9-4.* The fraction of the lighting energy that must be removed during any given hour depends on how many hours the lights are on each day and the number of hours it has been since the lights were first turned on that day. Notice in the first line (8 hours on) for zone type A, the value starts at 0.85 and increases as you move to the right, but drops dramatically from 0.98 to 0.13 after hour 8 when the lights are turned off, and continues to drop slowly for the remainder of the day. The effect of building mass storage can also be seen by moving from zone type A through zone type D for any given combination of hours (for example, the first hour when the lights are on for 8 hours per day).

There are a few exceptions to the above procedure. If the cooling system operates only during occupied hours, then the CLF_{el} should be considered 1.0 instead of the tabled values. If one portion of the lights operates on a different schedule of operation, then each portion should be treated separately. Finally, if the lights are left on continuously, then the CLF_{el} is 1.0.

Because the details of the lighting system are often poorly defined in the early stages of the design process, initial lighting allowances are typically made based on the floor area within the space. Values range from 0.5 to 4 W/ft^2, depending on the application. Use the values from the local energy code for design. Code values tend to range from 1 to 2 W/ft^2 for general uses (less for storage and corridors, more for retail). A conservative value of 1.5 W/ft^2 can be used for general office space.

Table 10-1. Cooling Load Factors for Lights[1]

Lights On For	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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.

10.2 Power

The instantaneous heat gain from electric motors operating within the conditioned space is calculated as:

$$q_{em} = 2545(P / E_M)(CLF)(F_{UM})(F_{LM}) \qquad (10\text{-}2)$$

where,

q_{em} = heat equivalent of equipment operation, Btu/h

P = motor power rating, horsepower

E_M = motor efficiency, as decimal fraction<1.0

CLF = Cooling Load Factor, see *Table 10-2*

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 rated motor horsepower is multiplied by 2545 (to convert units to Btu/h) and then divided by the motor efficiency. Typical heat gains, motor efficiencies and related data for electric motors are given in *Table 10-3*. These values are generally derived from the lower

Table 10-2. Cooling Load Factors for People and Unhooded Equipment[1]

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.

efficiencies reported by several manufacturers of open, drip-proof motors. Unless the manufacturer's technical literature indicates otherwise, the heat gain may be divided equally between radiant fractions (subject to time delay) and convective fractions (immediate) for subsequent cooling load calculations.

The Cooling Load Factor (CLF) used here (*Table 10-2*) will also be associated later in this chapter with people and unhooded equipment. Similar to the lighting value, the CLF depends on the zone type, the total hours of occurrence per day, and the number of hours since the motor was turned on.

The motor use factor (F_{UM}) may be applied when motor use is known to be intermittent with significant non-use during all hours of operation. Examples might include the drinking fountain compressor motor that may only run half the time and the overhead door motor that may only run a few minutes each day.

The motor load factor (F_{LM}) is the fraction of the rated load being delivered under the conditions of the cooling load estimate. For example, just because a 10-hp motor is installed does not always mean that it is running at full load. Often, processing equipment has its motors running, but the process is idle. Under these conditions, motors typically draw about 30% of their full load power.

Table 10-3. Heat Gain From Typical Electric Motors[1]

				Location of Motor and Driven Equipment with Respect to Conditioned Space or Airstream		
				A	B	C
Motor Name-plate or Rated Horse-power	Motor Type	Nominal rpm	Full Load Motor Effi-ciency, %	Motor in, Driven Equip-ment in, Btu/h	Motor out, Driven Equip-ment in, Btu/h	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

Equation 10-2 also assumes that both the motor and its load are located in the conditioned space or within the airstream. If the motor is outside the space or airstream, then:

$$q_{em} = 2545 \cdot P(F_{UM})(F_{LM}) \tag{10-3}$$

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

$$q_{em} = 2545 \cdot P(F_{UM})(F_{LM})(1.0 - E_M)/E_M \tag{10-4}$$

This last equation also applies to a fan or pump within the conditioned space that exhausts air or pumps fluid outside the space. The exhaust fan above the range in your home would be an example of this.

10.3 Appliances

Appliance usage is one of the hardest areas of the cooling load estimate to get accurate values for. Not only is there wide variation among manufacturers in the energy consumption of similar equipment, but the daily operating schedule is often at the unpredictable whim of the user. Usually it is sufficient to identify all of the major contributors and then be conservative in estimating their heat gains. Remember that the energy for these appliances could come from electricity, natural gas or steam. To account for the sensible storage capacity of the structure, use the equation:

$$q = SHG(CLF) \tag{10-5}$$

where the sensible heat gain (SHG) is given in the following tables, and the Cooling Load Factor (CLF) is given in *Table 10-2* for unvented equipment, or in *Table 10-4* for hooded equipment.

Table 10-4. Cooling Load Factors for Hooded Equipment[1]

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.

Types of sources that must be considered usually vary with the application. Here we will briefly consider sources common to offices, medical and laboratory facilities, and food preparation areas.

Office appliances. A list of typical office equipment and their heat gains is shown in *Table 10-5a*. Modern offices with a computer display terminal at each workstation can have a connected load of up to 15 Btu/h·ft^2. Older offices required only 3 to 4 Btu/h·ft^2 in the general offices, with somewhat higher usage in the purchasing and accounting areas. However, newer computers and printers power down during periods of non-use to only a fraction of their rated load, as shown in *Table 10-5b*. The measured total power consumption is significantly less than the nameplate rating or the corresponding values given in *Table 10-5a*. Because this field is changing so rapidly, computer manufacturers should be asked to provide data pertaining to their individual components whenever possible.

Medical and laboratory equipment. Table 10-6 shows heat gain values for various hospital and laboratory equipment. Commonly, heat gain from such equipment in a laboratory ranges from 15 to 70 Btu/h·ft^2. Care must be taken in evaluating the probability and duration of simultaneous usage when many components are concentrated in one area, such as in a laboratory or operating room. Laboratories with vent hoods require special considerations that are beyond the scope of this course.

Food preparation. Table 10-7 shows input rating and recommended heat gain values for selected restaurant equipment. Notice that both sensible and latent values are presented in the "Without Hood" columns. The data in the "With Hood" columns assume installation under a properly designed exhaust hood connected to a mechanical fan exhaust system. It is assumed the vent hood removes all of the generated moisture and most of the non-radiant sensible heat.

Table 10-5a. Heat Gain From Office Equipment[1]

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 10-5b. Heat Gain From Computer Equipment[1]

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 10-6. Heat Gain From Hospital Equipment[2]

Appliance Type	Size	Maximum Input Rating, Btu/h	Recommended Rate of Heat Gain, Btu/h[a]
Autoclave (bench)	0.7 ft^3	4270	480
Bath, hot or cold circulating, small	1.0 to 9.7 gal, −22 to 212°F	2560 to 6140	40 to 1060 (sensible) 850 to 2010 (latent)
Blood analyzer	120 samples/h	2510	2510
Blood analyzer with CRT screen	115 samples/h	5120	5120
Centrifuge (large)	8 to 24 places	3750	3580
Centrifuge (small)	4 to 12 places	510	480
Chromatograph	—	6820	6820
Cytometer (cell sorter/analyzer)	1000 cells/s	73,230	73,230
Electrophoresis power supply	—	1360	850
Freezer, blood plasma, medium	13 ft^3, down to −40°F	340[b]	136[b]
Hot plate, concentric ring	4 holes, 212°F	3750	2970
Incubator, CO_2	5 to 10 ft^3, up to 130°F	9660	4810
Incubator, forced draft	10 ft^3, 80 to 140°F	2460	1230
Incubator, general application	1.4 to 11 ft^3, up to 160°F	160 to 220[b]	80 to 110[b]
Magnetic stirrer	—	2050	2050
Microcomputer	16 to 256 kbytes[c]	341 to 2047	300 to 1800
Minicomputer	—	7500 to 15,000	7500 to 15,000
Oven, general purpose, small	1.4 to 2.8 ft^3, 460°F	2120[b]	290[b]
Refrigerator, laboratory	22 to 106 ft^3, 39°F	80[d]	34[d]
Refrigerator, blood, small	7 to 20 ft^3, 39°F	260[b]	102[b]
Spectrophotometer	—	1710	1710
Sterilizer, freestanding	3.9 ft^3, 212 to 270°F	71,400	8100
Ultrasonic cleaner, small	1.4 ft^3	410	410
Washer, glassware	7.8 ft^3 load area	15,220	10,000
Water still	5 to 15 gal	14,500[e]	320[e]

Source: Alereza and Breen (1984).
[a]For hospital equipment installed under a hood, the heat gain is assumed to be zero.
[b]Heat gain per cubic foot of interior space.
[c]Input is not proportional to memory size.
[d]Heat gain per 10 ft^3 of interior space.
[e]Heat gain per gallon of capacity.

Table 10-7. Heat Gain From Restaurant Equipment[1]

Appliance	Size	Energy Rate, Btu/h		Recommended Rate of Heat Gain,[a] Btu/h			
				Without Hood			With Hood
		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 ft³	7100	—	610	340	960	290
Cabinet (large hot serving)	37.4 to 406 ft³	6820	—	610	310	920	280
Cabinet (large proofing)	16 to 17 ft³	693	—	610	310	920	280
Cabinet (small hot holding)	3.2 to 6.4 ft³	3070	—	270	140	410	130
Cabinet (very hot holding)	17.3 ft³	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 ft³ of interior	6 to 67 ft³	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 ft²	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 ft³	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 ft²	9200	—	615	343	958	343
Griddle/grill (small), per square foot of cooking surface	2.2 to 4.5 ft²	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 ft³	8970	—	8970	—	8970	0
Microwave oven (residential type)	1 ft³	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 ft³ of interior space	25 to 74 ft³	753	—	300	—	300	0
Refrigerator (small), per 10 ft³ of interior space	6 to 25 ft³	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 ft³	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 ft²	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 10-7. Heat Gain From Restaurant Equipment (cont.)

Appliance	Size	Energy Rate, Btu/h		Recommended Rate of Heat Gain,[a] Btu/h			
				Without Hood			With Hood
		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.

10.4 People

Table 10-8 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. For short occupancy, the extra heat and moisture brought in by people may be significant. To estimate the sensible cooling load due to people, use the equation:

$$q_s = N\left(SHG_p\right)\left(CLF_p\right) \tag{10-6}$$

and the latent cooling load is:

$$q_1 = N\left(LHG_p\right) \tag{10-7}$$

where,

q_s = sensible cooling load due to people, Btu/h
N = number of people
SHG_p = sensible heat gain per person (see *Table 10-8*)
CLF_p = cooling load factor for people (see *Table 10-2*)
q_l = latent cooling load due to people, Btu/h
LHG_p = latent heat gain per person (see *Table 10-8*)

Table 10-8. Heat Gain From Occupants of Conditioned Spaces[1]

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).

There are some exceptions to the above calculation. For example, if the space temperature is not maintained constant during the 24-hour period (perhaps due to a night shutdown), then there is a pull-down load that occurs the following morning to remove the energy that had been stored within the structure. In this case, a CLF of 1.0 should be used. Also for applications with high occupant density (such as theaters, auditoriums and arenas), use a CLF of 1.0, because the effects of long wave radiation become negligible.

10.5 Cooling System Gains

The final internal heat source that must be considered as part of the cooling load calculation is the cooling system itself. Losses from the supply air fan, motor and drive system can contribute to the space cooling load. Heat transfer through the ductwork and air flow losses (or gains) due to leakage can be significant and must be accounted for in the cooling load estimate.

Typical fan efficiencies range between 50% and 70%, with an average value of 65%. Thus 35% of the energy required by the fan appears as instantaneous heat gain to the air being transported. Depending on the static pressure and system air flow rate, this will result in a slight (often less than 1°F) rise in the air temperature. Depending on the type of system installed, this heat gain will affect the system differently. For example, if the fan is in front of the cooling coil (blow-through), then the coil will remove the energy immediately, but the space load will be unaffected. However, when the fan is after the cooling coil (draw-through), these losses become heat gains to the system. Either the supply air temperature must be reduced slightly, or the air flow through the system must be increased slightly to compensate for this energy gain.

Supply and return air ducts usually do not contribute significantly to overall space cooling loads. Generally it is adequate to add about 1% to the overall sensible load to account for these energy gains. However, if the ductwork runs are extremely long, or have significant lengths through rigorous environmental conditions, then additional calculations must be performed to account for these conditions. Uninsulated supply ductwork running through ceiling return air plenums will result in high thermal losses, loss of space cooling capability by the supply air, and condensation difficulties during a warm startup. Avoid these problems by always specifying insulated supply air ducts.

Air leakage into or from the cooling distribution system can have dramatic effects on the overall system performance. Conditioned air that escapes before it is distributed to the space through the supply register or diffuser may not help meet the cooling load. If the leakage occurs within the conditioned space but before the diffuser, control or noise could be a problem. However, if the leakage occurs before the air even gets to the conditioned space, the air flow through the cooling system must be increased to compensate for this leakage. Air leakage into the return system is usually not as serious, because it has not been conditioned yet. However, if the air is leaking in from beyond the conditioned space, there may be cooling capacity, air pressure and flow rate problems.

A well-designed and properly installed duct system should not leak more than 1% to 3% of the total system air flow. HVAC equipment and volume control units connected into the duct system should be delivered from manufacturers with allowable leakage rates not exceeding 1% or 2% of maximum air flow. Where duct systems are specified to be sealed and leak-tested, both low- and high-pressure types can be constructed and be required to fall into this range. Latent heat considerations are frequently ignored.

Poorly designed or installed systems can have leakage rates of 10% to 30%. Leakage from low-pressure lighting troffer connections lacking proper taping and sealing runs up to 35% or more of the terminal air supply. Such extremes can ruin the validity of any load calculation.

10.6 Examples

This section contains several solved problems to show you how to use the data tables contained in this chapter. Each problem will consist of several parts, to demonstrate a variety of aspects for each topic.

Example 10-1 (Lighting)

Problem: A 10×12 ft private office with carpeted floors and gypsum walls has six 34-W fluorescent tubes on a 277 V circuit in unvented fixtures. The lights are turned on at 8 am, and remain on for eight hours. Estimate the sensible heat gains at 2:00 pm, 4:00 pm and 6:00 pm.

Solution: From *Table 9-4*, the indicated zone type is B. The total installed wattage is 6 (bulbs)·34 (W/ bulb) = 204 W. (Note that the lighting allowance would be 204 W/ 120 ft^2 = 1.7 W/ ft^2.) The use factor is 1.0 (all lights are on) and the special allowance factor is 1.2. The CLF from *Table 10-1* for zone type B, 8 h on, 6 h after being turned on is 0.95. The values at 4 pm and 6 pm are 0.96 and 0.12, respectively. Therefore the sensible heat gains are as shown in the following table:

	Btu/W	W	F_{ul}	F_{sa}	(CLF_{el})	q_{el}	
at 2 pm:	3.41	204	1	1.2	0.95	793	Btu/h
at 4 pm:	3.41	204	1	1.2	0.96	801	Btu/h
at 6 pm:	3.41	204	1	1.2	0.12	100	Btu/h

Note that the residual load from the lights is still over 10% of the 4 pm load two hours after the lights have been turned off.

Example 10-2 (Motors)

Problem: Compare the rates of sensible heat gain for a 3-hp motor installed on a draw-through air-handling unit (AHU) fan that requires 2 hp. In the first case, the fan and motor are located within the conditioned air flow; in the second case, only the fan is within the air flow and the motor is outside the AHU. Finally, for the second case where the motor is external to the AHU, determine the motor heat gain to the mechanical room if this basement room has concrete floor, walls and ceiling. The motor is turned on at 7:00 am and runs for 14 hours each day. Estimate the sensible heat gains for the last case at 2:00 pm, 4:00 pm and 6:00 pm.

Solution: Refer to *Table 10-3* for a 3-hp motor (assuming a 3 phase/1750 rpm motor at 81% efficiency). The value in column A (for both the motor and fan within the air flow) is 9430 Btu/h. The value in column B (for the fan only within the air flow) is 7640 Btu/h. And the value in column C (motor only within the controlled space) is 1790 Btu/h (the difference between the previous two values). The fan runs continuously, so $F_{UM} = 1.0$. Because the fan only requires 2 hp, these values would be multiplied by $F_{LM} = 2/3 = 0.67$. Note that no CLF delay is used in the first two cases, because there is little thermal storage in the sheet metal walls of the AHU. Therefore, if the fan and motor are within the air flow, the heat gain to the air flow is $9430 \times 0.67 = 6318$ Btu/h, and if the motor is outside, then the heat gain to the air flow is $7640 \times 0.67 = 5119$ Btu/h.

For the third part of the problem, the motor heat loss goes directly to the mechanical room. Zone type D applies to basement areas with concrete walls and uncarpeted floors. The CLFs from *Table 10-2* for 14 h/day of operation and for 7, 9 and 11 hours after starting are 0.88, 0.91 and 0.93, respectively. The remaining calculations are shown below:

	Btu/hp-h	P	E_M	*CLF*	F_{UM}	F_{LM}	q_{em}	
at 2 pm:	2545	3	0.81	0.88	1	0.67	5558	Btu/h
at 4 pm:	2545	3	0.81	0.91	1	0.67	5747	Btu/h
at 6 pm:	2545	3	0.81	0.93	1	0.67	5873	Btu/h

EXAMPLE 10-3 (APPLIANCES)

Problem: The office in *Example 10-1* contains a personal computer with laser printer, a small copier and a coffeemaker. Estimate the usage pattern and sensible heat gains for each of these at 2:00 pm, 4:00 pm and 6:00 pm.

Solution: Reasonable recommended values from *Tables 10-5a* and *10-5b* for each of these items are shown in the table below for comparison. For this example, the values from *Table 10-5a* have been selected; the values from *Table 10-5b* could just as easily been used. If this example had been a large open-plan office with many desktop computers instead of a private office with one unit, the values from *Table 10-5b* would probably have been a better selection.

	Table 10-5b	*Table 10-5a*
Microcomputer	133 Btu/h	800 Btu/h
Printer	248 Btu/h	1000 Btu/h
Copier	181 Btu/h	3000 Btu/h
Coffeemaker	n/a	3580 Btu/h (sensible) + 1540 Btu/h (latent)

Assume that the computer and printer are turned on at 8:00 am, and stay on for eight hours. The copier is turned on at 10:00 am and is only on for the first two hours. The coffeemaker is turned on only during the morning hours. (Note that any other reasonable set of assumptions could have been made at this point.) Given the area is zone type B, then the CLFs from *Table 10-2* and estimated cooling loads at each hour are:

	Heat Gain	Hours/ Day	Start Time	CLF at			Cooling Load at		
				2:00	4:00	6:00	2:00	4:00	6:00
Microcomputer	800	8	8:00	0.91	0.95	0.22	728	760	176
Printer	1000	8	8:00	0.91	0.95	0.22	910	950	220
Copier	3000	2	10:00	0.11	0.06	0.04	330	180	120
Coffeemaker	3580	4	8:00	0.17	0.1	0.06	609	358	215
	+1540 (latent)								
Sensible Total, Btu/h							2577	2248	731
Latent Total, Btu/h (only occurs while on - 8:00 to 12:00)							0	0	0

Example 10-4 (People)

Problem: A 100-seat school band room is used continuously from noon until 4:00 pm each day. For the first two hours, it is at 50% capacity; during the last two hours, it is at 80% capacity. Estimate the sensible heat gain from people at 2:00 pm, 4:00 pm and 6:00 pm.

Solution: Assuming the walls are concrete block with few windows and the floor is not carpeted, this could be a zone type C construction. The activity level might best be described as sedentary work, comparable to a restaurant. From *Table 10-8*, the total adjusted heat gain per person is 275 Btu/h sensible and 275 Btu/h latent. The CLF and sensible cooling loads are shown in the table below. At 2:00 pm, there are 50 people in the room, with another 30 just entering. The energy the new class generates will not occur until 3:00 pm. Note that the latent load is always an instantaneous load.

People	Heat Gain (each)	Hours/ Day	Start Time	CLF at 2:00	CLF at 4:00	CLF at 6:00	Cooling Load at 2:00	Cooling Load at 4:00	Cooling Load at 6:00
50	275	4	12:00	0.68	0.79	0.18	9350	10863	2475
30	275	2	2:00	0	0.68	0.11	0	5610	908
	275	(Latent)					13750	0	0
Sensible Total, Btu/h							9350	16473	3383
Latent Total, Btu/h							13750	0	0

The Next Step

In the next chapter, we will use all of the materials learned in this course to estimate the cooling load on a small fast food restaurant. There are still a few concepts and techniques that must be discussed, but we will cover those as we do the example problem.

Summary

This chapter has dealt with all of the major internal sources that can contribute to the cooling load on a structure. While all of them are important, the most important one will depend on the application. For example, in commercial and office buildings, lighting is often the major contributor. However, in a laboratory, it might be the equipment and appliances that contribute the most heat gain to the space. At a sporting event, the cooling load will depend on the number of people attending. We also learned that the quantity of moisture or latent energy must be separately accounted for. This energy can come from processes, appliances, people and ventilation air.

After studying Chapter 10, you should be able to:

- Calculate the sensible heat gain from lighting, power, appliances and people, given the design details of a space.
- Calculate the latent heat gain from appliances and people, given the design details of a space.
- Compare the heat gain from three different lighting systems.
- Propose some alternative methods to deal with a typical internal load source.

Bibliography

1. ASHRAE. 1997. "Nonresidential cooling and heating load calculations." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 28.

2. ASHRAE. 1995. "Laboratory systems." *ASHRAE Handbook–HVAC Applications*. Atlanta, GA: ASHRAE. Chapter 13.

Skill Development Exercises for Chapter 10

Complete these questions by writing your answers on the worksheets at the back of this book.

10-01. A high school computer classroom includes 15 workstations for 30 students plus two printers and an overhead projector in the 40×30 ft room. The interior room is carpeted and has concrete block walls. Classes begin at 8:00 am and end at 3:00 pm. This room is in use about 75% of each school day (three 40-minute classes, then a 40-minute break). The normal lighting usage is 1500 W of indirect fluorescent bulbs. Find the heat gain for each of these three sources (lights, people and equipment) at noon, 2:00 pm and 4:00 pm.

10-02. For the 30 students in the classroom for *Exercise 10-01*, determine the rate of latent energy produced at noon.

10-03. The cafeteria on one floor of an office building opens at 7:30 am, closes at 5:30 pm, and has an hourly occupation rate as shown in the table below. The hot food (from opening until 9:00 am and between the hours of 11:00 am and 1:00 pm) is served mainly from a 3×15 ft unhooded food warmer. Estimate the sensible and latent heat gain from both sources at 10:00 am, noon and 2:00 pm.

Average Cafeteria Hourly Occupancy Counts

Hour	8	9	10	11	12	1	2	3	4	5
People	18	8	8	44	80	62	24	14	9	8

10-04. A retail shop owner is considering replacing the shop's present fluorescent fixtures (60 bulbs at 40 W each with magnetic ballast) with either new T-8 lamps (with electronic ballast) or 5000 W of incandescent bulbs to highlight the products. The shop is open from 9:00 am until 9:00 pm, seven days per week. Determine the sensible heat gain at 10:00 am, 3:00 pm and 8:00 pm for all three scenarios. Use this data to discuss briefly how each might affect the cooling load on the space, and make a recommendation to the owner from a thermal systems design perspective.

Chapter 11
Example Heating and Cooling Load Calculation

Contents of Chapter 11

Instructions

Read the material in Chapter 11. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 11

In this chapter, you will apply all the new knowledge learned in this course toward the thermal design load of a fast food restaurant. We will begin with a problem definition, then proceed in a step-by-step manner. As you become more proficient in making heating and cooling load calculations, your technique will become more fluid and integrated. However, to ensure that you understand each step of the process, we will use this sectional technique. In a way, this project represents your final exam for the course. (But we still have some new material waiting for you in Chapter 12.)

After studying Chapter 11, you should be able to:

- Estimate the heating load of a typical commercial building.
- Estimate the ventilation requirements for a facility.
- Calculate the cooling load at a given hour for a structure.

11.1 Sample Problem Definition

The sample problem is a new fast food restaurant to be located in Maryland, just northeast of the beltway around Washington, DC. The building dimensions are shown on the floorplan in *Figure 11-1a*, along with cross-sectional details of the walls and roof construction (*Figure 11-1b*). The dining area faces south, and there is a 5-ft roof overhang at the 10-ft elevation around the dining area only (between the main entrance and the drive-through window). The terrazzo floor is a 5-in. thick slab-on-grade with perimeter insulation.

The dining area window sections are all 5.5 ft high (from 2.5 ft above the floor to the 8 ft elevation) by 9.33 ft wide. This allows for 8-in. wide support columns, which are are difficult to insulate and assumed to have a loss rate similar to the windows. The width of the south wall (30×10 ft) is three glass sections except for the door. The east wall of the dining area contains two glass sections, one wall section and the main entrance. The thermal effects of the entry airlock are ignored, and the entry section's glass and door areas combined are comparable to the dining area windows (9.33×5.5 ft). The drive-up window glass area is similar to the dining area windows (9.33×5.5 ft), and the wall area for the drive-up window "bump-out" can be included in the west wall area.

There are three exterior doors: a 32×80 in. glass door on the south side, two 32×80 in. glass doors on the outside of the main entry, and a 36×80 in. insulated metal service door (without thermal breaks) on the north side. The glass doors are assumed equivalent to 0.25 in. acrylic/polycarbonate for aluminum frame double doors without thermal breaks. All windows are fixed, 0.25 in. clear double pane with 0.5 in. air space and fixed aluminum frames.

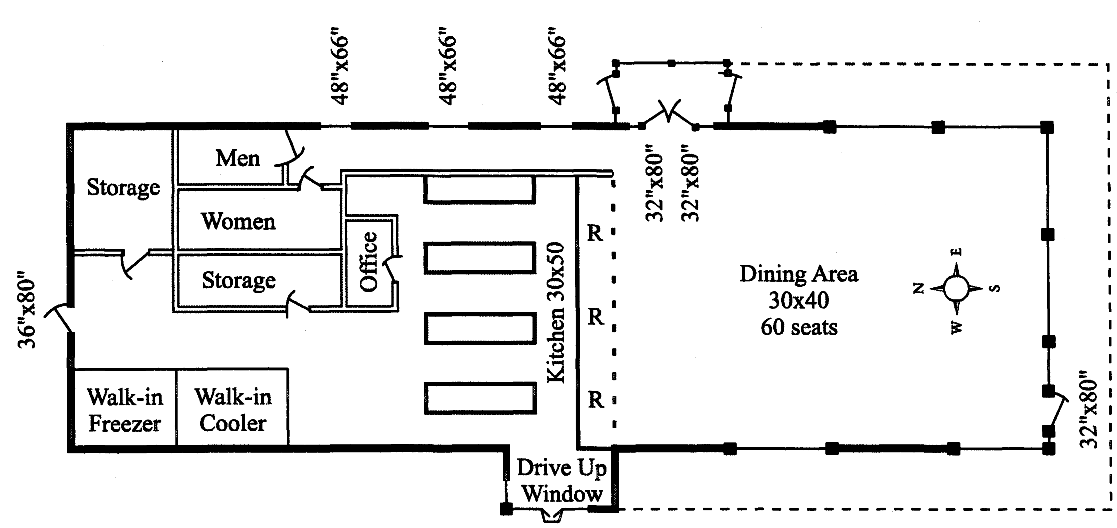


Figure 11-1a. Restaurant Floorplan

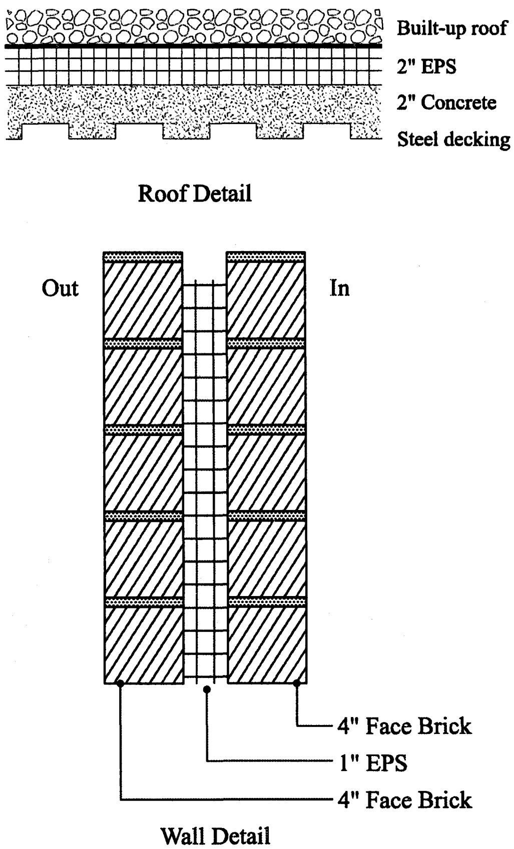


Figure 11-1b. Restaurant Roof and Wall Cross-Sections

Table 11-1. Kitchen Equipment

Qty	Description/Capacity
1	8×10 walk-in freezer
1	8×10 walk-in cooler
2	10 ft³ chest freezers
2	8 ft³ coolers
2	Ice makers, 10 lb/h
2	Soda drink dispensers
4	Commercial microwave ovens
2	36×36 in. gas broilers (1 back-up)
4	High capacity deep fryers
2	Steamers
4	36 in. infrared food warmers
3	Electronic cash registers
2	12 cup commercial coffee makers
1	120 gal water heater

Table 11-2. Exhaust Fan Schedule

Qty	Location	Capacity (each)
2	Broilers (1 standby)	1600 cfm
2	Fryers	900 cfm
2	Steamers	600 cfm
1	Rest rooms	500 cfm

The reflected ceiling plan shows 25 fixtures in the dining area, 20 more in the kitchen area, two fixtures in each bathroom, plus one in the office and one in each storage room. Each fixture contains two 35 W fluorescent bulbs, and is recessed and unventilated. There are also ten 150 W accent lights under the exterior overhang and six 250 W security lights in the parking area.

The plans and specifications indicate a number of energy producing devices in the kitchen area. These are summarized in *Table 11-1*. Note that only one of the two broilers is used; the other serves as a backup. The walk-in cooler and walk-in freezer both have their condensing units located on the roof, but all other units are self-contained. There are also seven exhaust fans: one above each broiler, above each pair of fryers, above each steamer, plus one for the rest rooms. These are scheduled in *Table 11-2*.

11.2 Initial Data Collection and Assumptions

Your first phone call is to the manager of the local franchise where you often eat lunch, because the buildings appear similar in size. When you mention that there are 60 seats in the dining area, the manager notes that her restaurant is comparable. You learn that she uses four rooftop units, two each in the dining and kitchen areas. (Multiple units are frequently specified, to ensure some comfort control when a system goes down.) You also get some useful information about the occupancy schedule and the normal daily operating schedule. These data are summarized in *Table 11-3.*

Your next step is to get information on the environmental conditions expected on the inside and outside under design conditions. In Chapter 3 of the *ASHRAE Handbook–HVAC Applications* under restaurants, the normal inside design temperature and humidity are:[1]

Winter: 70° to 74°F at 20% to 30% rh

Summer: 74° to 78°F at 55% to 60% rh

Table 11-3. People Schedule

Hour	Staff	Patrons	Hour	Staff	Patrons	Hour	Staff	Patrons
0100	0	0	0900	5	10	1700	6	26
0200	0	0	1000	6	12	1800	6	50
0300	0	0	1100	6	28	1900	6	40
0400	0	0	1200	6	45	2000	4	34
0500	0	0	1300	6	42	2100	4	22
0600	3	0	1400	4	26	2200	3	12
0700	5	12	1500	4	18	2300	3	5
0800	5	20	1600	5	22	2400	2	0

You will also need local outside design conditions, which can be found in Chapter 26 of the 1997 *ASHRAE Handbook–Fundamentals*[2] (see *Table 11-4*) or *Figure 3-2.*

Table 11-4. Example Weather Data

Project Name:	Fast food	**Location:**	Andrews AFB
Latitude:	39°N	**Summer dry bulb:**	91°F
Longitude:	76°W	**Summer wet bulb:**	74°F
Winter dry bulb:	18°F	**Mean daily range:**	18.7°F
Recom. ventilation:	5100 cfm		

Because there is no location that exactly matches this example, you must choose the nearest weather station. These data are for the 99% (winter) and 1% (summer) conditions at Andrews AFB in Camp Springs, MD. However, you also could have selected the 99.6% and 0.4% design conditions, or used the Baltimore BWI airport data if it appeared to better represent the location. In either case, your answers would be different, but not necessarily wrong. That is only the first of many assumptions that you will have to make to complete this chapter; just base your values on reasonable assumptions and they will be reasonably close to those given in this chapter.

In *Table 11-4*, a value of 1,320 cfm for the ventilation rate would be correct if the maximum number of people (60 patrons if every seat is taken plus 6 staff) were responsible for setting the ventilation rate. We are using 20 cfm per person in this course (as noted in Chapter 6) and the kitchen exhausts supplied their own makeup air (as required by some codes). However in this case, the exhaust fans are drawing 5,100 cfm from the building under full operation. (Remember that one of the broilers is for emergency use only, and its fan is off most of the time.) The ventilation system must provide an equal flow rate of outside air into the building for these systems to function properly. If the supply air flow is significantly less than the exhaust flow, every time a patron opens a door, there will be a tremendous influx of cold or hot air, blowing napkins and cups everywhere. And because the exhaust fans would be starved for air, the dining area would quickly fill up with greasy smoke and odors.

Next, we will calculate the U-factors for the wall and roof sections. Refer to *Figure 11-1*, Chapter 4 and *Appendix A* for help in completing *Table 11-5a.*

Table 11-5a. Wall/Roof Exercise

Wall type:	Brick/Insulation/Brick	Component R-values	
1	________	________	
2	________	________	
3	________	________	
4	________	________	
5	________	________	
	Total R-value =	________	h·ft²·°F/Btu
U-factor =	$1 / R_{total}$ = 1 /_____ =	________	Btu/h·ft²·°F
Roof type:	Built-up	Component R-values	
1	________	________	
2	________	________	
3	________	________	
4	________	________	
5	________	________	
	Total R-value =	________	h·ft²·°F/Btu
U-factor =	$1 / R_{total}$ = 1 /_____ =	________	Btu/h·ft²·°F

Table 11-5b. Wall/Roof Answers

Wall type:	Brick/Insulation/Brick	Component R-values
1	Outside air film	0.17
2	4 in. face brick	0.44
3	1 in. Expanded Polystyrene	5
4	4 in. face brick	0.44
5	Inside air film	0.68
	Total R-value =	6.73 h·ft²·°F/Btu
	U-factor = 1 / R_{total} =	1 / 6.73 = 0.15 Btu/h·ft²·°F
Roof type:	Built-up	Component R-values
1	Outside air film	0.17
2	Built-up roofing	0.33
3	2 in. EPS	10
4	2 in. concrete	0.2
5	Inside air film	0.61
	Total R-value =	11.31 h·ft²·°F/Btu
	U-factor = 1 / R_{total} =	1 /11.31 = 0.09 Btu/h·ft²·°F

The brick R-value assumed here was for a density of 150 lb/ft³. The tabled R-value of 0.11 h·°F·ft²/Btu·in. must be multiplied by 4, because each brick is 4 in. thick. Had you assumed a lighter brick (a density of 100 lb/ft³), then the brick R-value would have been 0.88 h·°F·ft²/Btu instead of 0.44 h·°F·ft²/Btu. The R_{total} for the wall would have been 7.61 h·°F·ft²/Btu, and the U-factor would have been 0.13 Btu/h·°F·ft². However, it is dangerous to assume that a contractor will always select the more energy efficient materials. Cost and availability are usually more important to the contractor.

Similarly, the concrete roof deck was calculated assuming a density of 130 lb/ft³. If the specification had called for a lighter weight aggregate, the thermal performance could be improved somewhat.

There are a few more component items to look up and some additional area calculations that must be made. Notice that the data for all four directions are required, and the floor and ceiling areas are split between the kitchen and the dining areas because these represent separate zones. Refer again to Chapters 2, 4, 5 and 9 as well as *Figure 11-1* to complete *Table 11-6a* (round all areas to the nearest ft²). The answers will be given in *Table 11-6b*.

Table 11-6a. Areas Exercise

Floor U-factor	________	Btu/h·ft·°F
Window U-factor	________	Btu/h·ft²·°F
Glass Door U-factor	________	Btu/h·ft²·°F
Metal Door U-factor	________	Btu/h·ft²·°F

	DINING ROOM AREA				**KITCHEN AREA**			
	Wall Area	**Net Wall Area**	**Glass**	**Doors**	**Wall Area**	**Net Wall Area**	**Glass**	**Doors**
North								
East								
South								
West								
Floor								
Ceiling								

Table 11-6b. Areas Answers

Floor U-factor	0.81 Btu/h·ft·°F
Window U-factor	0.64 Btu/h·ft²·°F
Glass Door U-factor	1.14 Btu/h·ft²·°F
Metal Door U-factor	0.4 Btu/h·ft²·°F

	DINING ROOM AREA				KITCHEN AREA			
	Wall Area	**Net Wall Area**	**Glass**	**Doors**	**Wall Area**	**Net Wall Area**	**Glass**	**Doors**
North	heated space	0	0	0	30×10-20	280	0	20
East	40×10-5.5×30	235	129	36	50×10-66	434	66	0
South	30×2.5-32×30/144+30×2	128	154	18	heated space	0	0	0
West	40×10-5.5×(9.33×2)	297	103	0	50×10+10×10-55	545	55	0
Floor	Perim. = 40+30+40	110 LF	0	0	Perim. = 60+30+50	140 LF	0	0
Ceiling	30×40	1200	0	0	50×30+5×10	1550	0	0

There is no north wall for the dining area because it interfaces the kitchen zone. The east wall area was determined by taking the gross wall area and subtracting the gross window and door areas. A different method is demonstrated for the south wall, where the net wall area below the windows (minus the door area) is added to the net wall area above the windows. The west wall area was determined like the east wall area, but the glass areas do not include the poorly insulated columns. You can use any visualization process that yields reasonably accurate areas and accounts for the total gross wall area.

Similarly, the kitchen wall areas are determined by subtracting the window or door areas from the gross area of that wall. The wall area of the drive-up window "bump-out" is included in the west wall area of the kitchen zone as an extra 10 ft section of wall. An extra roof area is included for the drive-up window. There is no south area for the kitchen because it is adjacent to the dining area.

We found the perimeter of both floor areas. Note that the kitchen perimeter includes the drive-up window. We will assume the floor slab loses 0.81 Btu/h·ft·°F for each foot of perimeter in each of the two areas. The values for the glass doors and windows are given in *Table 9-1* as ID #2 and ID #5, respectively. The windows are assumed to have no thermal breaks. If you assumed thermal breaks were present, the door and window U-factors would be 0.96 Btu/h·ft²·°F and 0.57 Btu/h·ft²·°F, respectively. The insulated north door U-factor comes from *Table 2-2*.

11.3 Heating Load

We now have all the information required to compute the winter heating load. Enter the above values into *Table 11-7a* below, and calculate the total heat loss. The answers are given in *Table 11-7b*.

Table 11-7a. Zone Load Exercise

Dining Area	**U-Factor**	**Area**	**Temp Diff.**	**Total Loss**
North	_______	0	_______	_______
East	_______	235	_______	_______
South	_______	128	_______	_______
West	_______	297	_______	_______
Windows	_______	386	_______	_______
Doors	_______	54	_______	_______
Ceiling	_______	1200	_______	_______
Floor	_______	110	_______	_______
Infilt/vent	_______	2550	_______	_______
		Total Zone Loss =		_______ Btu/h

Kitchen Area	**U-Factor**	**Area**	**Temp Diff.**	**Total Loss**
North	_______	280	_______	_______
East	_______	434	_______	_______
South	_______	0	_______	_______
West	_______	545	_______	_______
Windows	_______	121	_______	_______
Doors	_______	20	_______	_______
Ceiling	_______	1550	_______	_______
Floor	_______	140	_______	_______
Infilt/vent	_______	2550	_______	_______
		Total Zone Loss =		_______ Btu/h

Table 11-7b. Zone Load Answers

Dining Area	U-Factor	Area	Temp Diff.	Total Loss
North	0	0	47	0
East	0.15	235	47	1657
South	0.15	128	47	902
West	0.15	297	47	2094
Windows	0.64	386	47	11,611
Doors	1.14	54	47	2893
Ceiling	0.09	1200	47	5076
Floor	0.81	110	47	4188
Infilt/vent	1.09	2550	47	130,637
		Total Zone Loss =		159,058 Btu/h

Kitchen Area	U-Factor	Area	Temp Diff.	Total Loss
North	0.15	280	47	1974
East	0.15	434	47	3060
South	0	0	47	0
West	0.15	545	47	3842
Windows	0.64	121	47	3640
Doors	0.4	20	47	376
Ceiling	0.09	1550	47	6557
Floor	0.81	140	47	5330
Infilt/vent	1.09	2550	47	130,637
		Total Zone Loss =		155,416 Btu/h

Did you get close to these values? Remember that heating loads are calculated assuming an inside air temperature of 65°F . Notice that the ventilation load is equally distributed between the two zones and that it is 80% to 85% of the total heating load. Because all of the exhaust is from the kitchen zone, this will create a gentle air movement across the counter into the kitchen, trapping odors and maintaining good air quality in the dining area. The other option here is to recommend that the client install a kitchen hood with 90% outside makeup air provided directly to the hood, to save most of the heating energy that is only being exhausted. Following the energy cost of heating the makeup air, the loss through the windows is most significant. Notice also that the heating loads for the dining area and kitchen are nearly the same. This might suggest that four identical rooftop units could be specified, thus reducing the quantity of spare parts that must be inventoried. In the process of specifying the heating capacity of this equipment, it might be good to add up to 10% spare capacity. Not only would this provide a margin of safety to your design calculations, but it would also provide extra heating capacity for startup on cold winter mornings and to quickly overcome losses if a door was propped open for an extended period of time.

11.4 Cooling Load

Calculation of the cooling load for this example will be a little faster, because many of the values needed have already been determined. There will be four sections to our calculation for each of the two zones:

- Conduction through roofs, walls and glass.
- Solar gain through glass.
- Internal gains from lights, power, appliances and people.
- Ventilation and infiltration.

Remember that the first two calculations will result in only sensible heat gains, but the last two will also contribute latent gains to the structure. We must also select an appropriate hour and month. Because maximum cooling loads normally occur during the late afternoon, we will assume 6 pm EDT (which is 1700 Eastern Standard Time, EST). During this hour, the sun will appear under the overhang, and it is also the peak number of people within the establishment.

Conduction

Complete *Table 11-8a* for the roof, walls and glass. Use the U-factor and areas determined during the heat load calculation above. Find the CLTDs (remember to correct it) on *Table 8-3*, *Table 9-1* and *Appendix C*.

Table 11-8a. Cooling Load Exercise

Dining Area	U-Factor	Area	Temp Diff.	Total Loss	
North	______	______	______	______	
East	______	______	______	______	
South	______	______	______	______	
West	______	______	______	______	
Windows	______	______	______	______	
Doors	______	______	______	______	
Roof	______	______	______	______	
Floor	______	______	______	______	
		Total Skin Zone Gain =		______	Btu/h

Kitchen Area	U-Factor	Area	Temp Diff.	Total Loss	
North	______	______	______	______	
East	______	______	______	______	
South	______	______	______	______	
West	______	______	______	______	
Windows	______	______	______	______	
Doors	______	______	______	______	
Roof	______	______	______	______	
Floor	______	______	______	______	
		Total Skin Zone Gain =		______	Btu/h

Table 11-8b. Cooling Load Answers

Dining Area	U-Factor	Area	Temp Diff.	Total Loss
North	0	0	0	0
East	0.15	235	28	987
South	0.15	128	17	326
West	0.15	297	14	624
Windows	0.64	386	10	2470
Doors	1.14	54	10	616
Roof	0.09	1200	43	4644
Floor	0.81	110	4	356
	Total Skin Zone Gain =			10,023 Btu/h

Kitchen Area	U-Factor	Area	Temp Diff.	Total Loss
North	0.15	280	10	420
East	0.15	434	28	1823
South	0	0	0	0
West	0.15	545	14	1145
Windows	0.64	121	10	774
Doors	0.4	20	10	80
Roof	0.09	1550	43	5999
Floor	0.81	140	4	454
	Total Zone Skin Gain =			10,695 Btu/h

We assume the roof mass is inside the insulation with an R-11.3 h·°F·ft²/Btu value and suspended ceiling. With 2 in. of concrete, this produces a roof number of 13. Assuming face brick (C4) with R-6.6 h·°F·ft²/Btu in *Appendix B* yields a type 16 wall. At this hour, the roof, north wall and glass CLTDs are 46°F, 13°F and 13°F, respectively. Each of these must be corrected for the outdoor temperature: (91-19/2)-85 = -3°F, yielding the values shown in the table. The average floor temperature difference is (91-19/2)-78 = 4°F.

Solar Gain

To calculate the solar gain through the windows, we will have to apply the techniques from Chapter 9. Use the following to complete *Table 11-9a*: *Tables 9-4a* and *9-4b* indicate the zone type for this construction, *Table 9-5* is used to determine the design solar cooling load, and *Table 9-3* offers a value for the Solar Heat Gain Coefficient (SHGC). You will also use *Figure 9-9* for the solar altitude and azimuth angles needed to calculate the shadow lines. Try to complete *Table 11-9a* before turning the page for the answers.

Table 11-9a. Solar Gain Exercise

Dining Area	SHGC	Area	SCL	Total Gain
North	________	_____	________	__________
East	________	_____	________	__________
South	________	_____	________	__________
West (shaded)	________	_____	________	__________
West (sunlit)	________	_____	________	__________
		Total Solar Zone Gain =		________ Btu/h

Kitchen Area	SHGC	Area	SCL	Total Gain
North	________	_____	________	__________
East	________	_____	________	__________
South	________	_____	________	__________
West (sunlit)	________	_____	________	__________
		Total Solar Zone Gain =		________ Btu/h

Table 11-9b. Solar Gain Answers

Dining Area	**SHGC**	**Area**	**SCL**	**Total Gain**	
North	0.64	0	29	0	
East	0.64	129	37	3055	
South	0.64	154	33	3252	
West (shaded)	0.64	5	29	93	
West (sunlit)	0.64	98	156	9784	
	Total Solar Zone Gain =			16,184	Btu/h
Kitchen Area	**SHGC**	**Area**	**SCL**	**Total Gain**	
North	0.64	0	29	0	
East	0.64	66	37	1563	
South	0.64	0	33	0	
West (sunlit)	0.64	55	156	5491	
	Total Solar Zone Gain =			7054	Btu/h

Because there were three walls exposed in each zone, hard floor, block walls and no shading, zone type C was selected for solar, people and lights. This value was used at 1700 hour in July to determine the SCL from *Table 9-5*.

We also need to determine the shade angle. Using the solar altitude and azimuth angles of 24° and 97° respectively from *Table 9-9* for July at 0700 (which is the same as 1700) hour, we find that only the west windows are exposed. The SCL values for the east and south windows are significantly lower, and represent the residual effects of sunlight earlier in the day. The shadow height caused by a 5 ft wide overhang (P_H= 60 in.) is given by:

$$S_H = P_H \cdot (\tan \Omega) = 60 \tan [24°] = 60 \cdot 0.445 = 27 \text{ in.}$$

Because the overhang is at the 10 ft elevation, and the windows terminate at the 8 ft elevation, only the top 3 in. of the west windows are shaded at this hour. The remaining 95% of the west windows in the dining area are sunlit. The west window in the kitchen area is in the drive-up window area, which has no overhang. This window is fully sunlit.

Internal Gains

The third phase of the cooling load calculation involves the internal gains from lighting, equipment and people. Turn back to the equipment listed in *Table 11-1* and look up reasonable sensible and latent values for each component from *Table 10-7* before checking the answers given in *Table 11-10*. The data and equations for calculating the lighting gain in *Table 11-11* are also presented in Chapter 10. Estimate the sensible and latent contributions from people during this hour using *Tables 10-2* and *10-8*.

Table 11-10. Internal Gains Data

Qty.	Item	Sensible Each	Latent Each	Tot. Sensible	Tot. Latent
1	8×10 walk-in freezer	0	0	0	
1	8×10 walk-in cooler	0	0	0	
2	10 ft³ chest freezers	1090 Btu/h·(10/18) ft³	0	1211	
2	8 ft³ coolers (refrigerators)	665 Btu/h·(8/10) ft³	0	1064	
2	ice makers, 10 lb/h	9320	0	18640	
2	soda drink dispensers	n/a	0	0	
4	comm. microwave ovens	8970	0	35880	
1	36×36 in. gas broiler (1 backup)	5340/ft²	0	48060*	
4	30 lb deep fryers	1900	0	7600*	
2	50 lb steamers	11/lb	0	1100*	
4	36 in. infrared food warmers	990/ft	0	11880	
3	electronic cash registers	160	0	480	
2	12-cup comm. coffeebrewers	3750	1910	7500	3820
1	120 gal water heater	500	500	0	
		Total Equipment Gains		133,915×0.96	3820

* Hooded

Table 11-11. Internal Gains Exercise

Dining Area Lighting Load = ________ Btu/h
Kitchen Area Lighting Load = ________ Btu/h

Dining Area

Entry Time	Total Number of people	New people	Hrs since entry (1700)	Total hrs in	CLF CLF_p	Btu/each	Total	
____	________	____	________	____	____	______	____	
____	________	____	________	____	____	______	____	
____	________	____	________	____	____	______	____	Btu/h Sensible Load
____	________	____	________	____	____	______	____	Btu/h Latent Load

Kitchen Area

____	________	____	________	____	____	______	____	Btu/h Sensible Load
____	________	____	________	____	____	______	____	Btu/h Latent Load

Table 11-12. Internal Gains Answers

Entry Time	Total Number of people	New people	Hrs since entry (1800)	Total hrs in	CLF CLF_p	Btu/each	Total	
			Dining Area					
1000	25	25	8	12	0.91	275	6256	
1800	50	25	1	2	0.6	275	4125	
							10381	Btu/h Sensible Load
1800	50					275	13750	Btu/h Latent Load
			Kitchen Area					
700	6	0	11	16	0.94	275	1551	Btu/h Sensible Load
1800	6					275	1650	Btu/h Latent Load

How did you do? The total lighting gain is given by the equation below, where the lights are assumed to be on 16 h/d, and we are analyzing zone type C for 11 hours after the lights have been turned on. Two 35-W bulbs yield 70 total W, and 1.2 is assumed for the ballast gains. The CLF value comes from *Table 10-1*. Notice that the information on the exterior accent lights and security lights is not needed.

$$q_{el} = 3.41 \times W \times (F_{ul} \times F_{sa}) \times CLF_{el}$$

$$\text{Dining} = 3.41 \times 25 \times 70(1.0 \times 1.2) \times 0.95 = 6803 \text{ Btu/h}$$

$$\text{Kitchen} = 3.41 \times 27 \times 70(1.0 \times 1.2) \times 0.95 = 7347 \text{ Btu/h}$$

The values shown in *Table 11-10* are the recommended values for unhooded equipment except where noted. Notice that the walk-in freezer and cooler do not contribute to the internal load because their energy is discharged outside the building. The drink dispensers were listed, but contribute negligible heat gains because they are not associated with any refrigeration unit. The data for the cash registers is from *Table 10-5a*. Also, the water heater gain was estimated as 2 ft diameter by 5 ft high with R-4 h·°F·ft²/Btu insulation and a 70°F temperature difference. Assuming hour 12 of an 18 h/d operation, the CLF from *Table 10-4* is 0.96.

The occupancy load is the most difficult to predict, because people are constantly going in and out. *Table 11-12* shows one way of trying to estimate a reasonable value for the dining room occupancy. In this model, a base load of 25 people is assumed from 10 am on, and an additional 25 people are added at 6 pm. Notice that the stored energy from the breakfast and lunch crowds has essentially disappeared by late afternoon. The kitchen crew fortunately is much more stable at about 6 people. The occupant sensible and latent heat gains for restaurants is given in *Table 10-8* as 275 and 275 Btu/h, respectively. The latent heat gain must be removed immediately, but the CLF applies to the sensible values.

VENTILATION AND INFILTRATION

The final step in the cooling load calculation process is to determine the heat gain due to ventilation and infiltration. The total exhaust air flow (5,100 cfm) must be replaced with outside air, and the energy in that air flow must be removed by the cooling system. But because that process occurs in the air handling unit (AHU) or the rooftop unit (RTU), that thermal load is technically not part of our space load. Refer back to Chapter 6 and see if you can calculate the sensible and latent loads due to ventilation. (If you are not familiar with the use of a psychrometric chart yet, here's a hint: the inside and outside humidity ratios are 0.011 $lb_{m\ water} / lb_{m\ dry\ air}$ and 0.0142 $lb_{m\ water} / lb_{m\ dry\ air}$, respectively.)

$q_{sensible}$ =

q_{latent} =

As we did with the heating load, we will assume that the ventilation air is supplied equally by all four rooftop units (2,550 cfm each into dining and kitchen areas). Because the inside and outside design temperatures are 78°F and 91°F, respectively, the sensible gain due to ventilation is given as:

$$\begin{aligned} q_{sensible} &= 1.10 \cdot Q \cdot (t_o - t_i) \\ &= 1.10 \cdot 2550 \cdot (91 - 78) \\ &= 36{,}465 \text{ Btu/h} \end{aligned}$$

To determine the latent gain due to ventilation, a psychrometric chart must be used to find the humidity ratio for the inside and outside air conditions. Given the design conditions of 55% relative humidity inside and an outside wetbulb temperature of 74°F, the inside and outside humidity ratios are 0.011 and 0.0142. The latent gain due to ventilation is given as:

$$\begin{aligned} q_{latent} &= 4840 \cdot Q \cdot (W_o - W_i) \\ &= 4840 \cdot (2550 \text{ cfm}) \cdot (0.0142 - 0.011 \text{ lb}_{m,\ water} / \text{lb}_{m,\ dry\ air}) \\ &= 39{,}494 \text{ Btu/h} \end{aligned}$$

Finally, we should summarize the heating, cooling and ventilation loads, as shown in *Table 11-13*. The sensible and latent loads for both the dining area and the kitchen are given.

Table 11-13. Loads Summary

Table		Dining Area Sensible	Dining Area Latent	Kitchen Area Sensible	Kitchen Area Latent
11-7b	**Heating Loss**	159,058	0	155,416	0
	Cooling Gains				
11-8b	Roof, walls, glass	10,023	0	10,695	0
11-9b	Solar gain	16,184	0	7,054	0
	Internal lighting	6,803	0	7,347	0
11-11	Kitchen equipment	0	0	128,558	3,820
11-12	People	10,381	13,750	1551	1,650
	Ventilation	36,465	39,494	36,465	39,494
	Total Cooling Loads (Btu/h) =	79,856	53,244	191,670	44,964

11.5 Review

After the heating and cooling loads have been calculated, it is good practice to review the results to see where the larger loads are occurring and whether the values appear reasonable. In *Table 11-13*, most of the dining room cooling load is due to the ventilation air and from solar gain through the windows. The ventilation air flow is well defined, assuming that all exhaust fans are running during the dinner hour. Although the hour selected for analysis (6:00 pm EDT or 1700 EST) was based primarily on the highest occupancy rate, it also had the greatest solar gain, because the shadow line was near the top of the window. One hour earlier, the sun would be higher in the sky and more of the west windows would have been shaded and the solar gain would have been much less. One hour later, the intensity of the SCL would have decreased significantly (from 156 to 128 in *Table 9-5*).

It is fortuitous that in this case, the occupancy peak and solar peak occurred simultaneously; you will not always be so lucky. Usually, you will have to make several hourly calculations to ensure that you have determined the maximum load condition.

In the kitchen, most of the gain is due to the equipment load. You might want to double-check the size of the broiler, because it is the greatest contributor to the kitchen cooling load. You might also want to verify the capacity of the exhaust fans. A small change (in either direction) in their flow rate can have a dramatic effect on the design capacity of your rooftop units. Often in the early phase of design projects, estimated values are presented to allow the design to proceed. However, unless someone later asks the right question to the right person, revised values may never get included.

Finally, compare the overall cooling and heating load with previous experience. In this case, the total cooling load in the dining area (not including ventilation) is about 4 tons for 1,200 ft^2 of floor area, or 300 ft^2/ton. That value is in the expected range for dining areas. A quick call to your local franchise manager about the capacity of the rooftop units is another method to gain confidence in the reasonability of your values.

The Next Step

In the next chapter, you will learn how cooling loads are determined using the TFM and RTF concepts. These methods allow a wide variety of building types and construction details to be modeled accurately. They can account for the time-delay that occurs from various wall and roof construction methods as well as account for the interaction between the space surfaces and the solar gain. The procedure lends itself well to the next level beyond heating and cooling load calculations: modeling the flow of energy into and out of a building continuously.

The disadvantage of this new method is that it requires the use of a computer to implement effectively. To keep the scope of this course within the range of a calculator, we will only skim the surface of this complex issue. However, you will still find the calculations challenging for your calculator.

Summary

This chapter presented an opportunity to apply the heating and cooling load calculation methods to a small commercial building. While most parameters were clearly defined, there were several opportunities to use your own judgment in selecting reasonable values from the tables.

After studying Chapter 11, you should be able to:

- Estimate the heating load of a typical commercial building.
- Estimate the ventilation requirements for a facility.
- Calculate the cooling load at a given hour for a structure.

Bibliography

1. ASHRAE. 1995. "Commercial and public buildings." *ASHRAE Handbook–HVAC Applications*. Atlanta, GA: ASHRAE. Chapter 3.

2. ASHRAE. 1997. "Climatic design information." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 26.

Skill Development Exercises for Chapter 11

Complete these questions by writing your answers on the worksheets at the back of this book.

11-01. Calculate the thermal loads at 6:00 pm EDT in July if the building orientation is rotated 90° clockwise (north becomes east).

11-02. Calculate the thermal loads of the original design at noon in July.

11-03. Calculate the thermal loads of the original at 6:00 pm EDT (= 1700 EST) in July if the restaurant is located in Detroit, MI.

Chapter 12
Transfer Function Method

Contents of Chapter 12

Instructions

Read the material in Chapter 12. At the end of the chapter, complete the skill development exercises without consulting the text. Re-read parts of the text as needed to complete the exercises.

Study Objectives of Chapter 12

The CLTD method discussed and applied in the previous chapters usually provides fairly accurate answers and is fairly easy to follow. However, the advent of the personal computer allows more accurate mathematical models to be used for routine design calculations. It also allows for analysis of the effect of various design modifications, control strategies and operating schedule changes on the performance of the systems and conditions on an hour-by-hour basis.

The equations and data used in the Transfer Function Method (TFM) procedure will be discussed in this chapter. We will begin with basic wall and roof sections, which both follow a similar procedure. From there, we will discuss how thermal energy stored by the mass within the space affects the cooling load over time, and show how these values can be modeled using the Room Transfer Functions (RTF).

After studying Chapter 12, you will be able to:

- Use TFM to determine hourly heat gains through given walls and roof sections.
- Use RTF to determine cooling loads from heat gains through windows and wall sections and from equipment or lights.

12.1 Heat Gain by Conduction Through Exterior Walls and Roofs

As noted in the earlier discussion of the CLTD method, the thermal energy that is stored within the building structure and contents shifts the timing of when the energy is released into the space air. The TFM process accounts for the density, thermal capacitance and thermal conductance of the building materials used and determines the instantaneous heat gain based on the thermal history of the structure.

Obviously, the thermal history of a structural cross-section will depend strongly on the local weather conditions (temperature and solar energy) assumed. For this procedure, the sol-air temperatures discussed in Chapter 8 and presented in *Table 8-1* are used to represent the outdoor conditions. The indoor air temperature and both indoor and outdoor surface heat transfer coefficients are assumed constant. Thus, the heat gain through a wall or roof is given by:

$$q_{e,\theta} = A\left[\sum_{n=0} b_n\left(t_{e,\theta-n\delta}\right) - \sum_{n=1} \frac{d_n\left(q_{e,\theta-n\delta}\right)}{A} - t_{rc}\sum_{n=0} c_n\right] \qquad (12\text{-}1)$$

where,

$q_{e,\theta}$	= heat gain through wall or roof at calculation hour θ, Btu/h
A	= indoor surface area of a wall or roof, ft²
θ	= time, h
δ	= time interval, h
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 θ-nδ, °F
t_{rc}	= constant indoor room temperature, °F
b_n, c_n, d_n	= conduction transfer function coefficients

The Conduction Transfer Function (CTF) coefficients presented here are calculated using combined indoor and outdoor heat transfer coefficients of h_i = 1.46 (Btu/h·ft²·°F) and h_o = 3.0 (Btu/h·ft²·°F), respectively. For applications with different sol-air values or construction details, follow the procedure and computer program outlined in Mitalas and Arseneault[1] or as discussed by the *Cooling and Heating Load Calculation Manual*[2] and with the micro-computer software issued with that publication.

Harris and McQuiston investigated the thermal behavior of approximately 2600 walls and 500 roofs to determine how they influenced transmission of heat gain to conditioned spaces.[3] Based on that study, 41 representative wall assemblies and 42 roof assemblies have been identified. These represent a wide range of construction components, insulating values and mass densities. The mass can be concentrated on the inside surface, the outside surface or uniformly distributed across the wall or roof section. These prototypical assemblies can be used to model the performance of most typical construction practices.

These wall and roof sections are constructed from the selection of building materials listed in *Table 12-1*. The code letters A, B, C and E represent outside surface materials, light insulating materials, heavy non-insulating materials and inside surface materials, respectively. These groupings are basically for identification purposes only; the lettered components can be arranged in almost any reasonable sequence. However, notice that A0 is always the outside surface resistance, and E0 is always the inside surface resistance.

The representative roof group numbers are presented in *Table 12-2*. To determine the representative roof group number, select the appropriate section based on the existence of a suspended ceiling and/or roof terrace system. Next determine whether the roof mass is predominantly inside, outside or uniformly distributed (integral). Finally, select the appropriate R-value range number based on the values in the footnote at the bottom of the table.

EXAMPLE 12-1

Problem: Determine the roof number for the restaurant example of Chapter 11. That roof consisted of 2 in. of insulation on top of 2 in. of concrete for a total resistance of R = 11.31 $h \cdot ft^2 \cdot °F/Btu$.

Solution: In this case, the mass is inside, and we will assume a suspended ceiling without a roof terrace system. The 2 in. concrete deck is represented by C12 in *Table 12-1*. The R-value range in *Table 12-2* is 3 for the given R-value. Line 5 therefore indicates that the appropriate roof group number for this construction is No. 13.

The selected roof group number is then used in *Tables 12-3* and *12-4* to determine the roof CTF coefficients. These values can then be used in *Equation 12-1* above to calculate the rate of heat gain. Notice that in the above example, Roof Group 13 is assumed to be a 6 in. heavyweight concrete deck with 2 in. of insulation, which is somewhat different from the actual construction materials that we assumed in the example. Initially, it may be difficult to accept that such diverse systems can perform comparably from a thermal point of view. But these results have been validated experimentally many times.

Table 12-1. Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions[4]

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	1.19	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·ft^2·h/Btu
Mass = unit mass, lb/ft^2

Table 12-2. Roof Group Numbers[4]

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·ft²·°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 12-3. Roof Conduction Transfer Function Coefficients[4]

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 E0 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 12-3. Roof Conduction Transfer Function Coefficients (cont.)

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 12-4. Roof Conduction Transfer Function Coefficients, Time Lag, U-Factors and Decrement Factors[4]

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

Similar information for various wall groupings are provided in *Tables 12-5*, *12-6* and *12-7* for designs with the insulation predominantly on the inside, integral and outside, respectively. Each line represents one of 17 R-value ranges. Select the most massive wall material from the list of 25 Wall Material Layers presented in the abbreviated Table 11 on the bottom right of the two tables, and then select one of the three types of surface finish presented. The top of the table represents stucco or plaster finishes; the middle section represents steel or other thin surface materials; and the bottom section represents 4 in. face brick (or similar massive surfaces).

Example 12-2

Problem: Determine the appropriate wall group for a wall section that consists of 4 in. brick, 2 in. insulation and 4 in. brick (inside) with a total R-value of 6.73 h·ft²·°F/Btu.

Solution: Because the massive brick is evenly distributed, *Table 12-6* is used for the integral mass case. A brick surface is layer A2 or A7 indicated by column 2, and the R-value range is given on line 9 at the bottom of the table. The indicated wall group is 16. Referring to *Table 12-8*, this group is representative of 8 in. heavyweight filled concrete block with face brick. The thermal performance for both of these wall cross-sections is again comparable.

Similar to the roof group, the wall group number is used to look up the CTFs in *Tables 12-8* and *12-9*. The b_n and d_n values from *Table 12-8* are coefficient multipliers for the temperature and hourly heat flow, respectively. In both cases, the model is sensitive to the thermal history for up to six hours previously. Notice that for light construction walls (Wall Group 1 in *Table 12-8*), there is very little interaction after $n = 2$. When the b_n coefficients are very small or zero (for Wall Group 1 with $n = 3$ or greater), then they can usually be neglected and dropped from the calculations. *Table 12-9* is used to obtain values for Σc_n and U. The first term is substituted directly into *Equation 12-1*. The U-factor shown in the table was used to determine these coefficients. If the U-factor for your wall or roof is different than this value, then you must adjust the tabled values of b_n by the ratio of (U_{actual}/U_{tabled}). The d_n values are never corrected by this factor.

Table 12-5. Wall Group Numbers, Walls for Mass-In Case, Dominant Wall Material[4]

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	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	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

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	*	*	*	*	*	*	*	*
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

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	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
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, $h \cdot ft^2 \cdot °F/Btu$
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 12-6. Walls for Integral Mass Case, Dominant Wall Material[4]

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	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																									
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																									
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·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 12-7. Walls for Mass-Out Case, Dominant Wall Material[4]

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	*	*	*	*	*	*	*	*
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

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	*	*	*	*	*	*	*	*
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

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	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
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-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 12-8. Wall Conduction Transfer Coefficients[4]

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 12-8. Wall Conduction Transfer Coefficients (cont.)

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 12-9. Wall Conduction Transfer Coefficients $\sum c_n$, Time Lag, U-Factors and Decrement Factors[4]

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

The following format of *Equation 12-1* demonstrates heat flow calculations through the wall:

$$q_{e,\theta} / A = \begin{bmatrix} b_0\left(t_{e,\theta}\right) \\ +b_1\left(t_{e,\theta-\delta}\right) \\ +b_2\left(t_{e,\theta-2\delta}\right) \end{bmatrix} - \begin{bmatrix} d_1\left[\left(q_{e,\theta-\delta}\right)\right]/A \\ +d_2\left[\left(q_{e,\theta-2\delta}\right)\right]/A \\ +d_3\left[\left(q_{e,\theta-3\delta}\right)\right]/A \end{bmatrix} - \left[t_{rc}\sum_{n=0} c_n\right]$$

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

- 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 the previous hour is multiplied by b_1, etc.
- Sum of the products of d coefficients and the previously calculated values of hourly heat gain. Note that the first d used is d_1. Again, the order of values is the same as in the first term; for example, d_1 is multiplied by the heat gain value that was calculated for the previous hour, d_2 is multiplied by the value calculated for two hours back in time, etc.
- A constant, because room air temperature is constant and needs to be calculated only once.

Because no thermal history exists at the beginning of this procedure, significant error exists during this period. For good, repeatable results, it is usually necessary to simulate the hourly thermal performance over two or three days until consistent hourly values are observed.

To verify that the model has converged to a periodic steady-state condition, compare the average of the last 24 values with the average heat flow. The latter value is given by the product of the U-factor and the difference between the average sol-air temperature and the room temperature.

EXAMPLE 12-3

Problem: Determine the rate of heat transfer through the south-facing wall section discussed in *Example 12-2* above, and verify that a steady-state condition exists. The R-value is 6.73 h·ft²·°F/Btu.

Solution: From *Table 12-9* for Wall Group 16, the Σc_n and U-factors are 0.00545 and 0.222 Btu/h·ft²·°F, respectively. Because the U-factor for our problem is 1/6.73 = 0.1486 Btu/h·ft²·°F, it is necessary to adjust the b_n values by (0.1486/0.222 = 0.669) as shown in the third column below. The sol-air temperatures from *Figure 8-1* for a south-facing wall are:

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
Temp	76	76	75	74	74	76	78	82	88	95	102	106	108	106	103	99	96	93	87	85	83	81	79	77

The CTF coefficients of Wall Group 16 from *Table 12-8* and the corrected *b* and *c* coefficients are listed in *Table 12-10*.

Table 12-10. CTF Coefficients for *Example 12-3*

		Adjusted b_n values
b_0 = 0.00000	d_0 = 1.00000	b_0 = 0.00000
b_1 = 0.00014	d_1 = -2.00258	b_1 = 0.00009
b_2 = 0.00169	d_2 = 1.32887	b_2 = 0.00113
b_3 = 0.00270	d_3 = -0.32486	b_3 = 0.00181
b_4 = 0.00086	d_4 = 0.02361	b_4 = 0.00058
b_5 = 0.00006	d_5 = -0.00052	b_5 = 0.00004
b_6 = 0.00000	d_6 = 0.00000	b_6 = 0.00000
C_n = 0.00545		Corrected C_n = 0.00365

The sequence of calculation using the 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 the *b* and *d* coefficients 5 and 6 as insignificant):

$$q_{e,1} = \begin{bmatrix} +0.00000(76°\text{F}) \\ +0.00009(77°\text{F}) \\ +0.00113(79°\text{F}) \\ +0.00181(81°\text{F}) \\ +0.00058(83°\text{F}) \end{bmatrix} - \begin{bmatrix} -2.00258(0) \\ +1.32887(0) \\ -0.32486(0) \\ +0.02361(0) \end{bmatrix} - [0.00365(75°\text{F})]$$

$$= 0.017\ \text{Btu/h} \cdot \text{ft}^2$$

$$q_{e,2} = \begin{bmatrix} +0.00000(76°F) \\ +0.00009(76°F) \\ +0.00113(77°F) \\ +0.00181(79°F) \\ +0.00058(81°F) \end{bmatrix} - \begin{bmatrix} -2.00258(0.017\ \text{Btu/h}\cdot\text{ft}^2) \\ +1.32887(0) \\ -0.32486(0) \\ +0.02361(0) \end{bmatrix} - [0.00365(75°F)]$$

$$= 0.044\ \text{Btu/h}\cdot\text{ft}^2$$

The calculated hourly values for q_e are given in *Table 12-11* for four simulated days. The second column repeats the hourly sol-air temperatures. Notice that for days three and four, each pair of hourly values is consistent. This consistency implies convergence of the heat gain values to a periodic steady-state condition.

A similar calculation method can be used whenever a conditioned space is adjacent to other spaces at different temperatures. Simply substitute the temperature of the adjacent space for the sol-air temperature used in the previous calculation.

Table 12-11. Summary of Hourly Results for *Example 12-3*

n = hour	sol-air T	$q_{e,n}$	n = hour	$q_{e,n}$	n = hour	$q_{e,n}$	n = hour	$q_{e,n}$
1	76	0.017	25	2.267	49	2.348	73	2.350
2	76	0.044	26	2.142	50	2.211	74	2.213
3	75	0.070	27	1.990	51	2.049	75	2.051
4	74	0.088	28	1.821	52	1.871	76	1.872
5	74	0.097	29	1.643	53	1.686	77	1.687
6	76	0.095	30	1.463	54	1.500	78	1.501
7	78	0.082	31	1.285	55	1.317	79	1.318
8	82	0.064	32	1.116	56	1.143	80	1.144
9	88	0.050	33	0.966	57	0.990	81	0.990
10	95	0.051	34	0.847	58	0.867	82	0.867
11	102	0.083	35	0.772	59	0.789	83	0.789
12	106	0.163	36	0.758	60	0.772	84	0.773
13	108	0.305	37	0.818	61	0.831	85	0.831
14	106	0.516	38	0.957	62	0.968	86	0.968
15	103	0.787	39	1.167	63	1.176	87	1.176
16	99	1.098	40	1.424	64	1.432	88	1.432
17	96	1.419	41	1.700	65	1.706	89	1.706
18	93	1.721	42	1.961	66	1.967	90	1.967
19	87	1.981	43	2.187	67	2.191	91	2.192
20	85	2.185	44	2.361	68	2.365	92	2.365
21	83	2.325	45	2.476	69	2.479	93	2.479
22	81	2.396	46	2.525	70	2.528	94	2.528
23	79	2.403	47	2.514	71	2.517	95	2.517
24	77	2.357	48	2.452	72	2.454	96	2.454

12.2 Conversion of Cooling Load from Heat Gain

The cooling load of a space also depends on the interaction between sensible heat gains (such as sunlight, interior lights, appliances and equipment) and the location and mass of room objects that absorb that energy. For example, sunlight striking the fibers of a carpet releases energy to the space much more quickly than a similar quantity of solar energy striking a concrete floor. In the latter case, a significant fraction of the energy is absorbed by the more massive material and may not be released to the room for several hours. The thermal history of each source of room heat gain must be accounted for individually, and the sum of these various components at any time is the total cooling load at that time.

One component of the cooling load that must always be considered instantaneously is the latent heat gain. However, depending on the type of air-conditioning system assumed, this load may or may not contribute to the room load. For example, if ventilation air is dehumidified at a central location before distribution to individual zones, then those thermal loads will not contribute to the room load determined here.

Stephenson and Mitalas, Mitalas and Stephenson, and Kimura and Stephenson related heat gain to the corresponding cooling load by a room transfer function (RTF), which depends on both the nature of the heat gain and on the heat storage characteristics of the space surfaces and contents.[5-7] The history of both heat gains and concurrent cooling loads must be considered in this method. 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 ($Q_{\theta\text{-}n}$) and heat gain ($q_{\theta\text{-}n}$) by:

$$Q_\theta = \sum\left(v_0 \cdot q_\theta + v_1 \cdot q_{\theta-\delta} + v_2 \cdot q_{2\theta-2\delta} + \ldots\right) - \left(w_1 \cdot Q_{\theta-\delta} + w_2 \cdot Q_{\theta-2\delta} + \ldots\right) \qquad (12\text{-}2)$$

where the terms v_0, v_1..., w_1, w_2... are the coefficients of the RTF:

$$K_z = \frac{v_0 + v_1 z^{-1} + v_2 z^{-2} + \ldots}{1 + w_1 z^{-1} + w_2 z^{-2} + \ldots} \qquad (12\text{-}3)$$

The above term mathematically relates the transformation of the corresponding parts of the cooling load and of the heat gain. The value of these coefficients depends on three parameters: the time interval assumed (we will be using one hour); the nature of the heat gain (what fraction is in the form of radiation, and where is it absorbed); and the heat storage capacity of the room and its contents.

While a mathematical series expansion is presented in the basic equation above, the effect of terms beyond v_1 and w_1 is negligible, and the values tabulated later in this section may generally be used with confidence. Also, a minor inaccuracy can be expected for the initial hour calculated, because a load history does not exist for that time interval. However, values for all subsequent hours are realistic.

A series of ASHRAE-sponsored research projects resulted in numerous technical papers that collectively examined the various sensitivities and relationships among the wide range of design possibilities. The result was a list of 14 discrete screening parameters to describe an individual zone. Each parameter has between two and five levels of characterization, as shown in *Tables 12-12* through *12-15*. The research program calculated RTF values for all possible combinations of screening parameters levels, which represented a total of 200,640 individual cases. Electronic access to these data is available through methods outlined in the *Cooling and Heating Load Calculation Manual*.[2] To illustrate the process, a simplified method of RTF selection is presented in this chapter.

Before presenting the process used to determine RTF values, some precautionary comments and preliminary assumptions must be discussed. First, while the values presented in the table are accurate for the exact design conditions specified, it can be difficult to obtain precise construction details early in the design phase. Careful selection of the model values is required to ensure accuracy of the simulated results. (In computer simulation, this is "Garbage in = Garbage out").

The model also assumes a 24-hour periodic cycle. All heat gained during that period will be converted to the cooling load within that period. Rarely will all of the heat gain be converted to cooling load during the same hour. Two notable exceptions to this general rule are continuous inputs (such as emergency lighting) and in very low mass construction, which releases radiant energy almost immediately.

Table 12-12. Zone Parametric Level Definitions[4]

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 12-13. Exterior Wall Construction Types[4]

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 12-14. 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 12-15. 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.

The model also was developed assuming a "constant interior space temperature." However, today's cost-conscious building energy managers will often turn air-conditioning systems off during unoccupied periods. The primary impact of this operating strategy is to shift the cooling load that would have occurred overnight to the first few hours of operation the following day.

Finally, the TFM is based on the assumption that the cooling load for a space can be calculated by simply adding together the individual components. Theoretically, the various surfaces within a space will transfer radiant energy to each other when they are at slightly different temperatures, thus affecting how fast the energy is released to the space. Extensive studies by ASHRAE have shown that the error caused by ignoring these secondary effects is small and within the range of acceptable error that must be expected in any estimate of cooling load.

12.3 Use of Room Transfer Functions

To determine appropriate room transfer function data for use in the RTF cooling load equation above, first select the value of w_1 from *Table 12-16* for the approximate space envelope construction and range of air circulation. This w_1 value can be viewed as the fraction of storage energy released from the previous hour. Then select and/or calculate the values of v_0 and v_1 from *Table 12-17* for the appropriate heat gain component and range of space construction mass. These values represent the fraction of the heat gain for the current and previous hour, respectively, that contribute to the cooling load during the hour of calculation. Remember that latent heat gains from equipment, people and ventilation air must be removed immediately. Gains from solar and conduction heat gains through surfaces have some fraction of the instantaneous energy delayed, depending on the type of construction. The RTF coefficient for heat gains from lights depends on the furnishings, rate of air flow, and type of fixture.

These values are applied to the following equation for each hour of the simulated day:

$$Q_\theta = (v_0 \cdot q_\theta + v_1 \cdot q_{\theta-\delta}) - (w_1 \cdot Q_{\theta-\delta}) \qquad (12\text{-}4)$$

Table 12-16. Room Transfer Functions: *w* Coefficient[4]

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/ft²: 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·ft²·°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·ft²·°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·ft²·°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·ft²·°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.

Table 12-17. Room Transfer Functions: v_o and v_1 Coefficients[4]

Heat Gain Component	Room Envelope Construction[b]	v_0 (Dimensionless)	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 ($V \leq 0.5$)[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 ($V \geq 0.5$)[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 ($V \geq 0.5$)[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.

EXAMPLE 12-4

Problem: Consider a room having a clear double-glazed window with a 0.5 in. air space and fixed aluminum frame in a multistory office building of medium weight construction (approximately 75 lb/ft² floor area) and medium air circulation. The building is located at 40°N latitude, the date is June 21, and the window orientation is northwest. Calculate the cooling load due to solar gain.

Solution: Find the SHGC for this type of window in *Table 9-3* as 0.64. Look up the Solar Heat Gain Factor (SHGF) in *Table 9-6* for each hour of the day. Multiply the SHGF by 1.15×SHGC to get the Solar Heat Gain (SHG) as shown in *Table 12-18*.

The values of w_1 and v_0 are determined from *Tables 12-16* and *12-17* respectively for a medium construction building. The value v_1 is determined by the equation found in *Table 12-17*. These values are summarized below:

$v_0 = 0.197$

$w_1 = -0.94$

$v_1 = 1 + w_1 - v_0 = -0.137$

The cooling load component due to solar radiation through glass at any time θ is given by the equation:

$$Q_\theta = (v_0 \cdot \mathrm{SHG}_\theta + v_1 \cdot \mathrm{SHG}_{\theta-\delta}) - (w_1 \cdot Q_{\theta-\delta}) \tag{12-5}$$

As in the earlier heat gain calculation example, the calculation is started by assuming that the previous Qs are zero. Furthermore, in this example, SHG = 0 for θ = 1, 2, 3 and 4; therefore, Q_5 and Q_6 in Btu/h·ft² are as shown in *Table 12-19*.

Values for Q_θ for the remainder of the calculations are listed in *Table 12-20*. Four days (96 hr) of calculations are presented to demonstrate that the hourly values successfully converge, canceling the effect of the assumed zero initial conditions.

Table 12-18. Hourly Input Values for *Example 12-4*

Hour	SHGF	SHG
100	0	0.00
200	0	0.00
300	0	0.00
400	0	0.00
500	1	0.74
600	13	9.57
700	21	15.46
800	27	19.87
900	32	23.55
1000	35	25.76
1100	38	27.97
1200	38	27.97
1300	40	29.44
1400	63	46.37
1500	114	83.90
1600	156	114.82
1700	172	126.59
1800	143	105.25
1900	21	15.46
2000	0	0.00
2100	0	0.00
2200	0	0.00
2300	0	0.00
2400	0	0.00

Table 12-20. Hourly Output Values for *Example 12-4*

Hour	Day 1	Day 2	Day 3	Day 4
100	0	18.6025	22.8159	23.7703
200	0	17.4863	21.447	22.3441
300	0	16.4371	20.1602	21.0034
400	0	15.4509	18.9505	19.7432
500	0.144992	14.6688	17.9585	18.7036
600	1.92036	15.5728	18.6651	19.3655
700	3.53915	16.3724	19.2792	19.9375
800	5.12411	17.1874	19.9197	20.5386
900	6.73395	18.0734	20.6418	21.2236
1000	8.17801	18.8371	21.2514	21.7982
1100	9.6679	19.6875	21.9569	22.4709
1200	10.7659	20.1843	22.3176	22.8008
1300	12.088	20.9413	22.9466	23.4008
1400	16.464	24.786	26.671	27.0979
1500	25.6528	33.4756	35.2474	35.6487
1600	35.2375	42.5909	44.2565	44.6337
1700	42.3321	49.2443	50.8099	51.1645
1800	43.1829	49.6804	51.1521	51.4854
1900	29.2178	35.3254	36.7088	37.0221
2000	25.3473	31.0884	32.3888	32.6833
2100	23.8264	29.2231	30.4455	30.7223
2200	22.3968	27.4697	28.6187	28.879
2300	21.053	25.8216	26.9016	27.1463
2400	19.7899	24.2723	25.2875	25.5175

Table 12-19. Sample Hourly Calculation Process for *Example 12-4*

$Q_n =$	v_0^*	SHG_n +	v_1^*	SHG_{n-1}	w_1^*	Q_{n-1}	=
$Q_5 =$	0.197	0.74	-0.137	0	-0.94	0	0.1450
$Q_6 =$	0.197	9.57	-0.137	0.74	-0.94	0.1450	1.920

Example 12-5

Problem: Consider the heat gain from 3 W/ft^2 lights into the medium construction space above. The lights are recessed and unvented, and the space has ordinary furniture and medium air flow through ceiling diffusers. The lights operate continuously from 6 am until 9 pm (until the beginning of hour 2100) and are off the rest of the daily cycle. Find the rate of hourly heat gain under these conditions.

Solution: The w_1 value remains the same at -0.94, because this is the same building. The v_0 and v_1 values for lights are 0.55 and -0.49, respectively. The results for the first 96 hours are given in *Table 12-21*. The calculated results for the fourth day are also presented graphically in *Figure 12-1* to demonstrate how this heat gain is translated into a cooling load that builds slowly until the lights are turned off, then decays slowly until they are turned back on the following morning.

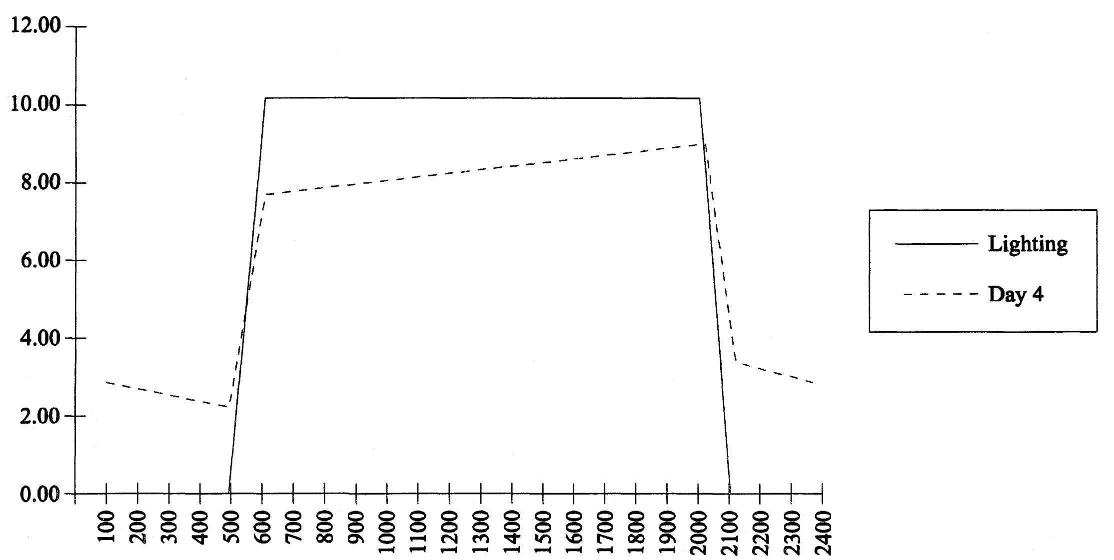


Figure 12-1. Graphical Results for *Example 12-5*

Table 12-21. *Example 12-5* Results

	Hour	Lighting Btu/h=3.41*W	Day 1	Day 2	Day 3	Day 4
	100	0.00	0	2.1734	2.6657	2.7772
	200	0.00	0	2.043	2.5058	2.6106
	300	0.00	0	1.9204	2.3554	2.4539
$v_0 = 0.55$	400	0.00	0	1.8052	2.2141	2.3067
	500	0.00	0	1.6969	2.0813	2.1683
$w_1 = -0.94$	600	10.23	5.6265	7.2216	7.5829	7.6647
	700	10.23	5.9027	7.4021	7.7417	7.8186
$v_1 = -0.49$	800	10.23	6.1623	7.5718	7.891	7.9633
	900	10.23	6.4064	7.7313	8.0313	8.0993
	1000	10.23	6.6358	7.8812	8.1633	8.2272
	1100	10.23	6.8515	8.0221	8.2873	8.3473
	1200	10.23	7.0542	8.1546	8.4038	8.4603
	1300	10.23	7.2447	8.2791	8.5134	8.5665
	1400	10.23	7.4238	8.3962	8.6164	8.6663
	1500	10.23	7.5922	8.5062	8.7132	8.7601
	1600	10.23	7.7505	8.6096	8.8042	8.8483
	1700	10.23	7.8993	8.7068	8.8898	8.9312
	1800	10.23	8.0391	8.7982	8.9702	9.0091
	1900	10.23	8.1706	8.8841	9.0458	9.0824
	2000	10.23	8.2941	8.9649	9.1168	9.1512
	2100	0.00	2.7838	3.4143	3.5571	3.5895
	2200	0.00	2.6167	3.2094	3.3437	3.3741
	2300	0.00	2.4597	3.0169	3.1431	3.1716
	2400	0.00	2.3122	2.8359	2.9545	2.9813

Summary

The TFM and RTF provide greater accuracy in the calculation of building thermal loads, but require more computational effort and the use of computer software to accomplish these calculations. It is not our intent here to make you proficient enough to author professional quality software. Rather, this chapter is intended to explain to you, as a software user, the process and equations that the computer is using to complete its estimate.

After studying Chapter 12, you should be able to:

- Use TFM to determine hourly heat gains through given walls and roof sections.
- Use RTF to determine cooling loads from heat gains through windows and wall sections and from equipment and lights.

Bibliography

1. Mitalas, G., Arsenault, J. 1971. "Fortran IV program to calculate Z-transfer functions for calculation of transient heat transfer through walls and roofs." *Proceedings of Use of Computers for Environmental Engineering Related to Buildings.* Gaithersburg, MD: National Bureau of Standards.

2. McQuiston, F., Spitler, J. 1992. *Cooling and Heating Load Calculation Manual*. Atlanta, GA: ASHRAE.

3. Harris, S., McQuiston, F. 1988. "A study to categorize walls and roofs on the basis of thermal response." *ASHRAE Transactions*. Atlanta, GA: ASHRAE. 94(2).

4. ASHRAE. 1997. "Nonresidential cooling and heating load calculations." *ASHRAE Handbook–Fundamentals*. Atlanta, GA: ASHRAE. Chapter 28.

5. Stephenson, D., Mitalas, G. 1967. "Cooling load calculation by thermal response factor method." *ASHRAE Transactions*. Atlanta, GA: ASHRAE. 73(2).

6. Mitalas, G., Stephenson, D. 1967. "Room thermal response factors." *ASHRAE Transactions*. Atlanta, GA: ASHRAE. 73(2).

7. Kimura, K., Stephenson, D. 1968. "Theoretical study of cooling loads caused by lights." *ASHRAE Transactions*. Atlanta, GA: ASHRAE. 74(2).

Skill Development Exercises for Chapter 12

Complete these questions by writing your answers on the worksheets at the back of this book.

12-01. *Example 12-3* discussed a south-facing wall section. For the same wall facing north, use TFM to determine the rate of heat transfer for the first 24-hour period.

12-02. For the office building discussed in *Example 12-4*, use RTF to determine the cooling load due to solar gain for the first 24-hour period with the following changed conditions: the date is August 21 and the window orientation is southwest.

12-03. Compare the values that you calculated in *Exercise 12-02* with the results determined in *Example 12-4* for the same time period. Explain what factors cause the differences between the values at these hours: 0600, 0900, 1200, 1500, 1800 and 2100.

Appendix A: Thermal Properties of Building and Insulating Materials

Description	Density, lb/ft³	Conductivity[b] (k), Btu·in / h·ft²·°F	Conductance (C), Btu / h·ft²·°F	Resistance[c] (R) Per Inch Thickness (1/k), °F·ft²·h / Btu·in	Resistance[c] (R) For Thickness Listed (1/C), °F·ft²·h / Btu	Specific Heat, Btu / lb·°F
BUILDING BOARD						
Asbestos-cement board	120	4.0	—	0.25	—	0.24
Asbestos-cement board 0.125 in.	120	—	33.00	—	0.03	
Asbestos-cement board 0.25 in.	120	—	16.50	—	0.06	
Gypsum or plaster board 0.375 in.	50	—	3.10	—	0.32	0.26
Gypsum or plaster board 0.5 in.	50	—	2.22	—	0.45	
Gypsum or plaster board 0.625 in.	50	—	1.78	—	0.56	
Plywood (Douglas Fir)[d]	34	0.80	—	1.25	—	0.29
Plywood (Douglas Fir) 0.25 in.	34	—	3.20	—	0.31	
Plywood (Douglas Fir) 0.375 in.	34	—	2.13	—	0.47	
Plywood (Douglas Fir) 0.5 in.	34	—	1.60	—	0.62	
Plywood (Douglas Fir) 0.625 in.	34	—	1.29	—	0.77	
Plywood or wood panels 0.75 in.	34	—	1.07	—	0.93	0.29
Vegetable fiber board						
Sheathing, regular density[e] 0.5 in.	18	—	0.76	—	1.32	0.31
0.78125 in.	18	—	0.49	—	2.06	
Sheathing intermediate density[e] 0.5 in.	22	—	0.92	—	1.09	0.31
Nail-base sheathing[e] 0.5 in.	25	—	0.94	—	1.06	0.31
Shingle backer 0.375 in.	18	—	1.06	—	0.94	0.31
Shingle backer 0.3125 in.	18	—	1.28	—	0.78	
Sound deadening board 0.5 in.	15	—	0.74	—	1.35	0.30
Tile and lay-in panels, plain or acoustic	18	0.40	—	2.50	—	0.14
0.5 in.	18	—	0.80	—	1.25	
0.75 in.	18	—	0.53	—	1.89	
Laminated paperboard	30	0.50	—	2.00	—	0.33
Homogeneous board from repulped paper	30	0.50	—	2.00	—	0.28
Hardboard[e]						
Medium density	50	0.73	—	1.37	—	0.31
High density, service-tempered grade and service grade	55	0.82	—	1.22	—	0.32
High density, standard-tempered grade	63	1.00	—	1.00	—	0.32
Particleboard[e]						
Low density	37	0.71	—	1.41	—	0.31
Medium density	50	0.94	—	1.06	—	0.31
High density	62	.5	1.18	—	0.85	—
Underlayment 0.625 in.	40	—	1.22	—	0.82	0.29
Waferboard	37	0.63	—	1.59	—	—
Wood subfloor 0.75 in.	—	—	1.06	—	0.94	0.33
BUILDING MEMBRANE						
Vapor—permeable felt	—	—	16.70	—	0.06	
Vapor—seal, 2 layers of mopped 15-lb felt	—	—	8.35	—	0.12	
Vapor—seal, plastic film	—	—	—	—	Negl.	
FINISH FLOORING MATERIALS						
Carpet and fibrous pad	—	—	0.48	—	2.08	0.34
Carpet and rubber pad	—	—	0.81	—	1.23	0.33
Cork tile 0.125 in.	—	—	3.60	—	0.28	0.48
Terrazzo 1 in.	—	—	12.50	—	0.08	0.19
Tile—asphalt, linoleum, vinyl, rubber	—	—	20.00	—	0.05	0.30
vinyl asbestos						0.24
ceramic						0.19
Wood, hardwood finish 0.75 in.	—	—	1.47	—	0.68	
INSULATING MATERIALS						
Blanket and Batt[f,g]						
Mineral fiber, fibrous form processed from rock, slag, or glass						
approx. 3-4 in.	0.4-2.0	—	0.091	—	11	
approx. 3.5 in.	0.4-2.0	—	0.077	—	13	
approx. 3.5 in.	1.2-1.6	—	0.067	—	15	
approx. 5.5-6.5 in.	0.4-2.0	—	0.053	—	19	
approx. 5.5 in.	0.6-1.0	—	0.048	—	21	
approx. 6-7.5 in.	0.4-2.0	—	0.045	—	22	
approx. 8.25-10 in.	0.4-2.0	—	0.033	—	30	
approx. 10-13 in.	0.4-2.0	—	0.026	—	38	
Board and Slabs						
Cellular glass	8.0	0.33	—	3.03	—	0.18
Glass fiber, organic bonded	4.0-9.0	0.25	—	4.00	—	0.23
Expanded perlite, organic bonded	1.0	0.36	—	2.78	—	0.30
Expanded rubber (rigid)	4.5	0.22	—	4.55	—	0.40
Expanded polystyrene, extruded (smooth skin surface) (CFC-12 exp.)	1.8-3.5	0.20	—	5.00	—	0.29

Appendix A: Thermal Properties of Building and Insulating Materials (cont.)

Description	Density, lb/ft³	Conductivity[b] (k), Btu·in / h·ft²·°F	Conductance (C), Btu / h·ft²·°F	Resistance[c] (R) Per Inch Thickness (1/k), °F·ft²·h / Btu·in	Resistance[c] (R) For Thickness Listed (1/C), °F·ft²·h / Btu	Specific Heat, Btu / lb·°F
Expanded polystyrene, extruded (smooth skin surface) (HCFC-142b exp.)[h]	1.8-3.5	0.20	—	5.00	—	0.29
Expanded polystyrene, molded beads	1.0	0.26	—	3.85	—	—
	1.25	0.25	—	4.00	—	—
	1.5	0.24	—	4.17	—	—
	1.75	0.24	—	4.17	—	—
	2.0	0.23	—	4.35	—	—
Cellular polyurethane/polyisocyanurate[i,j] (CFC-11 exp.) (unfaced)	1.5	0.16-0.18	—	6.25-5.56	—	0.38
Cellular polyisocyanurate[i] (CFC-11 exp.) (gas-permeable facers)	1.5-2.5	0.16-0.18	—	6.25-5.56	—	0.22
Cellular polyisocyanurate[i] (CFC-11 exp.) (gas-impermeable facers)	2.0	0.14	—	7.04	—	0.22
Cellular phenolic (closed cell) (CFC-11, CFC-113 exp.)[k]	3.0	0.12	—	8.20	—	—
Cellular phenolic (open cell)	1.8-2.2	0.23	—	4.40	—	—
Mineral fiber with resin binder	15.0	0.29	—	3.45	—	0.17
Mineral fiberboard, wet felted						
Core or roof insulation	16-17	0.34	—	2.94	—	—
Acoustical tile	18.0	0.35	—	2.86	—	0.19
Acoustical tile	21.0	0.37	—	2.70	—	—
Mineral fiberboard, wet molded						
Acoustical tile[j]	23.0	0.42	—	2.38	—	0.14
Wood or cane fiberboard						
Acoustical tile[j] ... 0.5 in.	—	—	0.80	—	1.25	0.31
Acoustical tile[j] ... 0.75 in.	—	—	0.53	—	1.89	—
Interior finish (plank, tile)	15.0	0.35	—	2.86	—	0.32
Cement fiber slabs (shredded wood with Portland cement binder)	25-27.0	0.50-0.53		2.0-1.89	—	
Cement fiber slabs (shredded wood with magnesia oxysulfide binder)	22.0	0.57	—	1.75	—	0.31
Loose Fill						
Cellulosic insulation (milled paper or wood pulp)	2.3-3.2	0.27-0.32	—	3.70-3.13	—	0.33
Perlite, expanded	2.0-4.1	0.27-0.31	—	3.7-3.3	—	0.26
	4.1-7.4	0.31-0.36	—	3.3-2.8	—	—
	7.4-11.0	0.36-0.42	—	2.8-2.4	—	—
Mineral fiber (rock, slag, or glass)[g]						
approx. 3.75-5 in.	0.6-2.0	—	—	—	11.0	0.17
approx. 6.5-8.75 in.	0.6-2.0	—	—	—	19.0	—
approx. 7.5-10 in.	0.6-2.0	—	—	—	22.0	—
approx. 10.25-13.75 in.	0.6-2.0	—	—	—	30.0	—
Mineral fiber (rock, slag, or glass)[g]						
approx. 3.5 in. (closed sidewall application)	2.0-3.5	—	—	—	12.0-14.0	—
Vermiculite, exfoliated	7.0-8.2	0.47	—	2.13	—	0.32
	4.0-6.0	0.44	—	2.27	—	—
Spray Applied						
Polyurethane foam	1.5-2.5	0.16-0.18	—	6.25-5.56	—	—
Ureaformaldehyde foam	0.7-1.6	0.22-0.28	—	4.55-3.57	—	—
Cellulosic fiber	3.5-6.0	0.29-0.34	—	3.45-2.94	—	—
Glass fiber	3.5-4.5	0.26-0.27	—	3.85-3.70	—	—
Reflective Insulation						
Reflective material ($\varepsilon < 0.5$) in center of 3/4 in. cavity forms two 3/8 in. vertical air spaces[m]	—	—	0.31	—	3.2	—
METALS (See Chapter 36, Table 3)						
ROOFING						
Asbestos-cement shingles	120	—	4.76	—	0.21	0.24
Asphalt roll roofing	70	—	6.50	—	0.15	0.36
Asphalt shingles	70	—	2.27	—	0.44	0.30
Built-up roofing ... 0.375 in.	70	—	3.00	—	0.33	0.35
Slate ... 0.5 in.	—	—	20.00	—	0.05	0.30
Wood shingles, plain and plastic film faced	—	—	1.06	—	0.94	0.31
PLASTERING MATERIALS						
Cement plaster, sand aggregate	116	5.0	—	0.20	—	0.20
Sand aggregate ... 0.375 in.	—	—	13.3	—	0.08	0.20
Sand aggregate ... 0.75 in.	—	—	6.66	—	0.15	0.20

Appendix A: Thermal Properties of Building and Insulating Materials (cont.)

Description	Density, lb/ft³	Conductivity[b] (*k*), Btu·in / h·ft²·°F	Conductance (*C*), Btu / h·ft²·°F	Resistance[c] (*R*)		Specific Heat, Btu / lb·°F
				Per Inch Thickness (1/*k*), °F·ft²·h / Btu·in	For Thickness Listed (1/*C*), °F·ft²·h / Btu	
Gypsum plaster:						
Lightweight aggregate ..... 0.5 in.	45	—	3.12	—	0.32	—
Lightweight aggregate ..... 0.625 in.	45	—	2.67	—	0.39	—
Lightweight aggregate on metal lath ..... 0.75 in.	—	—	2.13	—	0.47	—
Perlite aggregate	45	1.5	—	0.67	—	0.32
Sand aggregate	105	5.6	—	0.18	—	0.20
Sand aggregate ..... 0.5 in.	105	—	11.10	—	0.09	—
Sand aggregate ..... 0.625 in.	105	—	9.10	—	0.11	—
Sand aggregate on metal lath ..... 0.75 in.	—	—	7.70	—	0.13	—
Vermiculite aggregate	45	1.7	—	0.59	—	—
MASONRY MATERIALS						
Masonry Units						
Brick, fired clay	150	8.4-10.2	—	0.12-0.10	—	—
	140	7.4-9.0	—	0.14-0.11	—	—
	130	6.4-7.8	—	0.16-0.12	—	—
	120	5.6-6.8	—	0.18-0.15	—	0.19
	110	4.9-5.9	—	0.20-0.17	—	—
	100	4.2-5.1	—	0.24-0.20	—	—
	90	3.6-4.3	—	0.28-0.24	—	—
	80	3.0-3.7	—	0.33-0.27	—	—
	70	2.5-3.1	—	0.40-0.33	—	—
Clay tile, hollow						
1 cell deep ..... 3 in.	—	—	1.25	—	0.80	0.21
1 cell deep ..... 4 in.	—	—	0.90	—	1.11	—
2 cells deep ..... 6 in.	—	—	0.66	—	1.52	—
2 cells deep ..... 8 in.	—	—	0.54	—	1.85	—
2 cells deep ..... 10 in.	—	—	0.45	—	2.22	—
3 cells deep ..... 12 in.	—	—	0.40	—	2.50	—
Concrete blocks[n, o]						
Limestone aggregate						
8 in., 36 lb, 138 lb/ft³ concrete, 2 cores	—	—	—	—	—	—
Same with perlite filled cores	—	—	0.48	—	2.1	—
12 in., 55 lb, 138 lb/ft³ concrete, 2 cores	—	—	—	—	—	—
Same with perlite filled cores	—	—	0.27	—	3.7	—
Normal weight aggregate (sand and gravel)						
8 in., 33-36 lb, 126-136 lb/ft³ concrete, 2 or 3 cores	—	—	0.90-1.03	—	1.11-0.97	0.22
Same with perlite filled cores	—	—	0.50	—	2.0	—
Same with vermiculite filled cores	—	—	0.52-0.73	—	1.92-1.37	—
12 in., 50 lb, 125 lb/ft³ concrete, 2 cores	—	—	0.81	—	1.23	0.22
Medium weight aggregate (combinations of normal weight and lightweight aggregate)						
8 in., 26-29 lb, 97-112 lb/ft³ concrete, 2 or 3 cores	—	—	0.58-0.78	—	1.71-1.28	—
Same with perlite filled cores	—	—	0.27-0.44	—	3.7-2.3	—
Same with vermiculite filled cores	—	—	0.30	—	3.3	—
Same with molded EPS (beads) filled cores	—	—	0.32	—	3.2	—
Same with molded EPS inserts in cores	—	—	0.37	—	2.7	—
Lightweight aggregate (expanded shale, clay, slate or slag, pumice)						
6 in., 16-17 lb 85-87 lb/ft³ concrete, 2 or 3 cores	—	—	0.52-0.61	—	1.93-1.65	—
Same with perlite filled cores	—	—	0.24	—	4.2	—
Same with vermiculite filled cores	—	—	0.33	—	3.0	—
8 in., 19-22 lb, 72-86 lb/ft³ concrete	—	—	0.32-0.54	—	3.2-1.90	0.21
Same with perlite filled cores	—	—	0.15-0.23	—	6.8-4.4	—
Same with vermiculite filled cores	—	—	0.19-0.26	—	5.3-3.9	—
Same with molded EPS (beads) filled cores	—	—	0.21	—	4.8	—
Same with UF foam filled cores	—	—	0.22	—	4.5	—
Same with molded EPS inserts in cores	—	—	0.29	—	3.5	—
12 in., 32-36 lb, 80-90 lb/ft³ concrete, 2 or 3 cores	—	—	0.38-0.44	—	2.6-2.3	—
Same with perlite filled cores	—	—	0.11-0.16	—	9.2-6.3	—
Same with vermiculite filled cores	—	—	0.17	—	5.8	—
Stone, lime, or sand	180	72	—	0.01	—	—
Quartzitic and sandstone	160	43	—	0.02	—	—
	140	24	—	0.04	—	—
	120	13	—	0.08	—	0.19
Calcitic, dolomitic, limestone, marble, and granite	180	30	—	0.03	—	—
	160	22	—	0.05	—	—
	140	16	—	0.06	—	—
	120	11	—	0.09	—	0.19
	100	8	—	0.13	—	—

Appendix A: Thermal Properties of Building and Insulating Materials (cont.)

Description	Density, lb/ft³	Conductivity[b] (*k*), Btu·in / h·ft²·°F	Conductance (*C*), Btu / h·ft²·°F	Resistance[c] (*R*) Per Inch Thickness (1/*k*), °F·ft²·h / Btu·in	Resistance[c] (*R*) For Thickness Listed (1/*C*), °F·ft²·h / Btu	Specific Heat, Btu / lb·°F
Gypsum partition tile						
3 by 12 by 30 in., solid	—	—	0.79	—	1.26	0.19
3 by 12 by 30 in., 4 cells	—	—	0.74	—	1.35	—
4 by 12 by 30 in., 3 cells	—	—	0.60	—	1.67	—
Concretes[o]						
Sand and gravel or stone aggregate concretes (concretes	150	10.0-20.0	—	0.10-0.05	—	—
with more than 50% quartz or quartzite sand have	140	9.0-18.0	—	0.11-0.06	—	0.19-0.24
conductivities in the higher end of the range)	130	7.0-13.0	—	0.14-0.08	—	—
Limestone concretes	140	11.1	—	0.09	—	—
	120	7.9	—	0.13	—	—
	100	5.5	—	0.18	—	—
Gypsum-fiber concrete (87.5% gypsum, 12.5% wood chips)	51	1.66	—	0.60	—	0.21
Cement/lime, mortar, and stucco	120	9.7	—	0.10	—	—
	100	6.7	—	0.15	—	—
	80	4.5	—	0.22	—	—
Lightweight aggregate concretes						
Expanded shale, clay, or slate; expanded slags;	120	6.4-9.1	—	0.16-0.11	—	—
cinders; pumice (with density up to 100 lb/ft³); and	100	4.7-6.2	—	0.21-0.16	—	0.20
scoria (sanded concretes have conductivities in the	80	3.3-4.1	—	0.30-0.24	—	0.20
higher end of the range)	60	2.1-2.5	—	0.48-0.40	—	—
	40	1.3	—	0.78	—	—
Perlite, vermiculite, and polystyrene beads	50	1.8-1.9	—	0.55-0.53	—	—
	40	1.4-1.5	—	0.71-0.67	—	0.15-0.23
	30	1.1	—	0.91	—	—
	20	0.8	—	1.25	—	—
Foam concretes	120	5.4	—	0.19	—	—
	100	4.1	—	0.24	—	—
	80	3.0	—	0.33	—	—
	70	2.5	—	0.40	—	—
Foam concretes and cellular concretes	60	2.1	—	0.48	—	—
	40	1.4	—	0.71	—	—
	20	0.8	—	1.25	—	—
SIDING MATERIALS (on flat surface)						
Shingles						
Asbestos-cement	120	—	4.75	—	0.21	—
Wood, 16 in., 7.5 exposure	—	—	1.15	—	0.87	0.31
Wood, double, 16-in., 12-in. exposure	—	—	0.84	—	1.19	0.28
Wood, plus ins. backer board, 0.312 in.	—	—	0.71	—	1.40	0.31
Siding						
Asbestos-cement, 0.25 in., lapped	—	—	4.76	—	0.21	0.24
Asphalt roll siding	—	—	6.50	—	0.15	0.35
Asphalt insulating siding (0.5 in. bed.)	—	—	0.69	—	1.46	0.35
Hardboard siding, 0.4375 in.	—	—	1.49	—	0.67	0.28
Wood, drop, 1 by 8 in.	—	—	1.27	—	0.79	0.28
Wood, bevel, 0.5 by 8 in., lapped	—	—	1.23	—	0.81	0.28
Wood, bevel, 0.75 by 10 in., lapped	—	—	0.95	—	1.05	0.28
Wood, plywood, 0.375 in., lapped	—	—	1.69	—	0.59	0.29
Aluminum, steel, or vinyl[p, q], over sheathing						
Hollow-backed	—	—	1.64	—	0.61	0.29[q]
Insulating-board backed nominal 0.375 in.	—	—	0.55	—	1.82	0.32
Insulating-board backed nominal 0.375 in., foil backed	—	—	0.34	—	2.96	—
Architectural (soda-lime float) glass	158	6.9	—	—	—	0.21
WOODS (12% moisture content)[e,r]						
Hardwoods						0.39[s]
Oak	41.2-46.8	1.12-1.25	—	0.89-0.80	—	
Birch	42.6-45.4	1.16-1.22	—	0.87-0.82	—	
Maple	39.8-44.0	1.09-1.19	—	0.92-0.84	—	
Ash	38.4-41.9	1.06-1.14	—	0.94-0.88	—	
Softwoods						0.39[s]
Southern Pine	35.6-41.2	1.00-1.12	—	1.00-0.89	—	
Douglas Fir-Larch	33.5-36.3	0.95-1.01	—	1.06-0.99	—	
Southern Cypress	31.4-32.1	0.90-0.92	—	1.11-1.09	—	
Hem-Fir, Spruce-Pine-Fir	24.5-31.4	0.74-0.90	—	1.35-1.11	—	
West Coast Woods, Cedars	21.7-31.4	0.68-0.90	—	1.48-1.11	—	
California Redwood	24.5-28.0	0.74-0.82	—	1.35-1.22	—	

Appendix B: Wall Types
Mass Located Inside Insulation

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

Appendix B: Wall Types
Mass Evenly Distributed

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
	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	*	*	*	*	*	*	*	*	*	*	*
Stucco and/or plaster	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	*	*	*	*	*	*	*	*	*	*	*
	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	*	*	*	*	*	*	*	*	*	*	*
Steel or other light-weight siding	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	*	*	*	*	*	*	*	*	*	*	*
	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
Face brick	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

Appendix B: Wall Types
Mass Located Outside Insulation

Secondary Material	R-Factor ft²·°F/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.

Appendix C: July CLTD for Calculating Cooling Load

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

Appendix C: July CLTD for Calculating Cooling Load (cont.)

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

Appendix C: July CLTD for Calculating Cooling Load (cont.)

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
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·ft²·°F)/Btu
- Inside surface resistance of 0.685 (h·ft²·°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

Skill Development Exercises

Contents

Instructions

After reading each chapter, answer all of the questions pertaining to that chapter on the following worksheets. Be sure to include your name and address.

Skill Development Exercises for Chapter 1

Name ____

Company/Department ______________________________________

Address ____

City ________________________ State ______ Zip ________

Telephone _____________________ Fax ____________________

E-mail Address ______________________________________

Student Number ______________________________________

1-01. Explain the type of heat transfer in each of the following situations: a gas water heater; the wall of an oven; a whistling teakettle; a light bulb; a hair dryer; a sealed thermos bottle; and an electric baseboard heater.

1-01. (cont.)

1-02. If fiberglass insulation has a thermal conductivity of 0.33 (Btu·in/h·ft^2·°F), find the R-value of a 5.5-in.-thick batt.

1-03. A building has a roof with continuous rigid insulation rated at R-26. Neglecting air films and the roof structure, what is the approximate U-factor of this roof?

1-04. A water heater measures 24 in. in diameter and 48 in. high. The outside wall is covered with fiberglass insulation rated at R-3. The shell of the water heater is 130°F and the outside is 75°F. Find the rate of heat loss through the wall of the unit.

1-05. Some people argue that night setback thermostats are worthless, because the furnace has to run so long in the morning to make up the difference in temperature for the space. With your knowledge of heat capacitance and heat conduction as a function of temperature, how would you answer that argument?

Skill Development Exercises for Chapter 2

Name ______________________________

Company/Department ______________________________

Address ______________________________

City ______________________ State ______ Zip ________

Telephone ____________________ Fax ____________________

E-mail Address ______________________________

Student Number ______________________________

2-01. Calculate the heat loss from the bedroom of the example cabin.

2-02. Decrease the outside temperature to -5°F, and repeat the calculation for both rooms of the cabin.

2-03. If the door was moved to the east wall, explain if and how the rate of heat loss from the cabin would be affected.

2-04. If the building was rotated on its axis, or mirrored end-to-end, explain if and how the rate of heat loss from the cabin would be affected.

2-05. If you wanted to reduce the rate of heat loss from the cabin, explain what changes you might make.

2-06. Suppose a 20,000 Btu/h heating system is installed in the front room of the cabin with a 4,800 Btu/h design heating load. The total mass of the cabin and its contents is 5,000 lb, with an average specific heat of 0.25 Btu/lb·°F. How long would it take to raise the cabin temperature by 10°F under design conditions? How long would it take to raise this temperature if the outdoor temperature is 32°F?

2-07. Given the mass and specific heat of the cabin and its contents in *Exercise 2-06*, how large must the heating system capacity be (in Btu/h) to raise the temperature of the space from 65°F to 70°F in 20 minutes. Remember that your heating system must also provide the heat losses that occur during that time period.

Skill Development Exercises for Chapter 3

Name ____

Company/Department ______________________________________

Address ____

City ______________________________ State _____ Zip ________

Telephone ______________________ Fax ______________________

E-mail Address ______________________________________

Student Number ______________________________________

3-01. Assume you are working for a mobile home manufacturer that ships to all of the states shown in *Figure 3-2*. In which state would you expect the highest heating load? The highest cooling load? Explain which data columns you used to make your selection.

3-02. In Massachusetts, Boston and Worcester are only 25 miles apart. How would you explain the large difference in their winter design temperatures?

3-03. In Michigan, Grand Rapids and Muskegon are only 30 miles apart. How would you explain the difference in their summer design temperatures?

3-04. Discuss how the wind speed at a typical single-family house with trees and other vegetation around it might compare with the recorded wind speeds. How would the local terrain (hills and valleys) affect the actual wind speed at a site? How would the recorded wind speed compare to the actual wind speed at the top floor of the tallest office building in town?

Skill Development Exercises for Chapter 4

Name ______________________________

Company/Department ______________________________

Address ______________________________

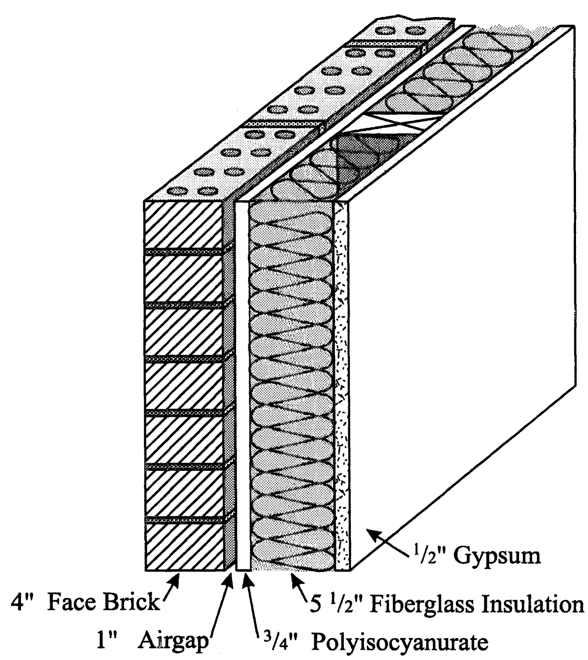
City ______________________ State _____ Zip _________

Telephone ______________________ Fax ______________________

E-mail Address ______________________________

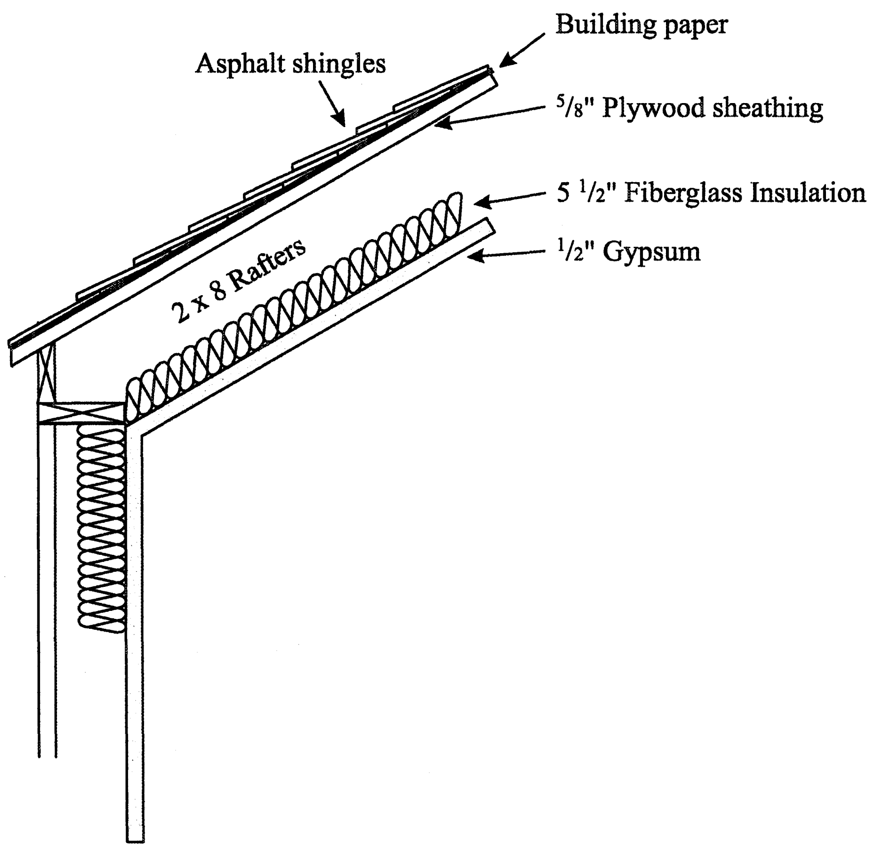
Student Number ______________________________

4-01. The sample wall section shown below consists of 2×6 wood studs on 24 in. centers with R-19 insulation. Assuming 10% of the wall area is framing, calculate the effective U-factor.



4-01. (cont.)

4-02. For the roof detail section shown below, calculate the effective net U-factor, assuming a 20% framing factor.



4-03. Closing the drapes on a single-pane window effectively adds a 4 in. dead air space (assuming a perfect seal). If the emissivities of the drapery material and glass surface are 0.9 and 0.8 respectively, determine the difference in the rate of heat loss through a 5×9 ft single-pane window with the drapes open and closed. Assume negligible R-value for the glazing material itself, and a temperature difference of 60°F.

4-04. Explain why the air film coefficient (h_i) for horizontal surfaces is higher for upward heat flows than for downward heat flows.

Skill Development Exercises for Chapter 5

Name ______________________________

Company/Department ______________________________

Address ______________________________

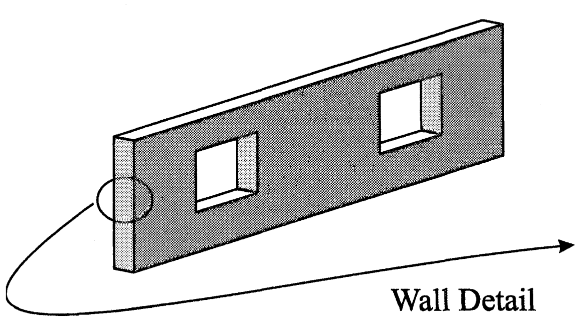
City ______________________ State ______ Zip ________

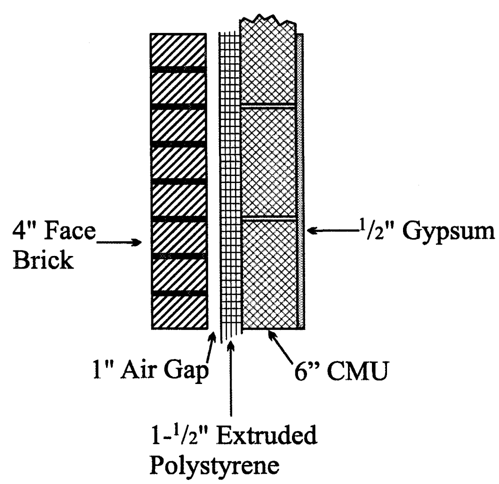
Telephone ______________________ Fax ______________________

E-mail Address ______________________________

Student Number ______________________________

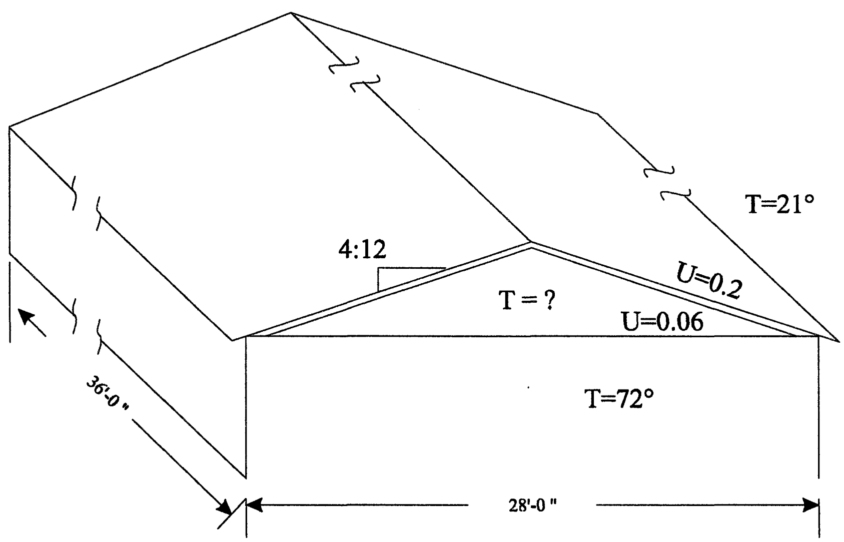
5-01. Calculate the heat loss through the 24×8 ft wall section shown below (less the two 30×42 in. windows rated at U=0.6 Btu/h·ft^2·°F each) when the inside temperature is 72°F and the outside design temperature is 21°F.





5-01. (cont.)

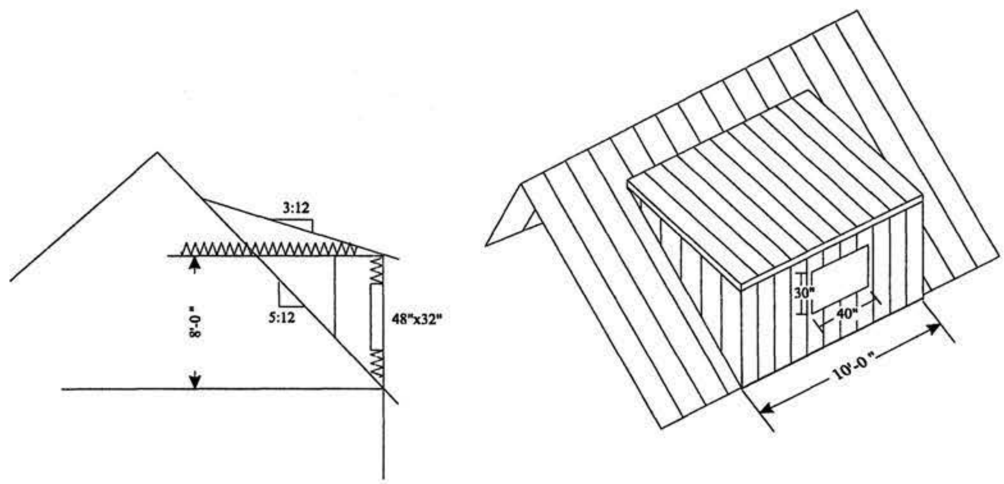
5-02. Determine the temperature in the 36×28 ft unheated attic shown below when the inside temperature is 72°F and the outside design temperature is 21°F. The attic floor and roof have effective U-factors of 0.06 Btu/h·ft²·°F and 0.2 Btu/h·ft²·°F respectively, and the roof pitch is 4:12. Assume 1.0 ACH through the attic.



5-03. Determine the heat loss through a 26×38 ft slab-on-grade floor with R-5.4 h·ft²·°F/Btu in a cold climate. Assume a design temperature difference of 75°F.

5-04. Determine the rate of heat loss through the floor area in *Exercise 5-03* if it is located above an unvented crawlspace and the 24 in. of exposed wall is insulated down to 3 ft below grade with R-5.4 h·ft^2·°F/Btu. Assume outside design temperature is -10°F.

5-05. Determine the rate of heat loss from the dormer shown below when the inside and outside temperatures are 74°F and 37°F, respectively. The 30×40 in. thermopane window is rated at U=0.6 Btu/h·ft²·°F. The effective U-factors for the dormer walls and ceiling are 0.07 and 0.05 Btu/h·ft²·°F, respectively.



Skill Development Exercises for Chapter 6

Name ____

Company/Department ____

Address ____

City ____________________ State _____ Zip __________

Telephone ____________________ Fax ____________________

E-mail Address ____

Student Number ____

6-01. For the example house discussed in Chapter 5, determine the total infiltration rate (in ft^3/h) using the air change method, assuming 0.5 ACH for each room.

6-02. For the same house in Baltimore, MD, determine the total rate infiltration (in ft^3/h) using the effective leakage area method. Include five double-hung windows (with weatherstripping) with caulked wood framing, both doors (weatherstripped in caulked wood framing), 20 electrical outlets, gas water heater and dryer, kitchen and bathroom vents with dampers, and appropriate crawlspace (no ductwork) and caulked joint details. Discuss the difference between the calculated values from using both methods.

6-02. (cont.)

6-02. (cont.)

6-03. Convert both of the above air flow estimates to energy flows if the inside and outside temperatures are 75°F and 15°F, respectively.

6-04. Estimate the forced ventilation required in a 100-seat restaurant. If the grill and restroom exhaust fans remove 1,400 cfm and 400 cfm respectively, how much outside air must be brought into the building?

Skill Development Exercises for Chapter 7

Name ____

Company/Department ________________________________

Address ____

City ________________________ State _____ Zip ________

Telephone __________________ Fax ____________________

E-mail Address ____________________________________

Student Number ____________________________________

7-01. Name several differences between cooling load calculations and heating load calculations.

7-02. Describe the four basic building heat flows used in cooling load calculations.

7-03. List six initial design considerations and explain how each can affect a cooling load calculation.

7-04. Describe three different methods used to calculate cooling loads and give the advantages and disadvantages of each.

Skill Development Exercises for Chapter 8

Name ____

Company/Department ______________________________________

Address ____

City ___________________________ State ______ Zip _________

Telephone ____________________ Fax ______________________

E-mail Address ______________________________________

Student Number ______________________________________

8-01. A building in Baltimore, Maryland with identical dimensions to Figure 8.2, Sample Building, has a different roofing detail and is rotated 90° counterclockwise (north becomes west). The new roof cross-section is a membrane roof on 2 in. of R-5.4 $h \cdot ft^2 \cdot °F/Btu$ per in. insulation, a steel deck, and 3.5 in. of fiberglass batts between the joists and without a suspended ceiling. Determine the appropriate roof number and heat gain through the roof at noon in July.

8-01. (cont.)

8-02. The rotated building in Baltimore, MD, used in *Exercise 8-01* also has a different wall detail, although the dimensions remain the same. The new wall cross-section includes (from the inside): 0.5 in. gypsum, 3.5 in. fiberglass between metal studs, 4 in. heavyweight concrete block, 1 in. air space, and 4 in. face brick. Determine the appropriate wall type and heat gain through the walls in July at noon.

Skill Development Exercises for Chapter 9

Name ______________________________

Company/Department ______________________________

Address ______________________________

City ______________________________ State ______ Zip ________

Telephone ______________________ Fax ______________________

E-mail Address ______________________________

Student Number ______________________________

9-01. For a fixed window in a vinyl frame with double glazing, 0.5 in. air space, and two 0.25 in. panes of glass, determine the total window SHGC and VT for: bronze glass, low-e of 0.2 on surface 3; and high performance green, low-e of 0.2 on surface 3. Discuss which is better for reducing solar gain, and which is better for daylighting.

9-01. (cont.)

9-02. Determine the solar cooling load at 10:00 am EDT in July through a southeast-facing retail store window (clear double 0.25 in. pane and 0.5 in. air space with fixed aluminum frame) that is 12 ft tall and 40 ft wide and has a continuous 6 ft overhang for weather protection located 12 in. above the window. Local latitude is 40°N.

9-03. If the overhang in *Exercise 9-02* was increased to 10 ft wide, explain how the solar heat gain would be affected throughout the day in July and again in January. Show your calculations.

9-04. For a one-story carpeted office with gypsum walls and vertical blinds, determine the solar cooling load and conduction heat gain through a 10 ft wide by 6 ft high window (clear double 0.25 in. pane and 0.5 in. air space with low-e of 0.1 on surface 3) in July at 9 am, noon and 3 pm. The window faces south-southeast.

Skill Development Exercises for Chapter 10

Name ______________________________

Company/Department ______________________________

Address ______________________________

City ______________________ State ______ Zip ________

Telephone ______________________ Fax ______________________

E-mail Address ______________________________

Student Number ______________________________

10-01. A high school computer classroom includes 15 workstations for 30 students plus two printers and an overhead projector in the 40×30 ft room. The interior room is carpeted and has concrete block walls. Classes begin at 8:00 am and end at 3:00 pm. This room is in use about 75% of each school day (three 40-minute classes, then a 40-minute break). The normal lighting usage is 1500 W of indirect fluorescent bulbs. Find the heat gain for each of these three sources (lights, people and equipment) at noon, 2:00 pm and 4:00 pm.

10-01. (cont.)

10-01. (cont.)

10-02. For the 30 students in the classroom for *Exercise 10-01*, determine the rate of latent energy produced at noon.

10-03. The cafeteria on one floor of an office building opens at 7:30 am, closes at 5:30 pm, and has an hourly occupation rate as shown in the table below. The hot food (from opening until 9:00 am and between the hours of 11:00 am and 1:00 pm) is served mainly from a 3×15 ft unhooded food warmer. Estimate the sensible and latent heat gain from both sources at 10:00 am, noon and 2:00 pm.

Average Cafeteria Hourly Occupancy Counts

Hour	8	9	10	11	12	1	2	3	4	5
People	18	8	8	44	80	62	24	14	9	8

10-04. A retail shop owner is considering replacing the shop's present fluorescent fixtures (60 bulbs at 40 W each with magnetic ballast) with either new T-8 lamps (with electronic ballast) or 5000 W of incandescent bulbs to highlight the products. The shop is open from 9:00 am until 9:00 pm, seven days per week. Determine the sensible heat gain at 10:00 am, 3:00 pm and 8:00 pm for all three scenarios. Use this data to discuss briefly how each might affect the cooling load on the space, and make a recommendation to the owner from a thermal systems design perspective.

Skill Development Exercises for Chapter 11

Name ______________________________

Company/Department ______________________________

Address ______________________________

City ______________________ State ______ Zip ________

Telephone ______________________ Fax ______________________

E-mail Address ______________________________

Student Number ______________________________

11-01. Calculate the thermal loads at 6:00 pm EDT in July if the building orientation is rotated 90° clockwise (north becomes east).

11-01. (cont.)

11-02. Calculate the thermal loads of the original design at noon in July.

11-02. (cont.)

11-03. Calculate the thermal loads of the original at 6:00 pm EDT (= 1700 EST) in July if the restaurant is located in Detroit, MI.

11-03. (cont.)

Skill Development Exercises for Chapter 12

Name ______________________________

Company/Department ______________________________

Address ______________________________

City ______________________________ State ______ Zip __________

Telephone ______________________ Fax ______________________

E-mail Address ______________________________

Student Number ______________________________

12-01. *Example 12-3* discussed a south-facing wall section. For the same wall facing north, use TFM to determine the rate of heat transfer for the first 24-hour period.

12-01. (cont.)

12-02. For the office building discussed in *Example 12-4*, use RTF to determine the cooling load due to solar gain for the first 24-hour period with the following changed conditions: the date is August 21 and the window orientation is southwest.

12-03. Compare the values that you calculated in *Exercise 12-02* with the results determined in *Example 12-4* for the same time period. Explain what factors cause the differences between the values at these hours: 0600, 0900, 1200, 1500, 1800 and 2100.

ASHRAE LEARNING INSTITUTE
Self-Directed Learning Course Evaluation Form

Course Title: *Fundamentals of Heating and Cooling Loads, I-P Edition (2000)*

On a scale of 1 to 5, circle the number that corresponds to your feeling about the statements below.
(1 = strongly agree, 5 = strongly disagree, 3 = undecided)

Course Content	**Strongly Agree**		**Undecided**		**Strongly Disagree**
1. The objectives of the course were clearly stated.	1	2	3	4	5
2. The course content supported the stated objectives.	1	2	3	4	5
3. The content quality and format of the course material make it valuable as a future reference.	1	2	3	4	5
4. The quality and clarity of the charts and diagrams enhanced your ability to understand the course concepts.	1	2	3	4	5
5. The organization of course material supported effective mastery of the topic.	1	2	3	4	5
6. The material presented will be of practical use to you in your work.	1	2	3	4	5
7. The degree of difficulty (level) of this course was correct to meet your needs and expectations.	1	2	3	4	5

General

1. Which description best characterizes your primary job function?

_____Architect* _____Developer _____Manufacturer _____Sales
_____Code Agency _____Educator/Research _____Marketing _____Specifier
_____Consultant _____Energy Conservation _____Owner _____Student
_____Contractor/Installer _____Facilities Engineer _____Plant Engineer _____Utilities
_____Consumer/User _____Government _____Policy Maker/Regulator

_____Other (please specify) ____

*Are you a registered architect? ___No ___Yes, AIA Membership Number (required): ____________________

2. Which describes your educational background?

_____High School
_____Associates Degree/Certificate Program
_____Bachelor's Degree—Engineering Technology
_____Bachelor's Degree—Engineering
_____Bachelor's Degree—Other Than Engineering
_____Master's Degree—Engineering
_____Master's Degree—Other Than Engineering
_____Doctoral Degree—Engineering
_____Doctoral Degree—Other Than Engineering
_____Other (please specify) ____

3. Approximately how many hours did it take you to complete this course?

_____10 hours _____20 hours _____30 hours _____40 hours _____Other (please specify)___________

4. What topics would you suggest for future courses? ____

____

General Comments regarding any aspect of the course, including suggestions for improvement:

Name (optional) ______________________________

Phone (optional) ______________________________

E-mail (optional) ______________________________

Return to: ASHRAE, Education Department, 1791 Tullie Circle NE, Atlanta, GA 30329
Fax: 404-321-5478

1791 Tullie Circle
Atlanta, GA 30329-2305
Telephone: 404/636-8400
Fax: 404/321-5478
E-mail: edu@ashrae.org
www.ashrae.org/ali

Product Code: 98045 11/15 ISBN 978-1-931862-30-1
Errata noted in the list dated 2/14/12 have been corrected.