DOCUMENT RESUME

ED 193 043   SE 032 942

TITLE	Providing for Energy Efficiency in Homes and Small Buildings, Part II.
INSTITUTION	American Association for Vocational Instructional Materials, Athens, Ga.
SPONS AGENCY	Department of Energy, Washington, D.C. Office of Consumer Affairs.
REPORT NO	DOE/IR/06065-1 Pt. 2
PUB DATE	Jun 80
CONTRACT	EX-77-R-01-6065
NOTE	76p.: For related documents, see SE 032 941-945. Contains occasional marginal legibility in Tables.
AVAILABLE FROM	DOE Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830 (free).
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	Buildings: *Energy: *Energy Conservation: Heating: Independent Study: *Instructional Materials: *Science Education: Secondary Education: Units of Study: *Vocational Education

ABSTRACT

Presented is part two of a training program designed to educate students and individuals in the importance of conserving energy and to provide for developing skills needed in the application of energy-saving techniques that result in energy efficient buildings. Alternatives are provided in this program to allow for specific instruction in energy-saving methods and procedures, or for integration with construction courses. It may also be used for self-paced instruction. The materials are divided into three parts: (1) Understanding and practicing energy conservation: (2) Determining amount of energy lost or gained in a building: and (3) Determining which practices are more efficient and installing materials. Major topics presented in part two include terms used to measure energy in buildings, heat losses and gains in buildings, estimating heat loads and cooling loads in buildings, and determining cost benefits of using energy-saving procedures. (Author/DS)

Prepared for the U.S. Department of Energy DOE/IR/06065-1 Pt. 2

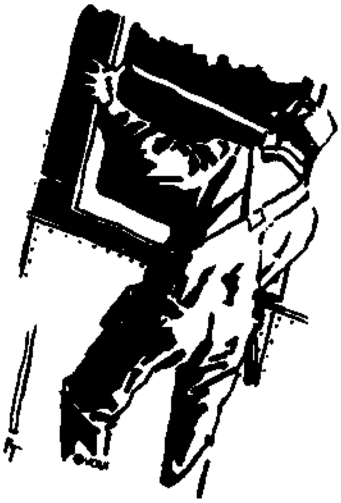
Office of Consumer Affairs
Education Division
Washington, D.C. 20585

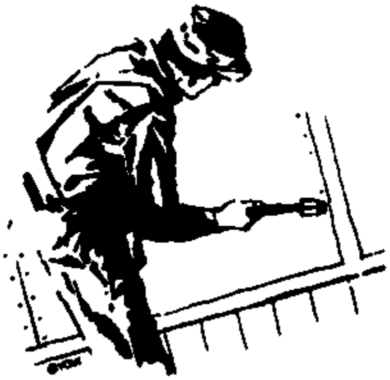
Providing for Energy Efficiency in Homes and Small Buildings

Part II

June 1980

Prepared by:
American Association for
Vocational Instructional Materials
Under Contract No. EX-77-R-01-6065





PROVIDING FOR ENERGY EFFICIENCY IN HOMES AND SMALL BUILDINGS

This instructional program was developed for the Department of Energy under Contract No. EX-77-R-01-6065 by the American Association for Vocational Instructional Materials.

W. Harold Parady, Ed.D., Program Manager, Executive Director, AAVIM.
J. Howard Turner, Principal Investigator, Editor and Coordinator, AAVIM.

Initial manuscripts were prepared by the following persons:

Part One: Sections I, III, IV and V; Part Three, Section I:

Dennis E. Darling, Ph.D., Energy Consultant, Education Systems, and Professor, Western Michigan University, Kalamazoo, Michigan.

Part One: Section II:

James G. Fausett, Professor of Architecture, Southern Technical Institute, Marietta, Georgia.

Part Two:

Harvey B. Manbeck, Ph.D., Professor, P.E., Structures and Environment, Agricultural Engineering Department, University of Georgia, Athens, Georgia.

Part Three: Sections II and III:

Walter Schwersinske, Professor, Building Construction, Industrial Education Department, Western Michigan University, Kalamazoo, Michigan.

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Acknowledgments

Albright, Ben, N. C. Department of Education.

Bear, Forrest, Agriculture Engineering, University of Minnesota.

Burks, Esther Lee, Research Engineer, Engineering Experiment Station, Georgia Institute of Technology.

Carey, John W., Director of Information, NAHB.

Clark, Frank, Professor, College of Architecture, Georgia Institute of Technology.

Cox, Ben, Engineer, Georgia Cooperative Extension Service.

Davis, Harry F., Asst. Director, Vocational, Trade & Industrial Education, Ohio.

Doggette, John R., Research Assoc., Oak Ridge Associate Universities.

Donald, Ross M., Lead Instructor, The Energy Conservation Company, Boston, Massachusetts.

Duggan, Donald D., Chief, Academic Program Branch, USDOE.

Espenschied, R. F., Professor, Agricultural Engineering, University of Illinois.

Foley, Tom, Manpower Skills Training Center, Union City, CA.

Goodwin, S. E., Structural Engineer, Portland Cement Association.

Gordon, Fred L., Super., Ind. Occupations P.S.

Gourley, Frank, Dept. of Community Colleges, North Carolina.

Howard, Cecil W., Extension Engineer, University of Georgia.

Hoerner, Thomas A., Prof., Agricultural Engineering, Iowa State University.

Hudson, Bill, Independent Living, Inc., Atlanta, Georgia.

Isakson, Hans, Prof., Real Estate, University of Georgia.

Johnson, Ralph J., President, NAHB, Research Foundations.

Jordan, Russell W., Assistant to President, Columbus Technical Institute, Columbus, OH.

Law, S. Edward, Professor, Agricultural Engineering, University of Georgia.

Lundy, Victor V., State Consultant, Career Education Division, Iowa.

Monachello, Frank, New Jersey Department of Energy.

Mosser, Don, Portland Cement Association.

Murphy, John A., Pataskala, OH.

Patterson, Robert S., Director, Vocational Industrial Education, Texas Education Agency.

Payne, Tom, Plumbers and Steam Filters Union, Atlanta, GA.

Pearce, John K., Solar Energy Education Dept., N.E. Solar Energy Center, Northern Energy Corporation, MA.

Rust, Jim, Professor, School of Nuclear Engineering, Georgia Institute of Technology.

Rusuda, Tanani, National Bureau of Standards.

Salini, Don, Georgia Power Company.

Sanerji, Rangit, College of Architecture, University of Houston.

Schramm, Don, Program Coordinator, Dept. of Engineering and Extension, Wisconsin.

Shivar, James F., Buildings and Community Systems, USDOE.

Silva, Anthony L., Johns-Manville Insulation Center.

Slyter, Damon E., Education Program Specialist, Kansas.

Tart, C. V., Chief Consultant, Agricultural Education, North Carolina.

Van Gulik, Richard, Vocational Industrial Education, New Jersey.

Weber, Neil V., Academic Coordinator, Indiana University at South Bend.

Williams, Earl, State Supervisor, Trade and Industrial Education, Georgia.

Williams, Richard, Assistant Dean, School of Engineering, Georgia Institute of Technology.

Winsett, Ivan L., Executive Director, Georgia Electrification Council.

Wrabel, Mary-Lynn, Program Manager, Buildings & Community Systems, USDOE.

Field-Test Sites and Teachers

COMPREHENSIVE HIGH SCHOOLS:

Richard Buchanan
Career Center
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Garrard County Area Voc.-Ed. Center
Lancaster, KY

Ron Farrier
S. E. Career Center
Columbus, OH

Jim Maddox
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Blue Earth, MN

Hans Dellith
West Milford High School
West Milford, NJ

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Hopkinsville, KY

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Bunn High School
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Anonka, MN

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Xenia, OH

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N. Kentucky State Vo-Tech
Covington, KY

Leo Plewa
Duluth A.V.T.I.
Duluth, MN

Tom Runnels
Moore-Norman Area Vo-Tech
Norman, OK

Cyril C. Stephens
Skyline Career Dev. Ctr.
Dallas, TX

Leroy Wilhelm
Western Oklahoma Area Vo-Tech
Burns Flat, OK

Richard Olszewski
Mercer Co. Vocational School
Trenton, NJ

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Mason City, IA

Leon Fox
Southeast Community College
Whiteville, NC

Russell R. Clark
Tacoma Community College
Tacoma, WA

John C. Comer
Northern Illinois University
DeKalb, IL

Frank Rubino
Middlesex County College
Edison, NJ

Joe Dollar
Albany Area Vo-Tech
Albany, GA

Earl Gibson
University of Wisconsin
River Falls, WI

Jerry Prescott
Craven Community College
New Bern, NC

Carl Squires
Central Piedmont Community College
Charlotte, NC

George Cox
Kalamazoo Valley Community College
Kalamazoo, MI

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Preface

This is a training program designed to educate students and individuals in the importance of conserving energy and to provide for developing skills needed in the application of energy-saving techniques that result in energy efficient buildings.

Upon successful completion of this course of instruction, a student will be able to perform at the job entry level.

Alternatives are provided in this program to allow for specific instruction in energy-saving methods and procedures, or for integration with construction courses. It may also be used for self-paced instruction.

When used in the classroom, the unit can be integrated with the buildin construction curriculum or it can be taught separately.

A teacher guide and student workbook are available to supplement the basic manuals. The resource person should consult the teacher guide and follow procedures given therein.

The material is provided in three parts:

PART ONE: UNDERSTANDING AND PRACTICING ENERGY CONSERVATION IN BUILDINGS.

PART TWO: DETERMINING AMOUNT OF ENERGY LOST OR GAINED IN A BUILDING.

PART THREE: DETERMINING WHICH PRACTICES ARE MOST EFFICIENT AND INSTALLING MATERIALS.

For Part Two, it is recommended that the students have access to the cooling and heating load calculation manual (GRP 158) ASHRAE, 1979. It is available from ASHRAE, 345 East 47th Street, New York, NY 10017.

Part 2

Determining Amount of Energy Lost or Gained in a Building

In Part One, the discussion was of a general nature and general examples were given. But if you are to provide for energy efficiency in a specific building you must be able to find the predicted heat loss or gain and to evaluate the cost benefits. This service is provided by the Energy Extension Service for the general public. But as an energy technician you should be able to calculate these values.

In order to do this, you must be familiar with terms used in measuring energy in buildings and have access to data that give heat flow through various building materials.

Heat energy will always flow from an area of high temperature to an area of low temperature. Thus, depending upon the outdoor temperature, heat will flow into or out of a building seeking equilibrium.

The primary places for heat flow into and out of buildings are as follows:

- Conduction through the walls, ceilings and floors.
- Conduction through the doors and windows.
- Infiltration of outside air into the living area through cracks in window frames, walls and door frames, and other openings.
- Introduction of outside air through the ventilation system.
- Radiation of solar energy through glass areas.
- Radiation heat loads on exterior walls and roof areas.
- Heat generated by occupants, lights and mechanical appliances.

Heat can flow into or out of a home in any or all of these modes at the same time.

The objectives of this section are as follows:

- To identify and define the primary modes of heat flow into and out of a building.
- To identify and define the factors which influence the heat flow into and out of a building.
- To evaluate the quantity of heat flow through typical structural components, such as floors, windows, walls, ceilings, and doors, by each of the heat flow modes.
- To estimate the quantity of heat lost or gained by a typical building.
- To evaluate the cost benefits of energy-saving practices.

Procedures are given under the following headings:

A. Terms Used to Measure Energy in Buildings.
B. Understanding Heat Losses and Gains in Buildings.
C. Estimating Heating Loads in Buildings.
D. Special Applications for Estimating Cooling Loads in Buildings.
E. Estimating Cooling Loads in Buildings.
F. Determining Cost Benefits of Using Energy-Saving Practices.

A. Terms Used to Measure Energy in Buildings

There are several terms used in measuring energy in buildings. Most of them are familiar. From your study of this section, you will be able to list and define these terms. They are described as follows:

1. Terms for Measuring Heat Flow.
2. Terms for Measuring Heat Conductivity.
3. Other Terms.

1. TERMS FOR MEASURING HEAT FLOW

Terms for measuring and calculating heat flow are as follows:

a. Unit of Heat (Btu).
b. Rate of Heat Flow (Btu/hr) or (q).
c. Heat Flow by Conduction (q_c).
d. Heat Flow by Infiltration (q_i).
e. Heat Flow by Radiation (q_{cr}).

a. Unit of Heat (Btu)

The British Thermal Unit (Btu) is the unseen quantity of heat that seeks an equilibrium of temperature between two temperature differences. By definition, it is the amount of heat energy required to raise the temperature of one pound of water one degree F (Figure 1). The Btu is the term for measuring heat.

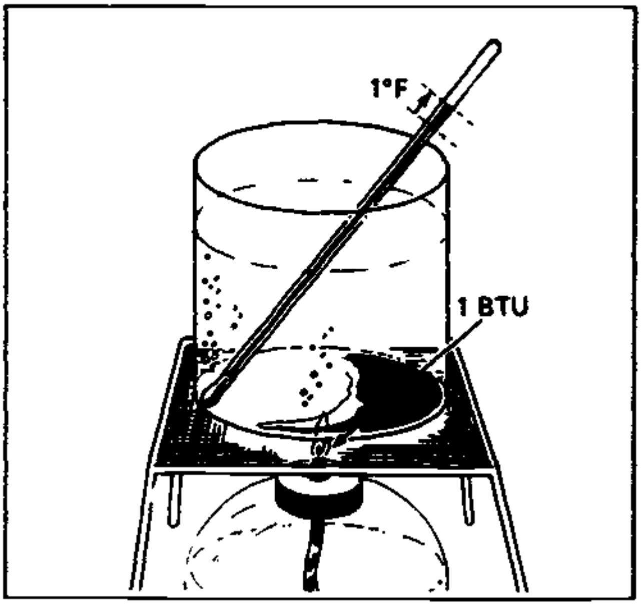


FIGURE 1. A Btu is the amount of heat energy required to raise the temperature of one pound of water one degree F.

For example, note the following equivalents:

1 Btu = 1 wood match
3,413 Btu = 1 kilowatt hour
1,000 Btu = 1 cu. ft. natural gas
140,000 Btu = 1 gal. fuel oil
13,000 Btu = 1 lb. coal

b. Rate of Heat Flow (Btu/hr) or (q)

Heat flow (q) is the movement of thermal energy from a point of high temperature to a point of lower temperature. It is measured in Btu/hour.

c. Heat Flow by Conduction (q_c).

Conduction (q_c) is the flow of heat energy through solid materials by means of molecular vibration. It is measured in Btu/hr.

d. Heat Flow by Infiltration (q_i).

Infiltration heat loss (q_i) is the heat lost by a building through infiltration air exchange. This is usually through cracks and crevices and opening of doors and windows. This is measured in Btu/hr.

e. Heat Flow by Radiation (q_r).

Radiation is usually the effect of sunlight on a building. It is the flow of heat energy from a warm body to a cooler body by means of electromagnetic energy.

Solar radiation is measured in Langleys or Btu. One Langley is equal to 3.687 Btu per square foot per day.

Solar radiation varies with latitude, seasons and weather. For example, a cloud cover will reduce the amount of solar radiation.

2. TERMS FOR MEASURING HEAT CONDUCTIVITY

How much heat a material will allow to transfer is measured in several terms:

a. Thermal Conductivity (k-Value).
b. Thermal Conductance (C-Value).
c. Coefficient of Heat Transfer (U-Value).
d. Thermal Resistance (R-Value).

a. Thermal Conductivity (k-Value)

Thermal conductivity is a scientific measurement of the rate of heat flow through a given substance. It is determined in a laboratory. It is the amount of heat in Btu/hr that will flow through a substance that is 1 foot square, 1 inch thick when there is a temperature difference of 1° between sides (Figure 2).

The thermal conductance (C) varies with thickness of the material.

The lower the k-Value, the higher the insulation value. This value is not used for building materials because it is limited to 1" thickness and will vary at different temperatures.

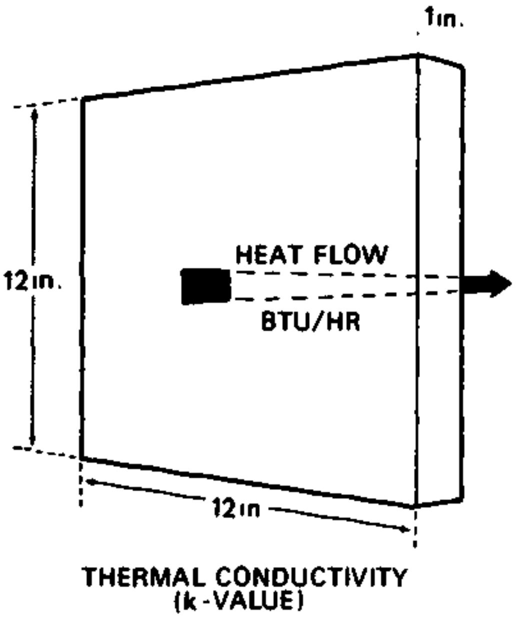


FIGURE 2. The thermal conductivity of a substance is the amount of heat that will transfer through 1 square foot, 1 inch thick when there is a temperature difference of 1°F.

b. Thermal Conductance (C-Value)

The thermal conductance of a material is similar to k-Value, but it may be based on a specified thickness rather than 1 inch (Figure 3). Therefore, C-Value is the amount of heat in Btu/hr that will flow through a material that is 1 foot square, and any specified thickness for each degree F difference in temperature. Neither is it necessary for the material to be homogeneous or solid.

The lower the C-Value, the better the insulation.

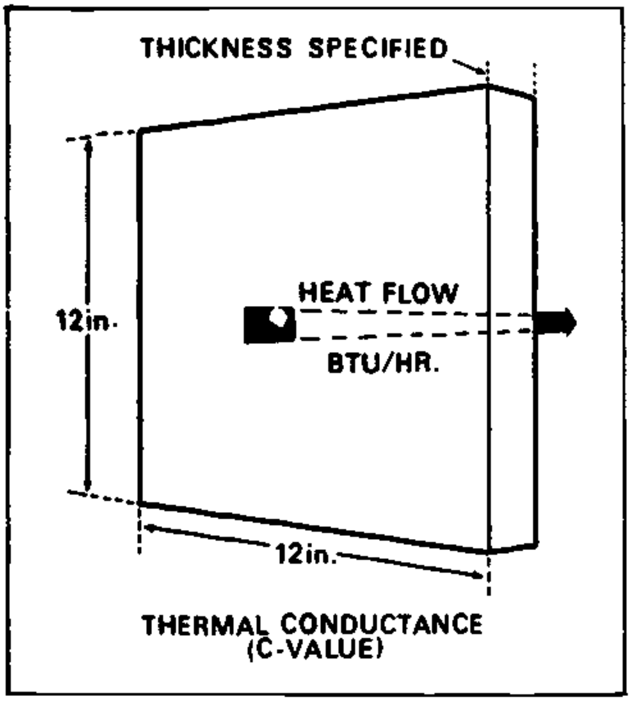


FIGURE 3. Thermal conductance.

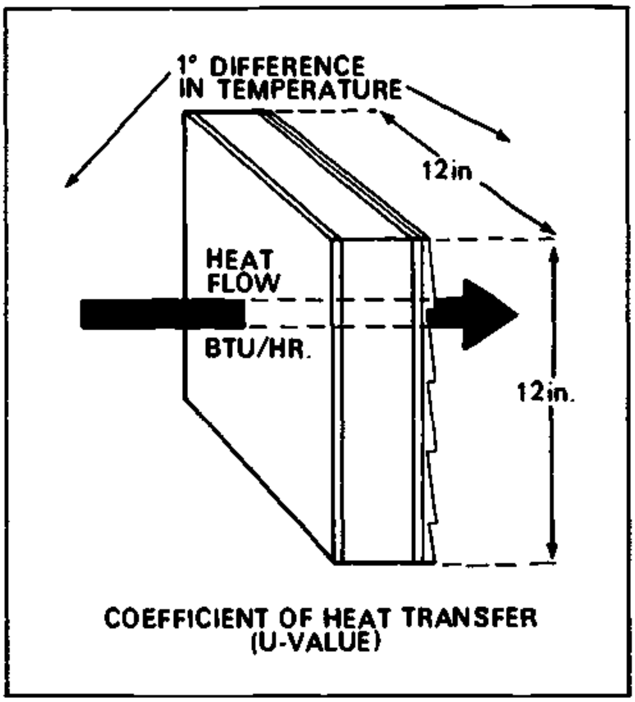


FIGURE 4. U-Value of a wall section.

c. Coefficient of Heat Transfer (U-Value)

The overall coefficient of heat transfer is more meaningful than C-Value when determining the insulating value of a building section. It includes all the materials and air space in a combined wall section. Therefore, U-Values are used to determine heat losses and gains in buildings.

The U-Value is defined as the amount of heat in Btu/hr that will transfer through 1 square foot of wall section in 1 hour for each degree F difference between sides (Figure 4).

As with C-Value, the lower the U-Value the better the insulation quality.

d. Thermal Resistance (R-Value)

The thermal resistance (R-Value) of a material is the term most commonly used for measuring insulation values. One reason, it is easier to understand because as the R-Value increases the value of the insulation increases. The unit for R-Value is hours x unit area x difference in degrees per Btu, $t \times ft^2 \times hr/Btu$.

R-Value is a measure of the resistance to heat flow, not rate of heat flow (Figure 5). To find R-Value from the C-Value and U-Value,

$$R = \frac{1}{C} \text{ and } R = \frac{1}{U}$$

To find the R-Value from the k-Value,

$$R = \frac{\text{thickness of homogenous material}}{\text{conductivity of material}}$$

R-Values are also used to calculate heat transfer in buildings. Most insulating materials are rated in R-Values.

3. OTHER TERMS

Other terms you will be using are defined as follows:

a. Infiltration

Infiltration is the movement of outside air into or out of a building through unplanned openings in components such as cracks around windows.

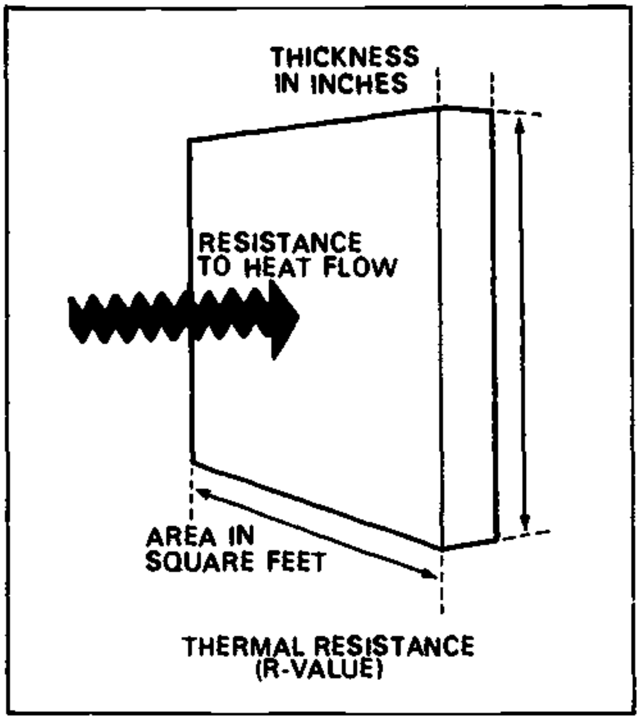


FIGURE 5. The higher the R-Value, the better the insulation.

b. Ventilation

Ventilation is the introduction of outside air through the heating or cooling system or by means of ventilation fans.

c. Fenestration

Fenestration is the glass or other transparent area of the building through which solar radiation can be transmitted.

d. Kilowatt Hour

Kilowatt hour is a measurement of electric energy.

1 kilowatt hour = 3,413 Btu

e. Inside Design Temperature

Inside design temperature is the dry-bulb temperature that is most comfortable. While the most comfortable temperature will vary with humidity, the following temperatures are required by ASHRAE standard 90-75:

- Winter inside design temperature - 72°F
- Summer inside design temperature - 78°F

Note: These temperatures all may be changed in order to conserve more energy. For example,

- winter - 68°F.
- summer - 80°F.

f. Outside Design Temperature

Outside design temperature is based on average extreme temperatures in a certain locality during a "specified" season. These have been computed by ASHRAE. They are listed for different cities in Cooling and Heating Load Calculation Manual, ASHRAE, 1979. Table II gives excerpts from the table.

Outside design temperatures are given for both winter and summer conditions.

g. Heating Degree Day

A heating degree-day is a term used to describe cold climatic conditions in a certain area for computing heating loads. A heating degree-day is the average number of degrees outside temperature is below 65° for a day. The annual degree days are a total of all the degree-days for a year.

For example, the temperature is taken every hour for 24 hours and the average is recorded at 60°F. The heating degree-day is 65°F - 60°F = 5°F. Most of the heating degree days will occur during December, January and February.

h. Cooling Degree Day

A cooling degree day is a term used to describe warm climatic conditions in a certain area for computing cooling loads. A cooling degree day is the average number of degrees outside dry-bulb temperature above 75% (70°F in New York and 60°F in Florida). Multiply the degrees below 75°F times number of days to get cooling degree days.

i. Discomfort Index

When figuring air conditioning, a discomfort index is used instead of dry-bulb temperature. Using the discomfort index, a cooling degree-day is the average discomfort index above 60 for a given day.

Discomfort index is computed from both the dry-bulb and wet-bulb temperature (Figure 6).

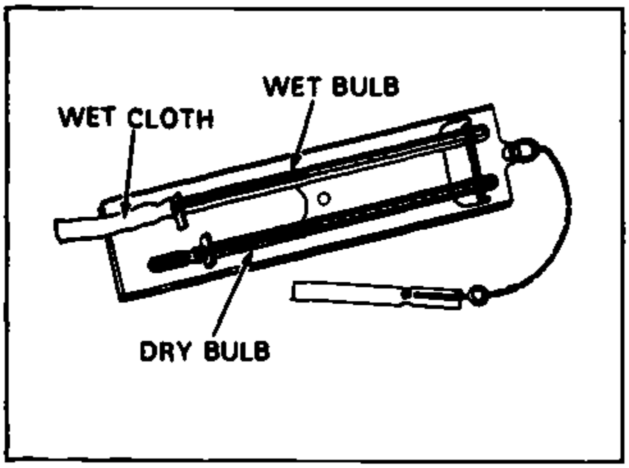


FIGURE 6. Sling psychrometer for measuring wet and dry bulb temperature.

j. Relative Humidity

The relative humidity influences comfort or discomfort. It is the approximate amount of moisture in the air as compared to the maximum amount that could be there at a specific temperature. Relative humidity is determined by taking the readings on a sling psychrometer and referring to a chart designed for the instrument.

k. Comfort Zone

The comfort zone for a person is between 72°F and 80°F with a relative humidity of between 20% and 60%.

The body is more tolerant of higher temperatures at lower moisture levels (Figure 7).

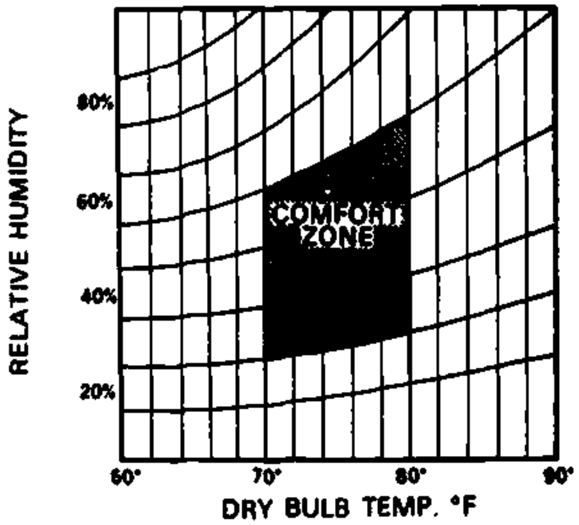


FIGURE 7. Comfort zone.

B. Understanding Heat Losses and Gains in Buildings

Heat transfer through building sections is computed by the use of formulas. Once you understand the formulas, it is a simple matter to substitute the values and arrive at heat losses or gains.

From your study of this section you will be able to explain which formulas are used for determining heat transfer in buildings and the terms used.

They are discussed under the following headings:

1. Conduction Heat Flow Through Homogeneous Materials.
2. Conduction Heat Flow Through Composite Walls.
3. Infiltration Heat Losses or Gains.
4. Ventilation Heat Losses or Gains.
5. Radiation Heat Losses or Gains.
6. Energy Losses and Gains from Equipment Operation.

1. CONDUCTION HEAT FLOW THROUGH HOMOGENEOUS MATERIALS

The fundamental relationship defining conduction heat flow through a homogeneous solid is the Fourier equation:

$$\underset{\text{(Btu/hr)}}{\text{Heat Transfer}} = \frac{\text{Conductivity of material (k)} \times \text{surface area (sq. in.)}}{\text{Thickness in inches}}$$

$$\text{X}$$

$$\text{Temperature Difference between the sides of the solids } (t_2 - t_1) \text{ in °F}$$

or

$$q_c = \frac{kA}{L}(t_2 - t_1)$$

Where

q_c = Heat flow by conduction (Btu/hour).

k = Thermal conductivity of the material, Btu/hr x ft^2 x °F x In.

L = Thickness of the solid in the direction of heat flow in inches.

$(t_2 - t_1) = \Delta T$ = Temperature difference between the two surfaces of the solid (°F).

A = Area of the solid perpendicular to the direction of heat flow.

The terms in equation 1 are illustrated in Figure 8.

It is important that equation 1 and its implications be understood. Notice that the heat transfer by conduction through the material will be small if:

- A material with a small conductivity (k) is used.
- The material thickness (L) is large.
- The temperature difference $(t_2 - t_1)$ between the two surfaces is kept small.
- The area (A) of the wall is kept small.

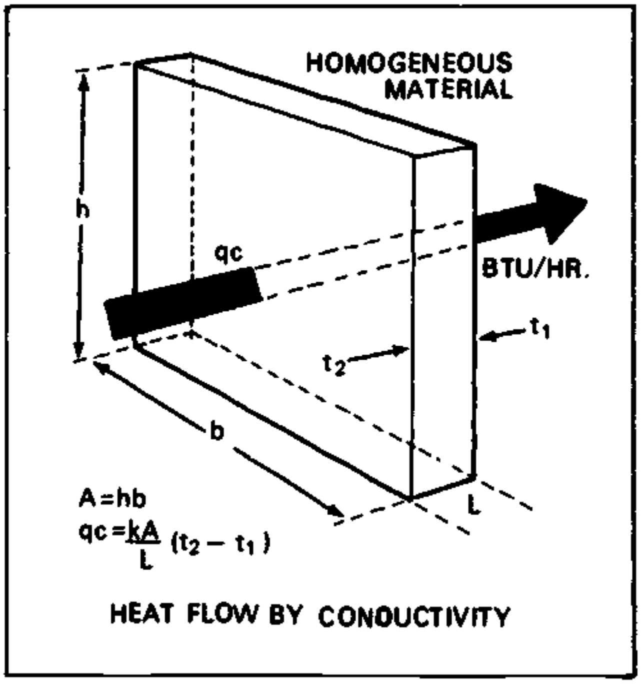


FIGURE 8. Conduction heat flow definition sketch.

Conduction heat losses in a building can be minimized by decreasing the building size, by selecting thick materials with low thermal conductivities, and by reducing the temperature difference between inside and outside air.

The thermal conductivity (k) of a material is a physical property which is obtained experimentally in the laboratory. Note that the conductivity is based on a material thickness of unity, or 1 inch. The conductivities of selected building materials are given in Table III.

Often, the thermal conductivity (C) of a material is given for a specified thickness rather than for a unit thickness. Typical cases are 8-inch concrete masonry blocks, or dressed timber boards. When the thermal conductivity is given for a specified thickness, it is called the thermal conductance (C). Typical values of thermal conductance are also given in Table IV.

When thermal conductances of materials are used, the conduction heat transfer equation must be modified since the material thickness is already incorporated into the conductance value. Thus

$$\underset{(\text{Btu/hr})}{\text{Heat Transfer}} = \underset{(C)}{\text{Thermal Conductance}} \times \underset{(A)}{\text{Area}} \times \underset{(t_2 - t_1)}{\text{Temperature Difference}}$$

$q_c = CA\ (t_2 - t_1)$ . . . . (Equation 2)

where C = thermal conductance, Btu/hr x ft^2 x Δt°F.

Another common way to describe a material's ability to conduct heat is its thermal resistivity (r) and thermal resistance (R). The resistivity is the reciprocal of the conductivity, whereas, the resistance is the reciprocal of the conductance. That is, the resistivity is the material's resistance to heat flow per unit thickness and the resistance is the material's resistance to heat flow for a specified thickness. Typical resistances are given for some insulation materials in Table I.

$$\underset{(r)}{\text{Thermal Resistivity}} = \frac{1}{\text{Conductivity (k)}}$$

$$R = \frac{1}{\text{Conductance (C)}} = \frac{\text{Thickness of material}}{\text{Conductivity (k)}}$$

$r = 1/k$ and $R = 1/C = L/k$ . . (Equation 3)

The conduction heat flow equation for a single material can now be expressed in terms of thermal resistivity and resistance by:

$$\underset{(\text{Btu-hr})\ (q_c)}{\text{Conduction Heat Flow}} = \frac{1}{\text{Resistance (R)}} \times \frac{\text{Area (A) (ft}^2)}{\text{Thickness (L) (in)}} \times \underset{(t_2 - t_1)}{\text{Temperature Difference}}$$

$q_c = \frac{1}{r}\frac{A}{L}\ (t_2 - t_1)$, and . . . (Equation 4)

$q_c = \frac{1}{R} A\ (t_2 - t_1)$ . . . . . (Equation 5)

EXAMPLE NO. 1

To illustrate the use of the conduction equation, suppose a 4' x 8' sheet of 1/2-inch thick plywood has surface temperatures of 100°F and 70°F. Evaluate the heat conducted through the panel.

The thermal properties of the plywood are:
$k = 0.80$
$C = 1.60$
$r = 1.25$
$R = 0.625$

The heat conducted in Btu/hour may be calculated by either equation (1), (2), (4) or (5):

$$q_c = \frac{kA}{L}(\Delta t) = \frac{0.8(4x8)\ (100-70)}{0.5} = 1536 \text{ Btu/hr}$$

$$q_c = CA\ (\Delta t) = 1.6(4x8)\ (100-70) = 1536 \text{ Btu/hr}$$

$$q_c = \frac{A}{rL}(\Delta t) = \frac{1}{1.25}\,\frac{(4x8)}{0.5}(100-70) = 1536 \text{ Btu/hr}$$

$$q_c = \frac{A}{R}(\Delta t) = \frac{4x8}{0.625}(100-70) = 1536 \text{ Btu/hr}$$

2. CONDUCTION HEAT FLOW THROUGH COMPOSITE WALLS

If structural components were made of single homogeneous materials, equations (1), (2), and (4) would be adequate to estimate conduction heat flow. Most wall partitions, however, are composite walls. That is, they are constructed of two or more materials as shown in Figure 9.

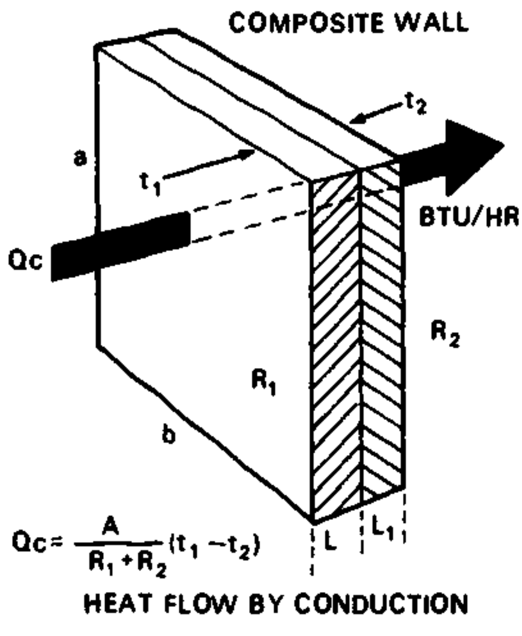


FIGURE 9. Definition sketch for a composite wall.

The procedures for estimating heat flow through a composite wall follow:

The total thermal resistance (R_T) of the composite wall is the sum of the resistance of each component of the wall. In equation form

$$R_T = R_1 + R_2$$

$$R_T = L/k_1 + L/k_2 \quad . . . \text{ (Equation 6)}$$

By placing the total thermal resistance into the conduction equation, the conduction heat transfer through a composite wall is

$$q_c = \frac{1}{R_T}A\ (\Delta t) \quad . . . . \text{ (Equation 7)}$$

Another way to write equation 7 is to let $U = 1/R$; then

$$q_c = UA\ (\Delta t) \quad . . . . . \text{ (Equation 8)}$$

where U = overall heat transmission coefficient, Btu/hr x ft^2 x °F.

When determining the overall thermal resistance of a wall, it is only necessary to add up the resistances of each component in the wall. Fortunately, the total thermal resistance and overall thermal transmission coefficients are tabulated for many partition constructions.*

---

*From Table V.

The following example will illustrate how to evaluate overall transfer coefficients and heat flow through composite walls.

EXAMPLE NO. 2

Evaluate the conduction heat transferred through a 8' x 10' wall section composed of 3/4-inch wood siding, 3 1/2-inches fiberglass insulation and 1/2-inch gypsum board (Figure 10).

Outside temperature (t_o) 10°F.
Inside temperature (t_i) 68°F.

	R-Values *
Outside film	0.17
Wood siding	0.81
Sheathing	1.32
Insulation	11.
Gypsum board	0.45
Inside film	.68
R_T =	14.43

---

*From Table V.

NOTE: There is a small amount of resistance due to the air film on both the outside and inside surface of materials.

$q_c = UA\ (\Delta t)$

$R_T = R_o + R_{sh} + R_{wood} + R_{insul} +$

$R_{gb} + R_i = 0.17 + 1.32 +$

$0.81 + 11.0 + 0.45\ \_\ 0.68 =$

14.43

Thus $U = 1/R_T = 1.14.43 - 0.069$

and $q_c = 0.069\ (8 \times 10)\ (68-10) =$

321 Btu/hr.

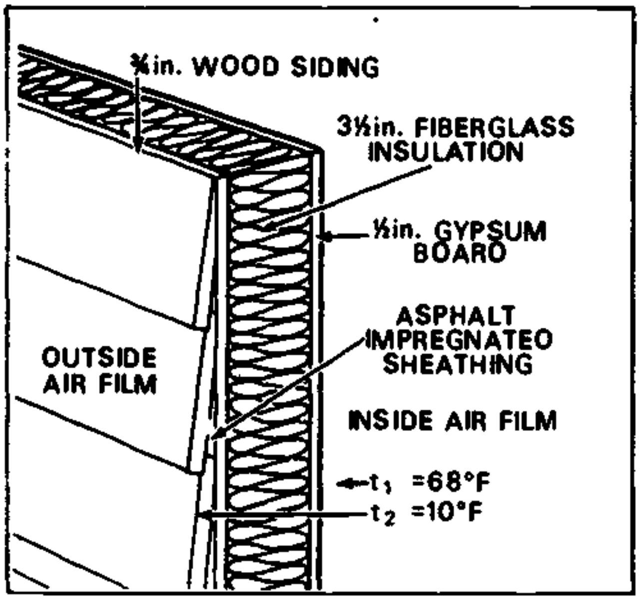


FIGURE 10. Sketch of wall section for conduction heat flow through a composite wall.

Using Table V, the overall heat transfer coefficient is U-0.081. The discrepancy between U calculated (.069) and U tabulated (0.081) is that the tabulated values account for the difference in thermal resistance at the studs and between the studs. The tabulated U-Value is the weighted average of the U-Values at and between the studs.

To illustrate the value of insulation, consider the same composite wall, but remove the 3 1/2 inches of insulation. Now the insulation is replaced by a vertical air space which has a resistance of 1.01 and

$R_T = R_o + R_{sh} + R_{wood} + R_{air} + R_i$

$= 0.17 + 1.32 + 0.81 + 1.01 + 0.45 + 0.68 = 4.44$

and $U = 1/R = 1/4.44 = 0.23$

and $q_c = UA\ (\Delta t) = 0.23\ (8 \times 10)\ (68-10) = 1044$ Btu/hr

Note that by removing the insulation, the heat flow by conduction through the wall increased from 321 to 1044 Btu/hr. The heat loss increased by a factor of 2.25.

EXAMPLE NO. 3

To illustrate the influence of indoor temperature upon heat loss from a building, consider again the insulated wall section with U - 0.069. Compare the heat flow through the wall for an outdoor temperature of 10°F and inside temperatures of both 60°F and 72°F.

At 60°F, $q_c = UA\ (\Delta t) = 0.069\ (80)\ (60-10) = 276$ Btu/hr.

AT 72°F, $q_c = UA\ (\Delta t) = 0.069\ (80)\ (72-10) = 342$ Btu/hr.

By increasing the indoor temperature from 60° to 72°F, Δt increased and thus increased the heat loss through the wall by 66 Btu/hr, or by 24%.

3. INFILTRATION HEAT LOSSES OR GAINS

Outside air enters a residence through many unplanned cracks in walls, doors and windows. This air movement is called infiltration. Since infiltration air is seldom at the temperature of the air inside the living area, it must be warmed or cooled. This fact, of course, represents a heat loss by the house during cold weather and a heat gain by the house during warm weather.

In estimating infiltration heat flow, it is necessary to estimate first the volume, or cubic feet, of air which flows into the building. The quantity of air flow is dependent upon many factors, including the number and sizes of cracks in the structural components and the outside wind speed.

There are two basic methods for evaluating the infiltration air volume. One method requires that the crack widths and lengths and the wind speeds be estimated whereupon air flow can be evaluated. Another method is the air exchange method. In this method, tabulated values of the number of air changes occurring per hour are used for typical residential rooms. Typical air exchange values are given in Table VI. Note that an air exchange rate of 1.0 per hour indicates that the air flow into the room per hour equals the volume (length x width x height) of the room.

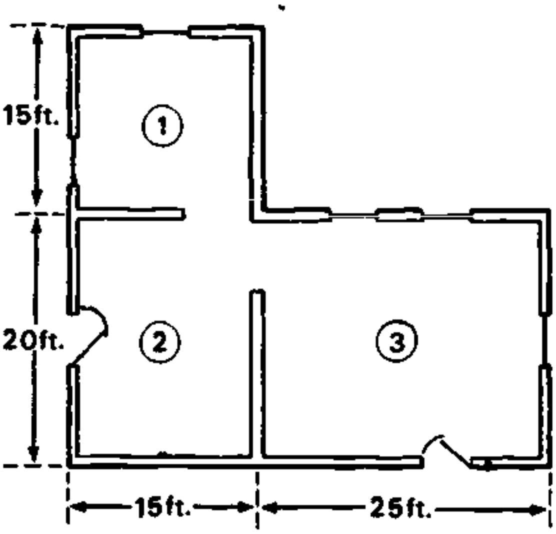


FIGURE 11. Plan view for infiltration volume illustration.

In residential construction the air exchange method is sufficiently accurate for infiltration volume calculations and is much simpler than the crack length and width method. Thus, the air exchange method will be used exclusively in this text.

EXAMPLE NO. 4

To illustrate the air exchange method, estimate the infiltration air volume for the simple house plan show in Figure 11, if the ceiling height is 8 feet and if the windows are not weatherstripped or storm sashed.

The infiltration air volume for each room is estimated by the formula:

Infiltration volume = Q_i = Air exchanges x room volume

For room (1): $Q_i = 1.5\ (15\text{x}15\text{x}8) = 2700$ cu. ft/hr
For room (2): $Q_i = 1.0\ (15\text{x}20\text{x}8) = 2400$ cu ft/hr
For room (3): $Q_i = 2.0\ (20\text{x}25\text{x}8) = 8000$ cu ft/hr
For whole house: $Q_i = 2700 + 2400 + 8000 = 13{,}100$ cu ft/hr

Once the estimate of the volume of infiltration air is obtained, the energy required to heat or cool the air to the temperature of the living area can be calculated by the formula:

$$q_i = (0.018)\ Q_i\ (t_o - t_i)\ .\ .$$

(Equation 10)

Infiltration heat losses can now be illustrated by considering the house in Figure 11 and equation 10. The infiltration heat loss will be calculated when the outside temperature is 10°F and the living area temperature is 65°F.

$$q_i = (0.018)\ Q_i\ (t_o - t_i)$$

$$= 0.018\ (13{,}100)(65-10)$$

$$= 12{,}970 \text{ Btu/hr}$$

Notice that by weatherstripping the windows or adding storm windows, the infiltration heat loss could be reduced by 1/3, or

$$q_i = 2/3\ (12{,}970) = 8{,}650 \text{ Btu/hr}$$

4. VENTILATION HEAT LOSSES OR GAINS

The heat losses and gains due to ventilation air are evaluated in the same manner as infiltration heat losses and gains except the volume of air entering the building is different. That is

$$q_v = 0.018\ (Q_v)\ (\Delta t)\ .\ .\ .$$

(Equation 11)

where q_v = ventilation heat loss or gain, Btu/hr
Q_v = ventilation air volume, cu ft/hr

The ventilation air volume for residences is usually very small as compared to infiltration air volume.

Table VII gives typical ventilation air volumes.

In most single family residences the air exchange obtained by infiltration satisfies the ventilation requirements. If this is the case, the ventilation heat loss or gain is taken care of in the infiltration heat loss calculation. If supplemental ventilation is provided, simply determine the volume of air introduced by the ventilating fans, Q_v, and substitute Q_v into Equation 11.

5. RADIATION HEAT LOSSES OR GAINS

Radiation heat flow is far more important in cooling applications during warm weather than in heating applications during cold weather. Thus, our primary concern will be to estimate solar radiation heat gains during warm weather.

Solar radiation heat gains in residences may be conveniently divided into two categories:

a. Opaque Exterior Surfaces.
b. Windows and Transparent Surfaces,

a. Opaque Exterior Surfaces

When solar radiation strikes a building roof or wall, it increases the temperature of the building surface to a level above the outside temperature. The increased surface temperature thus changes the temperature difference between the inside and outside wall surfaces. Recalling the conduction heat transfer equation, $q_c = UA\ (t_o - t_i)$, an increase in t_o would increase the conduction heat transferred through the wall or roof.

A convenient method for accounting for the solar radiation heat load in a building is to use an equivalent air temperature called the sol-air temperature. Sol-air temperature is the equivalent outdoor air temperature which would yield the same heat transfer through a wall by conduction alone as that transferred due to the conduction heat transferred under the actual outdoor temperature and solar radiation. By using the sol-air temperature, t_e, instead of the actual outdoor temperature, t_o, the combined conduction and radiation heat transferred through opaque surfaces is estimated by equation (12):

$$q_{cr} = UA\ (t_e - t_i) \quad . \ . \text{ (Equation 12)}$$

The design sol-air temperature is dependent upon the solar radiation intensity. Thus, sol-air temperatures are dependent upon the time of the year, geographical location, the orientation of the surface (N, S, E, W), the inclination of the surface (horizontal or vertical), and the color of the wall. The wall color is significant since dark colored walls absorb larger quantities of solar radiation, whereas lightly colored walls tend to reflect a large portion of the incident solar radiation. Typical values of sol-air temperatures are given in Table VIII for a latitude of 40°N on July 21.

Table VIII illustrates vividly the effects of surface color, orientation and inclination upon sol-air temperatures. For example, at solar noon, when outside air temperature equals 90°F, sol-air temperatures of vertical surfaces varied from 96 to 112°F dependent upon orientation. At the same time the dark colored vertical surfaces experienced sol-air temperatures between 103 and 134°F. Comparison of sol-air temperatures for horizontal surfaces at solar noon indicates a difference of 172-127°F, or 45°F, between dark and light colored surfaces.

EXAMPLE NO. 5

Estimate the total heat transferred through an 8' x 10' vertical wall section at 4 p.m. on July 21. Assume the wall has an overall heat transfer coefficient of 0.02, west facing orientation, is lightly colored, and is located at 40°F latitude. Also assume an inside air temperature of 75°F and an outside air temperature of 94°F.

$$q_{cr} = UA\ (t_e - t_i)$$

$$= 0.02(8x10)(131-75)$$

$$q_{cr} = 89.6 \text{ Btu/hr}$$

b. Windows and Transparent Surfaces

Solar radiation affects the heat gain through transparent surfaces in two ways. First, the combined conduction heat transferred is increased by the surface heating of the outside of the glass. Thus, the heat transferred by conduction is a function of the difference between sol-air temperatures and inside air temperatures. Second, is the solar heat gain inside the room by transmission. In summary, the total heat gain through glass areas equals the heat flow due to indoor-outdoor temperature differences plus the radiation transmitted through the glass.

The heat gain due to conduction is dependent upon the sol-air temperature, the indoor temperature, the overall heat transmission coefficient of the glass and the glass area. The solar heat gain by transmission is dependent upon the intensity of solar radiation, the orientation of the glass area with respect to the North, the degree of shading and the transmission coefficient of the glass.

6. ENERGY LOSSES AND GAINS FROM EQUIPMENT OPERATION

Heat is given off by many appliances and equipment, such as refrigerators, stoves, washing machines, dryers, freezers, dishwashers and lighting fixtures. This energy should be considered as advantageous to heating and may even reduce the size of your heating system. On the other hand, heat producing equipment adds to the cooling load.

C. Estimating Heating Loads in Buildings

On completion of this section you will be able to estimate the heating load for a building by using the tables at the end of this section and calculating the heat flow in Btu/hr. General procedures are as follows:

1. Find the thermal resistance (R) and the overall transmission coefficient ($U=1/R$) for the walls, ceilings, roof, windows and floors from working drawings and/or tables. Excerpts are given in Tables V and IX.
2. Calculate the surface areas of the walls, ceiling, floor, windows and doors in each room of the building.
3. Find the design temperatures for the outside air and ground. Excerpts are given in Table II.
4. Establish the desired inside air temperature. Generally 68°F, winter, and 78°F, summer.
5. Calculate the heat loss by conduction through each component of each room using $q_c = UA\ (\Delta t)$.
6. Calculate the conduction loss from each room by adding losses through each component.
7. Calculate the total conduction heat loss from the building by adding the conduction losses from each room.
8. Estimate the infiltration heat loss from each room using $q_i = 0.018\ Q_i\ (\Delta t)$.
9. Calculate the total infiltration loss by adding the infiltration losses from each room.
10. Calculate the heat loss from the entire building by adding the total heat losses due to conduction and infiltration (or ventilation).
11. Estimate the seasonal heating load. Follow procedures under Section 7.

EXAMPLE NO. 6 CALCULATING HEATING LOAD

The building used in this example has been kept very simple in order to emphasize procedural details rather than construction details (Figure 11).

Data and calculations are recorded in Worksheet 1 to help you understand how to do a Worksheet of your own from a new or existing building.

Estimate the heating load for the building plan shown in Figure 11. It is described as follows (see Worksheet 1):

- The house is to be located near Philadelphia, Pennsylvania.
- The design indoor temperature is 65°F in all rooms.
- The house rests on a 4-inch concrete slab on grade with 1-inch thick perimeter insulation (k = 0.24) around the entire slab.
- The exterior walls are of 2" x 4" frame construction with studs 16 inches o.c. The space between studs is filled with 3 1/2 inches of insulation with an R-value of 11. The inside of the wall is covered with 1/2-inch gypsum wallboard, while the outside is sheathed with 1/2-inch asphalt impregnated wallboard and 1/2 x 8-inch wood siding.

- The interior walls are uninsulated and have 1/2-inch gypsum wallboard on each surface.
- The ceiling construction consists of 1/2-inch gypsum wallboard, and 2" x 8" ceiling joists (16" o.c.). The space between the joists are filled with 6 inches of R-19 blanket insulation.
- The roof has a slope of 1:3 and is constructed of 2" x 4" rafters, 16 inches o.c. and covered with 5/8-inch plywood sheathing, felt building paper, and asphalt shingles.
- The windows are all 36 x 60 inches in size and are doubly insulated glass, 0.125 inches thick with 0.25-in air spaces.
- All doors are of 1.5-inch thick wood construction without storm doors. The dimension of each door is 36 x 80 inches.
- The ceiling height is 8 feet.
- All doors and windows are weatherstripped.

SOLUTION:

Follow steps given under the following headings and observe the recorded values in Worksheet 1.

1. Determining Thermal Resistance (R-Values) and Overall Transmission Coefficients (U-Values).
2. Determining Areas of Building Components.
3. Determining Design Temperatures.
4. Calculating Heat Flow by Conduction.
5. Calculating Heat Flow by Infiltration.
6. Calculating Total Heat Flow.
7. Estimating Seasonal Heating Load.
8. Comparing Energy-Saving Practices.

1. DETERMINING THERMAL RESISTANCE (R-VALUES) AND OVERALL TRANSMISSION COEFFICIENTS (U-VALUES)

These values are discussed under the following headings and recorded in Worksheet 1:

a. Walls.

b. Ceilings.

c. Floors.

d. Windows.

e. Doors.

a. Walls

Proceed as follows:

1. Find U-Value from Table V.

   U-Value (Avg.) = .081
   Note recorded in Worksheet 1.

2. Compute R-Value.

   $$\text{R-Value} = \frac{1}{.081} = 12.35$$

b. Ceilings

Proceed as follows:

1. Find U-Value for roof from Table IX. The ceiling and roof act in combination in determining the heat loss through the roof area. Table IX gives the U- and R-Values for a pitched roof (with a 45° slope) with reflective and non-reflective air spaces. This example building has a slope of 1:3 (approximately 20°), a non-reflective air space between the roof and ceiling and 6 inches of insulation (R-19).

For the roof with non-reflective air space and no insulation, U-0.273 (From Table IX, for winter conditions with heat flow up).

2. Find ceiling-roof combination with insulation (R-19) from Table X.

(1) Enter Table X with a U-Value of 0.273 or approximately 0.30 in the first column.

(2) Proceed to the right to the column most nearly corresponding to the installed R-Value of insulation (R=20).

(3) Read directly the overall transmission coefficient of the roof-ceiling combination.

U = 0.04. Thus, R = 1/.04 = 25.

Note U-Value recorded in Worksheet 1. By using the roof-ceiling combination for the R-Values, the design outside and inside temperatures can be used in future heat loss calculations. It is not necessary to evaluate the attic space temperature. If the attic is well ventilated, use the R-Value for the ceiling construction and outside design air temperature.

c. Floors

The R-Value of the floor in this problem is not required since Table XI allows direct estimation of the floor slab heat losses in Btu/hr as a function of linear feet of exposed slab edge and outdoor design temperatures (See Figure 11).

It is given in Btu/hr per linear foot of exposed edge.

Proceed as follows:

1. Assume outside design temperature of -10 to -20 F.

2. Find heat loss in column 2 for 1" edge insulation (Table XI).

50 Btu/(hr-Ft)

d. Windows

Proceed as follows:

1. Find U-Value for double insulated .25 inch air space in Table XII. Double insulated, no indoor shade, winter:
U-Value = 0.58.
Note recordings in Worksheet 1.

2. Compute R-Value.

$$\text{R-Value} = \frac{1}{0.58} = 1.72.$$

e. Doors

Proceed as follows:

1. Find U-Value for 1.5-inch doors without storm doors in Table XIII.

U-Value = 0.49
Note recordings in Worksheet 1.

2. Compute R-Value.

$$\text{R-Value} = \frac{1}{0.49} = 2.04$$

2. DETERMINING AREAS OF BUILDING COMPONENTS

Assume that all the rooms are to be kept at the same temperature. Then there will be no heat transferred through interior walls, and it is necessary only to calculate the area of the exterior walls. To illustrate, find the required areas for room 3 in Figure 11 as follows (See Worksheet 1):

1. Compute exterior wall area (Room 3).

$25' \times 8' - 3' \times 6.67' =$ 180 ft.^2

$25' \times 8' - 3'\times5' - 3'\times5' =$ 170 ft.^2

$20' \times 8' - 3' \times 5' =$ 145 ft.^2

Total 495 ft.^2

2. Compute ceiling area (Room 3).

$20' \times 25' =$ 500 ft.^2

3. Compute window area (Room 3).

$3(3' \times 5') =$ 45 ft.^2

4. Compute door area (Room 3).

$3' \times 6.67 =$ 20 ft.^2

5. Compute exposed slab length (Room 3).

$25' + 20' + 25' =$ 70 ft.

6. Calculate areas for other rooms in the same manner.

3. DETERMINING DESIGN TEMPERATURES

1. Select inside design temperature (t_i). For this example use 65°F. Many designers use 68°F.

2. Select outside design temperature (t_o). Outside design temperatures for Philadelphia, PA are given in Table II. Two winter design conditions are given; one under the 99% column and one under the 97.5% column. These percentages are the percentage of the total number of hours during the months of December, January and February that the listed temperature is exceeded in an average year. For a residential building, the 97.5% design temperature is usually adequate.

Thus, the outside design temperature, t_o, is 14°F and $t_i - t_o = 65 - 14 = 51°\text{F}$.

4. CALCULATING HEAT FLOW BY CONDUCTION (q_c)

Proceed as follows (see Worksheet 1): (Calculations are shown for room #3 only.)

1. Find heat flow through walls (Room 3).

$$q_c \text{ (walls)} = U \text{ (wall) } A \text{ (wall) } (t_i - t_o)$$

$$q_c = .081 \times 495 \times 51 = 2045 \text{ Btu/hr}$$

2. Find heat flow through ceiling (Room 3).

$$q_c \text{ (ceilings)} = U \text{ (ceiling-roof) } A \text{ (ceiling) } (t_i - t_o)$$

$$q_c = .04 \times 500 \times 51 = 1020 \text{ Btu/hr}$$

3. Find heat flow through floor (Room 3).

q_c (floor) = factor from Table XI x exposed length of slab

$q_c = 50 \times 70 = 3500$ Btu/hr

4. Find heat flow through windows (Room 3).

q_c (windows) = U (windows) A (windows) $(t_i - t_o)$

$q_c = 0.58 \times 45 \times 51 = 1330$ Btu/hr

5. Find heat flow through doors (Room 3).

q_c (doors) = U (Doors) A (Doors) $(t_i - t_o)$

$q_c = 0.49 \times 20 \times 51 = 500$ Btu/hr

6. Find total heat flow through each room.
From steps 1, 2, 3, 4 and 5:

For room 3, 2045 + 1020 + 3500 + 1330 + 500 = 8395 Btu/hr.

NOTE: The values for rooms 1 and 2 are obtained in the same manner as those for room 3. The values are summarized and listed in Worksheet 1.

7. Find total heat flow by conduction from building.

Add heat flow for each room.

q_c (room 1) = 4959
q_c (room 2) = 3936
q_c (room 3) = 8395

Total q_c = 17,290 Btu/hr

5. CALCULATING HEAT FLOW BY INFILTRATION

Calculate the infiltration heat losses from each room as follows (see Worksheet 1):

1. Find air exchanges (Q_i) from Table VI. Use 2/3 since windows have storm sashes (Table VI).

Q_i (Room 1) = 2/3 (1.5) (15 x 15 x 8) = 1800 ft^3/hr
Q_i (Room 2) = 2/3 (1.0) (15 x 20 x 8) = 1600 ft^3/hr
Q_i (Room 3) = 2/3 (2.0) (20 x 25 x 8) = 5360 ft^3/hr

2. Find heat flow by infiltration for each room (q_i).

$q_i = .018 Q_i\ (\Delta t)$
q_i (Room 1) = .018 (1800) (51) = 1652 Btu/hr
q_i (Room 2) = .018 (1600) (51) = 1468 Btu/hr
q_i (Room 3) = .018 (5360) (51) = 4290 Btu/hr

3. Find total heat flow by infiltration (q_i).

Add heat flow from each room:
1652 + 1468 + 4920 = 8040 Btu/hr

6. CALCULATING TOTAL HEAT FLOW

Add heat flow by conduction and heat flow by infiltration.

q_c = 17,290
q_i = 8,040

q = 25,330 Btu/hr

NOTE: A blank Worksheet 2 is provided for you to calculate heat flow from your own new or existing building (in the student workbook).

WORKSHEET 1. HEAT FLOW CALCULATIONS

Overall Heat Transfer Coefficients (U)
Exterior Walls 0.081 Btu/hr-ft^2-°F
Ceiling-Roof Comb 0.04 Btu/hr-ft^2-°F
Floors N/A Btu/hr-ft^2-°F
Slabs 50 Btu/hr-ft
Windows 0.58 Btu/hr-ft^2-°F
Doors 0.49 Btu/hr-ft^2-°F

Design Temperatures
Inside Temperature (t_i) 65°F

Outside Temperature (t_o) 14°F

Room	Building Component	Transmission Coefficient (U)	Surface Area (A)	Temp. Difference (t_i-t_o)	Conduction Losses q_c=UA(t)	Air Exchange	Infiltration Rate (Q_i)	Infiltration Losses q_i=.018Q_i(t)
	Ext. walls	.081	330	51	1363			
	Ceiling-roof	.04	225	51	459			
	Floor	-	-	-	-			
1	Slab	50*	45*	-	2250*			
	Windows	.58	30	51	887			
	Doors	.49	0	51	0			
	TOTAL ROOM LOSS				4959	1.5	1800	1652
	Ext. walls	.081	260	51	1074			
	Ceiling-roof	.04	300	51	612			
	Floor	-	-	-	-			
2	Slab	50*	35*	-	1750*			
	Windows	.58	0	51	0			
	Doors	.49	20	51	500			
	TOTAL ROOM LOSS				3936	1.0	1600	1468
	Ext. walls	.081	495	51	2045			
	Ceiling-roof	.04	500	51	1020			
	Floor	-	-	-	-			
3	Slab	50*	70*	-	3500*			
	Windows	.58	45	51	1330			
	Doors	.49	20	51	500			
	TOTAL ROOM LOSS				8395	2.0	5360	4920

*Slab Loss - Factor from Table XI x Exposed Perimeter Length.

Total Conduction Loss = 4959 + 3936 + 8395 = 17,290 Btu/hr.
Total Infiltration Loss = 1652 + 1468 + 4920 = 8,040 Btu/hr.
Total Heat Loss = 17,290 + 8,040 = 25,330 Btu/hr.

7. ESTIMATING SEASONAL HEAT LOAD

The procedures described and illustrated thus far allow computation of the heat loss from a building when the outdoor temperatures are at the design, or some other specific, temperature. This occurs for only a few hours, or instants, during the heating season. The seasonal heating load can be estimated by evaluating heat losses on an hour by hour basis. However, this procedure would be too time consuming. Instead, an approximate method known as the Degree-Day Method has been recommended by ASHRAE for predicting seasonal heat losses and fuel consumption.

The Degree Day Method estimates seasonal heating loads by assuming there is no heat loss or gain when the outdoor temperature is 65°F and then predicting from weather data the number of hours in the heating season for which the outdoor temperature is below 65°F. The total number of hours for which the outdoor temperature is less than 65°F is called the number of Degree Days for the building location. The number of degree days is dependent upon climate. Typical values are summarized for several locations in Table II.

The seasonal heat loss is estimated by the equation:

$$q_s = \frac{q \times D \times 24}{\Delta t}$$

where q_s = seasonal heat loss, Btu
q = heat loss at design temperatures, Btu/hr
D = number of degree days, F. days
Δt = design temperature difference, °F
24 = 24 hour day

To estimate the fuel consumption during a heating season, the heating value of the fuel and several efficiency factors must be applied to the seasonal heat loss value, q_s.

$$E = q_s \frac{C_D \times C_F}{\gamma \times v}$$

where E = seasonal fuel or energy consumption
C_D = correction factor heat loss differences
C_F = correction factor for partial loads for fuel-fired systems. (Use 1.0 for electric resistance heating.)
γ = rated full load efficiency of heating equipment (decimal value).
v = heating value of fuel in units consistent with E and q_s. (Btu/gal, Btu/cu. ft, Btu/kwh)

Suggested values of C_D and C_F are found in Tables XIV and XV. Full load efficiencies are usually between 70% and 80% and are available from manufacturers.

EXAMPLE NO. 7. SEASONAL HEAT LOAD ESTIMATION.

Consider the same situation described in Example Problem No. 1. Assume the heating system has a capacity of 30,000 Btu/hr.

Step 1: Evaluate the seasonal heat loss.

$$q_s = \frac{q \times D \times 24}{t}$$

q = 25,330 Btu/hr (From Example Problem No. 6, Worksheet 1)
D = 5144 degree days (Table II)
Δt = 65°-14° = 51°F

Thus $q_s = \frac{25,330 \times 5,144 \times 24}{51}$

$= 61,300,000$ Btu/season.

Step 2: Evaluate the quantity of fuel required per heating season.

$$E = q_s \frac{C_D \times C_F}{\gamma \times v}$$

$C_D = 0.83$ (Table XIV at 14°F design temperature).

$C_F = 1.56$ (Table XV for 25% oversized heating unit.)

γ = Efficiency .75, fuel oil; 1.00 electricity.

$v = 800$ Btu/ft^3 gas.

$v = 144,000$ Btu/gal fuel oil

$v = 3,413$ Btu/kwh electrical energy.

Thus the estimated quantity of fuel consumed is

$E = 61,300,000 \left(\frac{0.83 \times 1.56}{0.75 \times 800}\right) =$ 132,000 cu. ft. gas.

$E = 61,300,000 \left(\frac{0.83 \times 1.56}{0.75 \times 144,000}\right) =$ 735 gal. fuel oil

$E = 61,300,000 \left(\frac{0.83 \times 1.56}{1.0 \times 3413}\right) =$ 23,250 KWh electrical energy.

8. COMPARING ENERGY-SAVING PRACTICES

It is often desirable to compare the energy savings realized by an energy-saving practice. This section outlines and illustrates the procedures for comparing the effect of various practices.

The house in Example No. 6 will be used to compare the energy consumption for the house specifications as given and for the same house without any insulation or weatherstripping. All the calculations will not be shown for the uninsulated house. Instead, the entries in Worksheet 1 which are affected by the modification in specs will be crossed out and replaced in longhand with the correct values.

Basically two items must be corrected for the modified house specifications; namely, the transmission coefficients for the walls, ceilings, and slab and the air exchange rates. These corrections along with their consequences are summarized in Worksheet 2.

EXAMPLE NO. 8: COMPARING ENERGY-SAVING PRACTICES

1. Evaluate the design heat loss for the modified specification (no insulation or weatherstripping).

(1) Change exterior wall transmission coefficient to 0.206 (Table V).

(2) Change ceiling-roof transmission coefficient to 0.273 (Table IX).

(3) Change slab transmission factor to 60 (Table XI).

(4) Calculate new conduction loss column entries.

(5) Calculate new total conduction loss entry.

(6) Change infiltration rate to full value as given in Table VII.

(7) Calculate new infiltration loss entries.

(8) Calculate new total infiltration loss entry.

(9) Evaluate total heat loss.

2. Evaluate the change in the seasonal heat loss, q_s.

(1) For the insulated, weather-stripped building, q_s= 61,300,000 Btu/season.

(2) For the uninsulated, non-stripped building,

$$q_s = \frac{49,925}{25,330} \times 61,300,000 =$$

122 million Btu/season.

(3) The increase in heat loss is 122-61.3, or 60.7 million Btu/season.

This represents an increase of $\frac{60.7}{61.3} = 99\%$.

3. Evaluate the change in the quantity of fuel required per season.

Use fuel oil for the illustration.

(1) For the insulated, weather-stripped building.

E = 735 gallons fuel oil/season.

(2) For the insulated building,

$$E = 122,000,000 \quad \left(\frac{0.83 \times 1.56}{0.75 \times 144,000}\right)$$

= 1535 gallons fuel oil/season

(3) Find the increase in fuel oil consumption.

1535 - 735 or 800 gallons.

The annual cost of fuel for heating for the current season can be evaluated by multiplying the seasonal fuel consumption, E, by the unit cost of the fuel. Similarly, the current year savings in fuel cost is simply the change in fuel consumption times the unit fuel cost. In the illustration just completed, if the cost of fuel oil is $0.50 gallon, the addition of insulation and weatherstripping would reduce the annual cost for heating fuel by 0.50 (800), or $400. Of course, as fuel costs increase, the dollar savings will also increase.

WORKSHEET 2. HEAT FLOW CALCULATIONS

Overall Heat Transfer Coefficients (U)
Exterior Walls ~~0.081~~ Btu/hr-ft²-°F .206
Ceiling-Roof Comb ~~0.04~~ Btu/hr-ft²-°F .273
Floors N/A Btu/hr-ft²-°F
Slabs ~~50~~ Btu/hr-ft 60
Windows 0.58 Btu/hr-ft²-°F
Doors 0.49 Btu/hr-ft²-°F

Design Temperatures
Inside Temperature (t_i) 65°F

Outside Temperature (t_o) 14°F

Room	Building Component	Transmission Coefficient (U)	Surface Area (A)	Temp. Difference ($t_i - t_o$)	Conduction Losses $q_c = UA(\Delta t)$	Air Exchange	Infiltration Rate (Q_i)	Infiltration Losses $q_i = .018Q_i(\Delta t)$
	Ext. walls	~~.081~~ .206	330	51	~~1363~~ 3467			
	Ceiling-roof	~~.04~~ .273	225	51	~~459~~ 3133			
	Floor	-	-	-	-			
1	Slab	~~.50*~~ 60	45*	-	~~2250*~~ 2700			
	Windows	.58	30	51	887			
	Doors	.49	0	51	0			
	TOTAL ROOM LOSS				~~4959~~ 10,187	1.5	~~1800~~ 2700	~~1652~~ 2478
	Ext. walls	~~.081~~ .206	260	51	~~1074~~ 2731			
	Ceiling-roof	~~.04~~ .273	300	51	~~612~~ 4177			
	Floor	-	-	-	-			
2	Slab	~~.50*~~ 60	35*	-	~~1750*~~ 2100			
	Windows	.58	0	51	0			
	Doors	.49	20	51	500			
	TOTAL ROOM LOSS				~~3936~~ 9,508	1.0	~~1600~~ 2400	~~1468~~ 2203
	Ext. walls	~~.081~~ .206	495	51	~~2045~~ 5200			
	Ceiling-roof	~~.04~~ .273	500	51	~~1020~~ 6962			
	Floor	-	-	-	-			
3	Slab	~~.50*~~ 60	70*	-	~~3500*~~ 4200			
	Windows	.58	45	51	1330			
	Doors	.49	20	51	500			
	TOTAL ROOM LOSS				~~8395~~ 18,192	2.0	~~5360~~ 8000	~~4920~~ 7344

*Slab Loss - Factor from Table XI x Exposed Perimeter Length.

Total Conduction Loss = ~~4959 + 3936 + 8395 = 17,290~~ Btu/hr. 10,187 + 9,508 + 18,192 = 37,887 Btu/hr.
Total Infiltration Loss = ~~1652 + 1468 + 4920 = 8,040~~ Btu/hr. 2478 + 2203 + 7344 = 12,025 Btu/hr.
Total Heat Loss = ~~17,290 + 8,040 = 25,330~~ Btu/hr. 37,887 + 12,025 = 49,912 Btu/hr.

D. Special Applications for Estimating Cooling Loads in Buildings

Cooling loads in buildings differ from instantaneous heat gain calculations because of flywheel effects. That is, some of the heat gained during the hottest portion of the day is stored in the building furnishings, walls and partitions and need not be removed until sometime later when the outdoor temperatures are lower and the instantaneous heat gain is smaller. Numerous techniques have been devised to account for this flywheel affect when calculating residential cooling loads.

Cooling loads are estimated by evaluating sensible cooling loads due to: (1) heat gain through floors, walls, ceilings; (2) windows; (3) infiltration and ventilation air exchange; and (4) occupancy. Then the latent cooling load (that required to control and remove excess moisture) is evaluated. A rule of thumb is to assume the latent cooling load is 0.3 times the sensible cooling load.

To help you understand the difference between heating loads and cooling loads, discussion is given under the following headings:

1. Cooling Load Due to Heat Gain Through Walls, Floors, Roofs and Ceilings.
2. Cooling Load Due to Windows.
3. Cooling Load Due to Infiltration.
4. Cooling Load Due to Occupancy.
5. Latent Cooling Load.
6. Total Cooling Load.

1. COOLING LOAD DUE TO HEAT GAIN THROUGH WALLS, FLOORS, ROOFS AND CEILINGS

The cooling load due to heat gain through structural components may be calculated by using an equivalent difference between the inside and outside temperatures in place of the actual indoor-outdoor temperature differences. Typical values of Equivalent Temperature Differences (ETD) are given in Table XVI. The ETD takes into account such factors as sol-air temperatures, construction type, thermal flywheel effects, and daily temperature ranges, and outdoor design temperatures. The cooling load due to structural components is obtained using equation (13):

$$q_{cs} = UA(ETD) \quad . \; . \; . \text{ Equation (13)}$$

To enter the table of ETD's, one must obtain both the outdoor design temperature and the range of daily temperatures for the building site (Table II). ETD's are given in 5°F increments of design temperatures from 85°F to 110°F (Table XVI). Daily temperature ranges are given for 3 conditions: I(0-15°F), M(15-25°F), and H(over 25°F). ETD's for design temperatures not listed can be obtained by adding 1°F to the tabulated value for each degree increase in design temperature. For this problem, walls are all assumed to be dark walls in Table XVI. Roofs, on the other hand, may be either dark or light colored.

2. COOLING LOAD DUE TO WINDOWS

The equivalent temperature difference concept has also been adopted to simplify cooling loads due to heat gains through window areas. Typical values of equivalent temperature differences (ETD) are given in Table XVII. The ETD's are given for 4 types of glass (regular, single glass, regular double glass, heat absorbing double glass, and clear triple glass, 6 design temperatures (85 to 110°F), for 8 compass points (N, S, E, W, etc.), and for 4 window treatments (no drapes, draperies, roller shades, and awnings). The ETD's are based upon an indoor temperature of 75°F.

The cooling load for windows is then calculated using equation 13, as was done for walls.

Permanent shades, such as overhangs, will reduce the cooling load due to windows. Shaded windows are considered as North-facing windows to get ETD's. Most permanent shades will shade only a portion of the window area. Thus, it is necessary to determine the extent of shading, or the shade line, for each window. Table XXIII gives typical shade line factors for several latitudes and window orientation. The shade line will extend downward over the shaded wall for a distance equal to the shade line factor (from Table XVIII) times the overhang width. The shaded portion of the window is then assumed to be a North-facing window for its ETD while the orientation of the remaining portion of the window is not altered for its ETD. Note that NE and NW facing windows are not effectively protected by permanent shades.

3. COOLING LOAD DUE TO INFILTRATION

Infiltration and ventilation air exchanges are smaller in warm weather than in cold weather. The infiltration and ventilation cooling loads given in Table XIX reflect this difference. Infiltration cooling loads are obtained by multiplying the area of the exposed wall area times the factor given in Table XIX for a specific design temperature. Ventilation cooling load is calculated by multiplying the factor in Table XIX times the cfm capacity of the ventilation fans. Most residences do not have mechanical ventilation systems and rely upon infiltration for their ventilation.

4. COOLING LOAD DUE TO OCCUPANCY

The cooling load due to occupants and appliances is usually approximated. The load per occupant is approximately 225 Btu/hr and the number of occupants may be estimated at twice the number of bedrooms unless a lot of large group entertaining is anticipated.

The cooling load due to appliances in most residences can be limited to the kitchen and estimated at 1200 Btu/hr.

5. LATENT COOLING LOAD

The latent cooling load may be estimated at 20 to 30% of the sensible cooling load.

6. TOTAL COOLING LOAD

The total cooling load is the sum of the sensible cooling load through the structural components, windows, infiltration gains, occupancy gains, and moisture removal (latent cooling load).

WORKSHEET 3. COOLING LOAD ESTIMATION

Overall Heat Transmission Coefficients (U)
Exterior Walls 0.081 Btu/hr-ft^2-°F
Ceiling-Roof Combo 0.04 Btu/hr-ft^2-°F
Floors ____ Btu/hr-ft^2-°F
Slabs 50 Btu/hr-ft
Windows 0.58 Btu/hr-ft^2-°F
Doors 0.49 Btu/hr-ft^2-°F

Design Temperatures

Inside Temperature 75°F
Outside Temperature 90°F
Mean Daily Range 21°F

Room	Building Component	Heat Transmission Coefficient (U)	Area	ETD	Conduction Sensible Cooling Load (Btu/hr)	Infiltration Factor	Gross Exposed Wall Area	Infiltration Sensible Cooling Load (Btu/hr)	Occupancy Cooling Load (Btu/hr)	Total Sensible Cooling Load (Btu/hr)	Total Cooling Load (Btu/hr)
	Ext. Walls	0.081	330	18.6	497						
	Ceiling-roof	0.040	225	31.0	279						
	Floor	-	-	-	-						
	Slab		225	0	0						
1	Doors	0.49	0	18.6	0						
	Window (N)	0.58	15	17.0	148						
	Window (W)	0.58	15	56.0	487						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	TOTAL				1411	1.1	360	...	1650	3457	4494
	Ext. walls	0.081	260	18.6	497						
	Ceiling-roof	0.040	300	31.0	372						
	Floor	-	-	-	-						
	Slab	-	225	0	0						
2	Doors	0.49	20	18.6	182						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	TOTAL				946	1.1	280	308	0	1254	1630
	Ext. walls	0.081	495	18.6	746						
	Ceiling-roof	0.040	500	31.0	620						
	Floor	-	-	-	-						
	Slab	-	225	0	0						
3	Doors	0.49	20	18.6	182						
	Window (N)	0.58	30	17.0	296						
	Window (E)	0.58	15	56.0	487						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	TOTAL				2331	1.1	560	616	0	2947	3831

TOTAL COOLING LOAD = 4494 + 1630 + 3831 = 9,955 Btu/hr

E. Estimating Cooling Loads in Buildings

The cooling load for a building can be estimated by using the tables and calculating the heat gained in Btu/hr. From this section you will be able to calculate the cooling loads in buildings. General procedures are as follows:

1. Estimate the overall heat transmission coefficient, (U), for walls, ceilings, roof, windows, doors and floors.

   Refer to Tables II, III, IX, X, XI, XII, and XIII.

2. Figure the surface areas of the walls, ceilings, floor, windows, doors and floors on each room.

3. Find the design indoor and outdoor temperatures.

   Refer to Table III.

4. Determine the equivalent temperature differences, ETD, for each component in each room.

   Refer to Table XVI.

5. Evaluate the conduction sensible cooling load required for each component.

   Use equation 13, $Q_{CS} = UA\ (ETD)$.

6. Evaluate the conduction sensible cooling load for each room.

   Add cooling load for each component.

7. Evaluate the infiltration sensible cooling load in each room by using factors in Table XIX and the gross exterior wall area and mechanical ventilation rates.

8. Evaluate the total sensible cooling load for each room by adding the conduction sensible cooling load and the infiltration sensible cooling loads.

9. Evaluate the total cooling load for each room by increasing the sensible cooling load per room by a factor of 1.3.

   This increase accounts for the cooling load required to remove moisture from the residence.

10. Evaluate the total cooling load by adding the cooling loads for each room.

EXAMPLE NO. 9. COOLING LOAD CALCULATION

Estimate the cooling load for the building plan shown in Figure 11. Additional features are as follows:

- The house orientation with respect to North is as shown.
- The roof is unshaded.
- The roof is light in color.
- The house eaves are too narrow to do any effective shading of windows.
- Desired indoor temperature is 75°F.
- All windows have roller shades half drawn.
- Assume no mechanical ventilation.
- Assume Room 1 is a kitchen and house has two occupants.

Data and calculations are recorded in Worksheet 3 to help you understand how to do a worksheet of your own from a new or existing building.

SOLUTION:

Follow steps given under the following headings:

1. Determining Thermal Resistance (R-Values).
2. Determining Overall Heat Transmission Coefficients (U-Values).
3. Determining Areas of Building Components.
4. Determining Design Temperatures and Mean Daily Range.
5. Finding Equivalent Temperature Differences (ETD's).
6. Calculating Conduction Sensible Cooling Loads.
7. Estimating Occupancy Cooling Loads.
8. Calculating Infiltration Sensible Cooling Loads.
9. Calculating Total Sensible Cooling Loads.
10. Calculating Total Cooling Load.
11. Estimating Seasonal Cooling Load.
12. Comparison of Seasonal Energy Used for Cooling.

1. DETERMINING THERMAL RESISTANCE (R-VALUES)

Follow procedures under "C. Estimating Heating Loads in Buildings," Example Problem No. 6.

2. DETERMINING OVERALL HEAT TRANSMISSION COEFFICIENTS (U-VALUES)

These are discussed under the following headings and given in Worksheet no. 3.

a. Walls.
b. Ceilings.
c. Floors.
d. Windows.
e. Doors.

a. Walls

U = .081 (Example No. 6).

b. Ceilings

The ceiling and roof heat transmission coefficient is combined as in the heat load example. However, the base U-Value changes as the heat flow is now downward instead of upward.

From Table IX, U = 0.262.

From Table X, U = 0.04.

NOTE that U did not change in this example between summer and winter conditions. This is because the R-19 insulation is much greater than any change in R in air spaces between summer and winter modes.

c. Floors

Use Table XI for factor on function of exposed perimeter length (See Example Problem No. 6).

d. Windows

From Table XII, U = 0.58 (Example Problem No. 6).

e. Doors

From Table XIII, U = 0.49, (Example Problem No. 6).

3. DETERMINING AREAS OF BUILDING COMPONENTS

Follow procedures in Example Problem No. 6.

4. DETERMINING DESIGN TEMPERATURES AND MEAN DAILY RANGE

Proceed as follows:

1. Use indoor temperature (t_i) = 75°F.

2. Use outdoor design temperature (t_o) = 90°F.

The 2.5% dry bulb temperature listed in Table II is used. This dry bulb temperature is not exceeded in more than 2.5% of the total homes during the months of June, July, August and September.

3. Find mean daily range of temperature in Table II.

Use 21°F from Table II.

5. FINDING EQUIVALENT TEMPERATURE DIFFERENCES (ETD'S)

Proceed as follows:

1. Find ETD's for all components except windows.

Refer to Table XVI. Enter the table with a design temperature of 90°F, and an M range (mean daily range of temperature, 21°F which lies between 15°F and 25°F.)

ETD (Walls) = 18.6°F
ETD (Doors) = 18.6°F
ETD (Ceiling-Roof) = 31.0°F
ETD (Floor) = 0°F

2. Find ETD for Windows.

Refer to Table XVII (regular double glass--roller shades).

ETD (North Facing) = 17°F
ETD (East Facing) = 56°F
ETD (West Facing) = 56°F

6. CALCULATING CONDUCTION SENSIBLE COOLING LOADS

Find conduction cooling loads for components and rooms. Proceed as follows:

1. Use equation No. 13.

q_{cs} = UA (ETD).

2. Substitute values in formula and compute.

7. ESTIMATING OCCUPANCY COOLING LOADS

For the kitchen, Room 1,
1200 Btu/hr + 2 occ. x 225 = 1650 Btu/hr.

8. CALCULATING INFILTRATION SENSIBLE COOLING LOADS

Calculate air infiltration cooling loads for each room. Proceed as follows:

1. Find factor Table XIX. Infiltration sensible cooling load (q_{is}) = gross exposed wall area x factor in Table XIX.

2. Compute for each room.

q_{is}(room 1) = 1.1 (45x8) = 396 Btu/hr
q_{is}(room 2) = 1.1 (35x8) = 308 Btu/hr
q_{is}(room 3) = 1.1 (70x8) = 616 Btu/hr

See Worksheet 3.

9. CALCULATING TOTAL SENSIBLE COOLING LOADS

Calculate total sensible load for each room. For example, Room No. 1:

1. Add conduction sensible load (Section 6) to infiltration sensible load (Section 8) and occupancy load (Section 7).

Room 1, q = 1411 Btu/hr
Room 1, q_{is} = 396
Room 1, q_{occ} = 1650

Total = 1411 + 396 + 1650

= 3457 Btu/hr

Compute for rooms 2 and 3.
See Worksheet 3.

10. CALCULATING TOTAL COOLING LOAD

Proceed as follows:

1. Add 30% of sensible load for each room. For example, room 1.
2. Multiply sensible load from Section 9 by 1.3 for moisture removal.

   Total cooling load for room 1 = 1.3 x 3457

   = 4494 Btu/hr.
3. Compute for rooms 2 and 3.
4. Add total cooling loads for each room.

   Room 1 = 4494
   Room 2 = 1630
   Room 3 = 3831
   Total 9955 Btu/hr

See Worksheet 3.

11. ESTIMATING SEASONAL COOLING LOAD

As with heating loads, it is often desirable to estimate the seasonal cooling load for a residence. Two simple methods are suggested by ASHRAE for rough estimation. They are the (1) Cooling Degree-Day Method, and (2) Equivalent Full-Load Hours Method.

The Cooling Degree-Day Method is similar to the Degree-Day Method for Seasonal Heating Loads. The difference is that the number of Cooling Degree-Days replace the Heating Degree-Days in the seasonal load equation:

$$q_{sc} = \frac{q \times D_c \times 24}{\Delta t}$$

where
q_{sc} = seasonal cooling load, Btu/season
q = design cooling load, Btu/hr
D_c = cooling degree-days
Δt = cooling design temperature difference, °F.

A cooling degree-day is theoretically a day during which the outdoor temperature is 1°F above the indoor temperature of 65°F. Cooling degree-day values are available from the National Climate Center, Asheville, North Carolina.

The Equivalent Full-Load Hours Method is based upon estimates of the full-load hours of operation of properly sized cooling equipment during normal cooling seasons. The estimates are based upon local observations and are summarized in Table XX. The seasonal cooling load is estimated by multiplying the estimated full-load hours of operation (from Table XX) times the cooling capacity of the air conditioning system (Design cooling load).

Seasonal Cooling Load (Btu) = Estimated full-Load Hours x Design Cooling Load (Btu/hr)

Note that the range of full-load hours is fairly wide for many localities. The values in the table are influenced greatly by the habits and preferences of the building occupants. Indoor temperature settings, use of attic fans, use of air conditioning only during the hottest days and opening windows at night all have a significant effect upon the seasonal energy usage for air conditioning. The values in Table XX are based upon an indoor temperature of 75°F. Utility company surveys indicate that residential buildings will fall near the lower end of the range.

EXAMPLE NO. 10: SEASONAL COOLING LOAD ESTIMATION

Estimate the cooling load for the residence in Example No. 2: Cooling Load Calculation.

1. Evaluate the design cooling load.

Design cooling load = 9,955 Btu/hr (Ex. Problem No. 2)

2. Estimate of Equivalent Full-Load Hours for Building.

Location:
- a. Philadelphia, PA is close to New York, NY, thus, equivalent full-load hours = 500 to 1000 hours.
- b. Use 500 hours for residences.
- c. Then Seasonal Cooling Load = 500 x 9,955 = 4,980,000 Btu.

3. Convert Seasonal Cooling Load to kwh.

$$\frac{\text{kwh}}{\text{season}} = \frac{4{,}980{,}000 \text{ Btu}}{3413 \text{ Btu/kwh}} = 1460 \text{ kwh}$$

12. COMPARISON OF SEASONAL ENERGY USED FOR COOLING

As with seasonal heating loads, it is often desirable to estimate the energy savings realized by use of various energy conservation practices. Cooling load comparisons can be made in a manner identical to that for heating loads. [To illustrate for the uninsulated, a non-weatherstripped house described is the example in the section, "Comparing Energy-Saving Practices."]

EXAMPLE NO. 11: COMPARISON OF COOLING ENERGY USAGE

Use same data as in Example No. 1 (insulated, weatherstripped house) and Example No. 2 (uninsulated and non-weatherstripped house).

1. Evaluate and enter new heat transmission coefficients for walls and ceiling-roof.

2. Calculate and enter new conduction sensible cooling load values.

3. Infiltration values do not change for cooling loads with or without weatherstripping.

4. Occupancy values do not change.

5. Calculate and enter new values of total sensible cooling load.

6. Calculate and enter new values of total cooling load for each room.

7. Calculate and enter new values of total cooling load for building.

The details of steps 1 through 7 are summarized on Worksheet 4. The required changes are handwritten on the worksheet for the cooling load calculation for the insulated house. The result of steps 1 through 7 is that the total, or design, cooling load increases from 9,955 to 22,860 Btu/hr when insulation is removed.

This is an increase of

$$\frac{22,860 - 9,955}{9,955} \times 100 = 130\%!$$

8. Evaluate and compare the cooling energy usage for the insulated and uninsulated house.

Uninsulated house

$$\frac{22,860 \times 500}{3413} = 3350 \text{ kwh}$$

Insulated house (prior example) = 1460 kwh

Difference = 1890 kwh

Thus, the uninsulated house will use approximately 1890 kwh more energy per cooling season than the insulated house. If electrical energy costs 4 1/2¢ per kwh, the dollar savings per year with insulation equals 0.045 x 1890, or $85 per season.

4J

WORKSHEET 4. COOLING LOAD ESTIMATION

Overall Heat Transmission Coefficients (U)
Exterior Walls 0.081 Btu/hr-ft^2-°F .206
Ceiling-Roof Combo 0.04 Btu/hr-ft^2-°F .273
Floors Btu/hr-ft^2-°F
Slabs 50 Btu/hr-ft
Windows 0.58 Btu/hr-ft^2-°F
Doors 0.49 Btu/hr-ft^2-°F

Design Temperatures

Inside Temperature 75°F
Outside Temperature 90°F
Mean Daily Range 21°F

Room	Building Component	Heat Transmission Coefficient (U)	Area	ETD	Conduction Sensible Cooling Load (Btu/hr)	Infiltration Factor	Gross Exposed Wall Area	Infiltration Sensible Cooling Load (Btu/hr)	Occupancy Cooling Load (Btu/hr)	Total Sensible Cooling Load (Btu/hr)	Total Cooling Load (Btu/hr)
	Ext. walls	~~0.081~~ .206	330	18.6	~~497~~ 1,264						
	Ceiling-roof	~~0.040~~ .273	225	31.0	~~279~~ 1,904						
	Floor	-	-	-	-						
	Slab		225	0	0						
1	Doors	0.49	0	18.6	0						
	Window (N)	0.58	15	17.0	148						
	Window (W)	0.58	15	56.0	487						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	TOTAL				1411	1.1	360	396	1650	~~3457~~ 5849	~~4494~~ 7603
	Ext. walls	~~0.081~~ .206	260	18.6	~~497~~ 1,264						
	Ceiling-roof	~~0.040~~ .273	300	31.0	~~372~~ 1,904						
	Floor	-	-	-	-						
	Slab	-	225	0	0						
2	Doors	0.49	20	18.6	182						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	TOTAL				946	1.1	280	308	0	~~1254~~ 4026	~~1630~~ 5234
	Ext. walls	~~0.081~~ .206	495	18.6	~~246~~ 1,897						
	Ceiling-roof	~~0.040~~ .273	500	31.0	~~620~~ 4,232						
	Floor	-	-	-	-						
	Slab	-	225	0	0						
3	Doors	0.49	20	18.6	182						
	Window (N)	0.58	30	17.0	[illegible]						
	Window (E)	0.58	15	56.0	487						
	Window ( )	-	-	-	-						
	Window ( )	-	-	-	-						
	TOTAL				~~2331~~ 7,094	1.1	560	616	0	~~2947~~ 7,710	~~3831~~ 10,023

TOTAL COOLING LOAD = ~~4494~~ + ~~1630~~ + ~~3831~~ = ~~9,955~~ Btu/hr 7603 + 5234 + 10,023 = 22,860 Btu/hr.

F. Determining Cost Benefits of Using Energy-Saving Practices

The bottom line of any energy conserving practice is the relative benefit to cost ratio or the time required to recoup the investment. In other words, the planner or homeowner needs to evaluate whether the energy savings (in dollars) is enough to offset the additional cost of additional insulation. In addition, you may not wish to sacrifice comfort, looks and life-style for some practices.

A benefit/cost analysis allows us to make a direct comparison between the present value of the energy savings (in dollars) over the expected life of the energy-saving practice to the first cost and maintenance of the energy-saving practice. If the benefit/cost ratio exceeds one, the energy-saving practice is economically feasible, whereas if the ratio is less than one, the practice will not pay for itself.

The benefit/cost ratio is evaluated by the formula:

$$\text{Benefit/Cost Ratio} = \frac{\text{Present Value of Net Annual Savings}}{\text{First Cost of the Energy-Saving Practice and Maintenance (if any)}}$$

The present value of the net annual savings is calculated by:

$$\text{Present Value} = \text{Net Annual Savings} \times \text{Present Worth Factor}$$

From your study of this section, you will be able to calculate cost benefits and payback periods for energy-saving practices.

Follow procedures under the following headings:

1. Calculating the Benefit/Cost Ratio.
2. How Expected Life Affects the Benefit/Cost Ratio.
3. How Increase in Fuel Prices Affects the Benefit/Cost Ratio.
4. How Interest Rates Affect the Benefit/Cost Ratio.
5. Calculating the Payback Period.

1. CALCULATING THE BENEFIT/COST RATIO

To illustrate the calculation of the benefit/cost ratio, consider the house in example No. 1 and evaluate the benefit/cost ratio for installing insulation and weatherstripping for the Philadelphia, PA location.

EXAMPLE NO. 12: BENEFIT/COST RATIO

Find the benefit/cost ratio of installing insulation (3 1/2 inches in walls and 5 1/2 inches in the ceiling areas) in the home described in example No. 1.

Assume that the expected life of the insulation and weatherstripping is 25 years, the expected rate of increase in energy cost is 10%, the discount rate is 10%, the cost of materials and installation of 3 1/2 inches of fiberglass in the sidewalls of new constructions is 19 1/2 cents per square foot, the cost of materials and installation of 5 1/2 inches of fiberglass insulation in the ceiling is 27 1/2 cents per square foot and weatherstripping costs 90 cents per linear foot (installed). Perimeter insulation costs 60 cents per square foot. Also assume the home is heated with fuel oil with a present cost of 45 cents per gallon and electrically air conditioned with a present cost of 4 1/2 cents per kwh.

Gallons of fuel saved per year, 800 gallons (heating problem No. 6).

Electricity saved per year, 1890 kwh (cooling problem No. 12).

1. Evaluate the net annual savings realized by insulation and weatherstripping.

Present worth factors are dependent upon the interest rate, the rate of increase in fuel prices, and the expected life of the energy-saving practice. Present worth factors are tabulated for a discount rate of 10%, several price increase rates and expected lives in Table XXI. Multiply this value times the net annual savings (NAS) as found in step 1 to get the present worth. Then find benefit/cost ratio by dividing the present worth by the first cost and maintenance costs (if any). See steps 3 and 4.

(1) Find the net annual savings (NAS) during the first year.

NAS = (Gallons of Fuel Oil Saved) x (Fuel Oil Price) + (kwh Electricity Saved) x (Electricity Price)

= 800 x 0.45 + 1890 x 0.045

= 360.00 + 85.05

= $445.05

(2) Find the present worth of the net annual savings.

This calculation computes the value of all the net annual savings over the expected life of the energy saving practice taking into account the anticipated increase in fuel prices and the increased value of money saved over time (For example, if the $445.05 were deposited in a savings account which earns 10% interest per year, it would be worth $4,821.99 after 25 years).

Present Worth of NAS = (NAS) x Present Worth Factor (Table XXI).

= 445.05 x 25

= $11,126.25

3. Find first cost of insulation and weatherstripping.

Insulation Cost

(1)	Exterior walls - $\$0.195/ft^2$ x 1085 ft^2 =	$211.58
(2)	Ceiling - $\$0.275/ft^2$ x 1025 ft^2 =	$281.88
(3)	Perimeter - $\$0.60/ft^2$ x (150 x 2 ft) =	$180.00
(4)	Total insulation cost	$673.46

Weatherstripping

(1) Linear feet at doors 20 ft/floor x 2 = 40 ft.
(2) Linear feet at windows = 16 ft/window x 5 = 80 ft.
(3) Total linear feet of stripping = 120 ft.
(4) Cost of weatherstripping = 120 ft x 0.90/ft = 108.00

First cost of insulation and weatherstripping.

= 673.46 + 108.00
= $781.46

4. Benefit/Cost Ratio

$$\text{Benefit/Cost Ratio} = \frac{\text{Present value of net savings}}{\text{First cost}}$$

= 11,126.25/781.2

= 14.24%

2. HOW EXPECTED LIFE AFFECTS BENEFIT/COST RATIO

The benefit/cost ratio is influenced significantly by the expected life of the energy conservation practice. The effect of expected life upon the benefit/cost ratio for insulating our example house is illustrated in Table XXII. It was assumed that:

1. The fuel price increases at 10% per year in first example and at 5% in second example.
2. The discount rate is 10% per year.
3. Current fuel costs are 45¢/gal fuel oil and 4.5¢/kwh electricity.
4. First cost of insulation and weatherstripping is $781.46.
5. Fuel savings: fuel oil, 800 gal/yr; electricity, 1890 kwh/yr.

Notice that the benefit/cost ratio increases with the expected life. However, the increase is not necessarily linear. Also note that for a constant discount rate, the benefit/cost ratio increases as the fuel price escalation rate increases.

3. HOW INCREASE IN FUEL PRICES AFFECTS THE BENEFIT/COST RATIO

The benefit/cost ratio is also influenced by the estimated annual increase in fuel prices. The following example demonstrates the change in benefit/cost ratio as the annual rate of increase of fuel varies from 0 to 10%. It is assumed that:

1. The expected life of the energy-saving practice is 7 years.
2. The interest rate is 10%.
3. The current fuel prices and first costs are the same as in the prior examples.
4. Fuel savings: fuel oil - 800 gal/yr and electricity - 1890 kwh/yr.

Note that the benefit/cost ratio increases as the annual percent increase in fuel cost increases (Table XXIII). It is estimated that fuel costs will probably increase at rates at or above 13%.

4. HOW INTEREST RATES AFFECT THE BENEFIT/COST RATIO

Interest rates also affect the benefit/cost ratio. The influence of interest rate upon the ratio can be evaluated with tables similar to Table XXI for various discount rates.

5. CALCULATING THE PAYBACK PERIOD

Other methods for evaluating the economical feasibility is the payback period and the time to recoup capital investment.

The payback period is the first cost divided by net annual savings:

$$\text{Payback Period} = \frac{\text{First Cost}}{\text{Net Annual Savings}}$$

For the previous example, the payback period is evaluated as:

$$\text{Payback Period} = \frac{\$781.46}{445} = 1.76 \text{ years}$$

5

The payback period does not consider the rate of increase in fuel prices, does not include the discount rate for net annual savings. Therefore, it is not as accurate as the <u>time to recoup investment method</u> which is described as follows:

Table XXI of Present Worth Factors (PWF) can be used to estimate the <u>time to recoup investment</u>. Locate the <u>fuel price escalation rate</u> (10% in this example) column. Move down the column until a PWF greater than the payback period is found (2.000 in this example). Thus, the time to recoup the investment lies between 1 and 2 years. By interpolation the time to recoup the investment is:

$$1 \text{ yr} + \frac{1.76 - 1.000}{2.000 - 1.000} = 1 + 0.76, \text{ or}$$

Time to recoup investment = 1.76 years

Note that the time to recoup the investment is the same as the payback period. This occurred in this example because the discount rate and the fuel price escalation rate were identical.

If the discount rate were 10% and the fuel price escalation rate were 5%, the time to recoup investment becomes:

$$1 \text{ yr} + \frac{1.76 - 0.9546}{1.8657 - 0.9546} = 1 + 0.88$$

Time to recoup investment = 1.88 years

Note that when the time value of savings and when the fuel price escalation rate is lower than the discount rate, the time to recoup investment will always be greater than the payback period.

Also note that the difference between the time to recoup investment and the payback period is small in this problem because the payback period is small. In cases where you have a payback period of 3 years or more, the time to recoup investment may be 1.5 to 2 times as long as the payback period.

TABLE I. APPROXIMATE THICKNESS OF INSULATION FOR THERMAL RESIDENCES, IN. (Reference, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Table 7.5, Page 7.21)

Thermal Resistance of Insulation	Batts or Blankets		Loose Fill			Boards and Slabs	
	Glass Fiber	Rock Wool	Glass Fiber	Rock Wool	Cellulosic	Polyurethane	Cellular Glass
R-7	2 1/4 to 2 3/4	2	3 to 4	2 to 3	2	1	2 5/8
R-11	3 1/2 to 4	3	5	4	3	1 3/4	4 1/4
R-13	3 5/8	3 1/2	6	4 to 5	4	2	5
R-19	6 to 6 1/2	5 1/4	8 to 9	6 to 7	5	3	7 1/4
R-22	6 1/2	6	10	7 to 8	6	3 1/2	8 3/8
R-30	9 1/2 to 10 1/2	9	13 to 14	10 to 11	8	4 3/4	11 3/8
R-38	12 to 13	10 1/2	17 to 18	13 to 14	10 to 11	6	14 1/2

TABLE II. OUTSIDE DESIGN TEMPERATURES AND HEATING DEGREE-DAYS (65°F BASE) FOR DIFFERENT CLIMATIC LOCATIONS

(Adapted from Cooling and Heating Load Calculation Manual,
ASHRAE, 1979, Pages 2.3 and 7.16)

State and Station	Winter Design Dry-Bulb		Summer Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Heating Degree Days
	99%	97.5%	1%	2.5%	5%		
ALABAMA							
Huntsville AP	11	16	95/75	92/74	91/74	23	3,070
Mobile AP	25	29	95/77	93/77	91/76	18	1,560
ALASKA							
Fairbanks AP (S)	-51	-47	82/62	78/60	75/59	24	14,279
Kodiak	10	13	69/58	65/56	62/55	10	
ARIZONA							
Flagstaff AP	- 2	4	84/55	82/55	80/54	31	7,152
Phoenix AP (S)	31	34	109/71	107/71	105/71	27	1,765
ARKANSAS							
Fayetteville AP	7	12	97/72	94/73	92/73	23	
Little Rock AP (S)	15	20	99/76	96/77	94/77	22	3,219
CALIFORNIA							
Los Angeles AP (S)	41	43	83/68	80/68	77/67	15	2,061
San Francisco AP	35	38	82/64	77/63	73/62	20	3,001
COLORADO							
Denver AP	- 5	1	93/59	91/59	89/59	28	6,283
Leadville	-18	-14	84/52	81/51	78/50	30	
CONNECTICUT							
Bridgport AP	6	9	86/73	84/71	81/70	18	5,617
Waterbury	- 4	2	88/73	85/71	82/70	21	
DELEWARE							
Dover AFB	11	15	92/75	90/75	87/74	18	
Wilmington AP	10	14	92/74	89/74	87/73	20	4,930
D.C.							
Andrews AFB	10	14	92/75	90/74	87/73	18	4,224
Wash Nat AP	14	17	93/75	91/74	89/74	18	

TABLE II (Continued)

State and Station	Winter Design Dry-Bulb 99%	Winter Design Dry-Bulb 97.5%	Summer Design Dry-Bulb and Mean Coincident Wet-Bulb 1%	Summer Design Dry-Bulb and Mean Coincident Wet-Bulb 2.5%	Summer Design Dry-Bulb and Mean Coincident Wet-Bulb 5%	Mean Daily Range	Heating Degree Days
FLORIDA							
Gainesville AP	28	31	95/77	93/77	92/77	18	
Miami AP (S)	44	47	91/77	90/77	89/77	15	214
Tallahassee							1,485
GEORGIA							
Atlanta AP (S)	17	22	94/74	92/74	90/73	19	2,961
Waycross	26	29	96/77	94/77	91/76	20	
Thomasville							1,529
HAWAII							
Honolulu AP	62	63	87/73	86/73	85/72	12	
Wahiawa	58	59	86/73	85/72	84/72	14	
IDAHO							
Boise AP (S)	3	10	96/65	94/64	91/64	31	5,809
Idaho Falls AP	-11	- 6	89/61	87/61	84/59	38	
ILLINOIS							
Carbondale	2	7	95/77	93/77	90/76	21	
Chicago, O'Hare AP	- 8	- 4	91/74	89/74	86/72	20	6,639
INDIANA							
Fort Wayne AP	- 4	1	92/73	89/72	87/72	24	6,205
Indianapolis AP (S)	- 2	2	92/74	90/74	87/73	22	5,699
IOWA							
Des Moines AP	-10	- 5	94/75	91/74	88/73	23	6,588
Waterloo	-15	-10	91/76	89/75	86/74	23	7,320
KANSAS							
Manhattan, Fort Riley (S)	- 1	3	99/75	95/75	92/74	24	
Wichita AP	3	7	101/72	98/73	96/73	23	4,660
KENTUCKY							
Lexington AP	3	8	93/73	91/73	88/72	22	4,683
Louisville AP	5	10	95/74	93/74	90/74	23	4,660
LOUISIANA							
Natchitoches	22	26	97/77	95/77	93/77	20	
New Orleans	29	33	93/78	92/78	90/77	16	1,385

Table II (Continued)

State and Station	Winter Design Dry-Bulb		Summer Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Heating Degree Days
	99%	97.5%	1%	2.5%	5%		
MAINE							
Caribou AP (S)	-18	-13	84/69	81/67	78/66	21	9,767
Lewiston	-7	- 2	88/73	85/70	82/68	22	
MARYLAND							
Baltimore CO	14	17	92/77	89/76	87/75	17	4,111
Frederick	8	12	94/76	91/75	88/74	22	
MASSACHUSETTS							
Boston AP (S)	6	9	91/73	88/71	85/70	16	5,634
Springfield, Westover AFB	- 5	0	90/72	87/71	84/69	19	
MICHIGAN							
Detroit	3	6	91/73	88/72	86/71	20	6,232
Sault Ste. Marie AP (S)	-12	- 8	84/70	81/69	77/66	23	9,048
MINNESOTA							
Intn'l Falls AP	-29	-25	85/68	83/68	80/66	26	
Minneapolis, St. Paul AP	-16	-12	92/75	89/73	86/71	22	8,382
MISSISSIPPI							
Biloxi. Keesler AFB	28	31	94/79	92/79	90/78	16	
Tupelo	14	19	96/77	94/77	92/76	22	2,041
MISSOURI							
Kansas City AP	2	6	99/75	96/74	93/74	20	4,711
St. Louis AP	2	6	97/75	94/75	91/74	21	4,900
MONTANA							
Bozeman	-20	-14	90/61	87/60	84/59	32	
Missoula AP	-13	- 6	92/62	88/61	85/60	36	8,125
NEBRASKA							
Lincoln CO (S)	- 5	- 2	99/75	95/74	92/74	24	5,864
Omaha AP	- 8	- 3	94/76	91/75	88/74	22	6,612
NEVADA							
Las Vegas AP(S)	25	28	108/66	106/65	104/65	30	2,709
Reno AP (S)	5	10	95/61	92/60	90/59	45	6,332

Table II (Continued)

State and Station	Winter Design Dry-Bulb 99%	Winter Design Dry-Bulb 97.5%	Summer Design Dry-Bulb and Mean Coincident Wet-Bulb 1%	Summer Design Dry-Bulb and Mean Coincident Wet-Bulb 2.5%	Summer Design Dry-Bulb and Mean Coincident Wet-Bulb 5%	Mean Daily Range	Heating Degree Days
NEW HAMPSHIRE							
Keene	-12	- 7	90/72	87/70	83/69	24	7,383
Portsmouth, Pease AFB	- 2	2	90/73	85/71	83/70	22	
NEW JERSEY							4,500
NEW MEXICO							
Albuquerque AP(S)	12	16	96/61	94/61	92/61	27	4,348
Raton AP	- 4	1	91/60	89/60	87/60	34	6,228
NEW YORK							
NYC-Kennedy AP	12	15	90/73	87/72	84/71	16	5,219
Utica	-12	- 6	88/73	85/71	82/70	22	
NORTH CAROLINA							
Asheville AP	10	14	89/73	87/72	85/71	21	4,042
Raleigh/ Durham AP (S)	16	20	94/75	92/75	90/75	20	3,393
NORTH DAKOTA							9,000
OHIO							
Cincinnati CO	1	6	92/73	90/72	88/72	21	4,410
Cleveland AP (S)	1	5	91/73	88/72	86/71	22	6,351
OKLAHOMA							
Lawton AP	12	16	101/74	99/74	96/74	24	
Oklahoma City AP (S)	9	13	100/74	97/74	95/73	23	3,725
OREGON							
Pendleton AP	- 2	5	97/65	93/64	90/62	29	5,127
Portland AP	17	23	89/68	85/67	81/65	23	4,635
PENNSYLVANIA							
Philadelphia AP	10	14	93/75	90/74	87/72	21	5,144
Pittsburgh AP	1	5	89/72	86/71	84/70	22	5,987
RHODE ISLAND							
Newport (S)	5	9	88/73	85/72	82/70	16	
Providence AP	5	9	89/73	86/72	83/70	19	5,954

Table II (Continued)

State and Station	Winter Design Dry-Bulb		Summer Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Heating Degree Days
	99%	97.5%	1%	2.5%	5%		
SOUTH CAROLINA							
Greenville AP	18	22	93/74	91/74	89/74	21	2,980
Spartanburg AP	18	22	93/74	91/74	89/74	20	
SOUTH DAKOTA							
Brookings	-17	-13	95/73	92/72	89/71	25	
Rapid City AP (S)	-11	- 7	95/66	92/65	89/65	28	7,345
TENNESSEE							
Knoxville AP	13	19	94/74	92/73	90/73	21	3,494
Memphis AP	13	18	98/77	95/76	93/76	21	3,232
TEXAS							
Amarillo AP	6	11	98/67	95/67	93/67	26	3,985
Dallas AP	18	22	102/75	100/75	97/75	20	2,363
Houston CO	28	33	97/77	95/77	93/77	18	1,278
UTAH							
Logan	- 3	2	93/62	91/61	88/60	33	
Salt Lake City AP (s)	3	8	97/62	96/62	92/61	32	6,052
VERMONT							
Barre	-16	-11	84/71	81/69	78/68	23	
Burlington AP (S)	-12	- 7	88/72	85/70	82/69	23	8,269
VIRGINIA							
Norfolk AP	20	22	93/77	91/76	89/76	18	3,421
Roanoke AP	12	16	93/72	91/72	88/71	23	4,150
WASHINGTON							
Seattle-Tacoma AP (S)	21	26	84/65	80/64	76/62	22	5,145
Spokane AP (S)	- 6	2	93/64	90/63	87/62	28	6,655
WEST VIRGINIA							
Morgantown AP	4	8	90/74	87/73	85/73	22	4,500
Wheeling	1	5	89/72	86/71	84/70	21	
WISCONSIN							
Ashland	-21	-21	85/70	82/68	79/66	23	7,635
Milwaukee AP	- 8	- 4	90/74	87/73	84/71	21	
WYOMING							
Cheyenne AP	- 9	- 1	89/58	86/58	84/57	30	7,381
Laramie AP (S)	-14	- 6	84/56	81/56	79/55	28	

TABLE III. CONDUCTIVITY OF SOME BUILDING MATERIALS

(Adapted from Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Page 3.4)

	Conductivity (k)
Hardboard, Medium Density	.73
Particleboard, Medium Density	.94
Polystyrene, Smooth Skin	.20
Glass Fiber, Organic Bonded	.25
Wood, Medium Density	1.49

TABLE IV. CONDUCTANCE OF SOME BUILDING MATERIALS

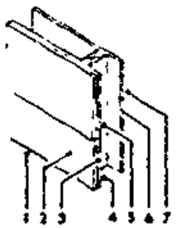
(Adapted from Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Page 3.4)

	Thickness (in)	Conductance (C)
Plywood	.5	1.60
Carpet and Fiberous Pad	-	.48
Mineral Fiber	3.5	.053
Concrete Block, Sand and Gravel	8	.90
Asphalt Shingle		2.27

TABLE V. COEFFICIENTS OF HEAT TRANSFER (U) THROUGH FRAME WALLS*

*(Reference, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Table 3.2A, Page 3.8)

These U coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides) and are based on an outside wind velocity of 15 mph. The Heat Capacity Units are Btu/ft²·F



Replace Air Space with 3.5-in. R-11 Blanket Insulation (New Item 4)

Construction	1 Resistance (R) Between Framing	1 Resistance (R) At Framing	2 Resistance (R) Between Framing	2 Resistance (R) At Framing	1 Heat Capacity Between Framing	2 Heat Capacity Between Framing
1. Outside surface (15 mph wind)	0.17	0.17	0.17	0.17		-
2. Siding, wood, 0.5 in × 8 in. lapped (average)	0.81	0.81	0.81	0.81	0.47	0.47
3. Sheathing, 0.5-in. asphalt impregnated	1.32	1.32	1.32	1.32	0.23	0.23
4. Nonreflective air space, 3.5 in. (50 F mean; 10 deg F temperature difference)	1.01	—	11.00	—		08
5. Nominal 2-in. × 4-in. wood stud	—	4.38	—	4.38	-	--
6. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
7. Inside surface (still air)	0.68	0.68	0.68	0.68		
Total Thermal Resistance (R)	R_i=4.44	R_s=7.81	R_i=14.43	R_s=7.81	1.24	1.32

Construction No. 1: $U_i = 1/4.44 = 0.225$; $U_s = 1/7.81 = 0.128$. With 20% framing (typical of 2-in. × 4-in. studs @ 16-in. o.c.), $U_{av} = 0.8 (0.225) + 0.2 (0.128) = 0.206$ (See Eq 9)

Construction No. 2: $U_i = 1/14.43 = 0.069$, $U_s = 0.128$. With framing unchanged, $U_{av} = 0.8(0.069) + 0.2(0.128) = 0.081$

TABLE VI. AIR EXCHANGES IN RESIDENCES FOR TYPICAL DESIGN CONDITIONS*
(Adapted from Tables 7.11A and 7.11B, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Page 7.23)

Type Room	Changes/Hour
Room w/o windows or exterior doors	0.5
Rooms with windows or exterior doors on one side	1.0
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exterior doors on three sides	2.0
Entrance halls	2.0

*Use 2/3 of tabulated values for weatherstripped windows or storm sashes.

TABLE VII. RECOMMENDED VENTILATION AIR VOLUME FOR SINGLE FAMILY RESIDENCES
(Adapted from Cooling and Heating Load Calculation Manual, ASHRAE, 1977, Page 5.12)

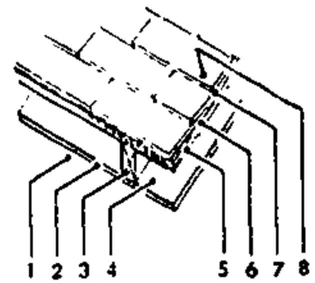
Room	Ventilation Air Per Occupant Minimum (cu ft/min)	Ventilation Air Per Occupant Recommended (cu ft/min)
General living areas; bedroom, utility areas	5.0	7.0-10.0
Kitchens, bathrooms	20.0	30.0-50.0

TABLE VIII. SOL-AIR TEMPERATURES FOR JULY 21 AT 40°N LATITUDE
(Adapted from Fundamentals Handboook, 1977, ASHRAE, Page 25.5)

Time	Air Temp.	Light Surfaces N	E	S	W	HOR	Dark Surfaces N	E	S	W	HOR
4	74	74	74	74	74	67	74	74	74	74	67
8	77	82	114	83	81	96	87	151	89	96	122
12	90	96	97	112	97	127	103	104	134	104	172
16	94	99	98	100	131	113	104	103	106	168	139
20	85	85	85	85	85	78	85	85	85	85	85
24	77	77	77	77	77	70	77	77	77	77	70
Avg.	83	86	91	89	91	91	89	100	85	100	107

TABLE IX. COEFFICIENTS OF HEAT TRANSFER (U) THROUGH PITCHED ROOFS[a]
(Reference, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Page 3.11)

Coefficients are expressed in Btu per (hour) (square foot) (degree Fahrenheit difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph for heat heat flow upward and 7.5 mph for heat flow downward. The Heat Capacity Units are Btu ft² · F.



Find U_{av} for same Construction 2 with Heat Flow Down (Summer Conditions)

Construction 1 (Heat Flow Up) (Reflective Air Space)	Resistance (R) 1 Between Rafters	1 At Rafters	2 Between Rafters.	2 At Rafters	Heat Capacity 1 Between Rafters	Heat Capacity 2 Between Rafters
1. Inside surface (still air)	0.62	0.62	0.76	0.76		—
2. Gypsum wallboard 0.5 in., foil backed	0.45	0.45	0.45	0.45	0.54	0.54
3. Nominal 2-in. × 4-in. ceiling rafter	—	4.38	—	4.38		—
4. 45 deg slope reflective air space, 3.5 in. (50 F mean, 30 deg F temperature difference)	2.17	—	4.33	—	—	—
5. Plywood sheathing, 0.625 in.	0.78	0.78	0.78	0.78	0.51	0.51
6. Felt building membrane	0.06	0.06	0.06	0.06	Neg	Neg
7. Asphalt shingle roofing	0.44	0.44	0.44	0.44	0.33	0.33
8. Outside surface (15 mph wind)	0.17	0.17	0.25**	0.25**		
Total Thermal Resistance (R)	R_i=4.69	R_s=6.90	R_i=7.07	R_s=7.12	1.38	1.38

Construction No. 1: U_i=1/4.69= 0.213; U_s = 1/6.90 = 0.145. With 10% framing (typical of 2-in. rafters @16-in. o.c.), U_{av}= 0.9 (0.213) + 0.1 (0.145) = 0.206

Construction No. 2: U_i=1/7.07 = 0.141; U_s = 1/7.12 = 0.140. With framing unchanged, U_{av}= 0.9 (0.141) + 0.1 (0.140) = 0.141

Find U_{av} for same Construction 2 with Heat Flow Down (Summer Conditions)

Construction 1 (Heat Flow Up) (Non-Reflective Air Space)	Resistance (R) 3 Between Rafters	3 At Rafters	4 Between Rafters	4 At Rafters	Heat Capacity 3 Between Rafters	Heat Capacity 4 Between Rafters
1. Inside surface (still air)	0.62	0.62	0.76	0.76	—	—
2. Gypsum wallboard, 0.5 in.	0.45	0.45	0.45	0.45	0.54	0.54
3. Nominal 2-in. × 4-in. ceiling rafter	—	4.38	—	4.38		
4. 45 deg slope, nonreflective air space, 3.5 in. (50 F mean; 10 deg F temperature difference)	0.96	—	0.90*	—		
5. Plywood sheathing, 0.625 in.	0.78	0.78	0.78	0.78	0.51	0.51
6. Felt building membrane	0.06	0.06	0.06	0.06	Neg	Neg
7. Asphalt shingle roofing	0.44	0.44	0.44	0.44	0.33	0.33
8. Outside surface (15-mph wind)	0.17	0.17	0.25**	0.25**	—	—
Total Thermal Resistance (R)	R_i=3.48	R_s=6.90	R_i=3.64	R_s=7.12	1.38	1.38

Construction No. 3: U_i= 1/3.48 = 0.287; U_s = 1/6.90 = 0.145. With 10% framing typical of 2-in. rafters @ 16-in. o.c.), U_{av}= 0.9 (0.287)+ 0.1 (0.145) = 0.273

Construction No. 4: U_i= 1/3.64 = 0.275; U_s = 1/7.12 = 0.140 With framing unchanged, U_{av}= 0.9 (0.275) + 0.1 (0.140) = 0.262

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[a] Pitch of roof - 45 deg

*Air space value at 90 F mean, 10 deg F temperature difference.

**7.5 mph wind

TABLE X. DETERMINATION OF U-VALUE RESULTING FROM ADDITION OF INSULATION TO THE TOTAL AREA[e] OF ANY GIVEN BUILDING SECTION (Adapted from Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Table A3.1, Page A3.4)

GIVEN BLDG SECTION PROPERTY		ADDITIONAL THERMAL INSULATION, R[a,b], (hr·ft^2·F)/Btu														
U	*R*	1	2	3	4	5	6	7	9	11	13	15	17	19	30	38
0.08	12.5	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.047	0.043	0.039	0.036	0.034	0.032	0.024	0.020
0.10	10.0	0.091	0.083	0.077	0.071	0.067	0.063	0.059	0.053	0.048	0.043	0.040	0.037	0.034	0.025	0.021
0.12	8.3	0.107	0.097	0.088	0.081	0.075	0.070	0.065	0.058	0.052	0.047	0.043	0.039	0.037	0.026	0.022
0.14	7.1	0.123	0.109	0.099	0.090	0.082	0.076	0.071	0.062	0.055	0.050	0.045	0.041	0.038	0.027	0.022
0.16	6.3	0.138	0.124	0.108	0.098	0.089	0.082	0.075	0.066	0.058	0.052	0.047	0.043	0.040	0.028	0.023
0.18	5.6	0.153	0.132	0.117	0.105	0.095	0.087	0.080	0.069	0.060	0.054	0.049	0.044	0.041	0.028	0.023
0.20	5.0	0.167	0.143	0.125	0.111	0.100	0.091	0.083	0.071	0.063	0.056	0.050	0.045	0.042	0.029	0.023
0.22	4.5	0.180	0.153	0.133	0.117	0.105	0.095	0.087	0.074	0.064	0.057	0.051	0.046	0.042	0.029	0.024
0.24	4.2	0.194	0.162	0.140	0.122	0.109	0.098	0.090	0.076	0.066	0.058	0.052	0.047	0.043	0.029	0.024
0.26	3.8	0.206	0.171	0.146	0.127	0.113	0.102	0.092	0.078	0.067	0.059	0.053	0.048	0.044	0.030	0.024
0.28	3.6	0.219	0.179	0.152	0.132	0.117	0.104	0.095	0.080	0.069	0.060	0.054	0.049	0.044	0.030	0.024
0.30	3.3	0.231	0.188	0.158	0.136	0.120	0.107	0.097	0.081	0.070	0.061	0.055	0.049	0.045	0.030	0.024
0.40	2.5	0.286	0.222	0.182	0.154	0.133	0.118	0.105	0.087	0.074	0.065	0.057	0.051	0.047	0.031	0.025
0.50	2.0	0.333	0.250	0.200	0.167	0.143	0.125	0.111	0.091	0.077	0.067	0.059	0.053	0.048	0.031	0.025
0.60	1.7	0.375	0.273	0.214	0.176	0.150	0.130	0.115	0.094	0.079	0.068	0.060	0.054	0.048	0.032	0.025
0.70	1.4	0.412	0.292	0.226	0.184	0.156	0.135	0.119	0.096	0.080	0.069	0.061	0.054	0.049	0.032	0.025

[a] If the insulation occupies a previously considered air space, an adjustment must be made in the given building section *R*-value

[b] Adjust for furring or framing sections as necessary, separately

TABLE XI. HEAT LOSS OF CONCRETE FLOORS AT OR NEAR GROUND LEVEL PER FOOT OF EXPOSED EDGE (LESS THAN 3 FT BELOW GRADE) (Reference, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Table 7.9A, Page 7.22)

Outdoor Design Temperature, F	Heat Loss per Foot of Exposed Edge, Btu/(hr·ft)		
	R = 5.0 Edge Insulation	R = 2.5 Edge Insulation	No Edge Insulation[a]
20 to -30	50	60	75
10 to 20	45	55	65
0 to -10	40	50	60
+10 to 0	35	45	55
+20 to +10	30	40	50

[a] This construction not recommended, shown for comparison only.

TABLE XII. OVERALL COEFFICIENTS OF HEAT TRANSMISSION (U-FACTOR) OF WINDOWS AND SKYLIGHTS, Btu/(hr·ft^2·F)

(Reference, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Table 3.14A, Page 3.24)

Table 3.14A Overall Coefficients[a] of Heat Transmission (*U*-Factor) of Windows and Skylights, Btu/(hr · ft^2 · F)

Description[k]	Exterior Vertical Panels				Exterior Horizontal Panels (Skylights)	
	Summer**		Winter*		Summer[j]	Winter[i]
	No Indoor Shade	Indoor Shade***	No Indoor Shade	Indoor Shade***		
Flat Glass[b]						
Single Glass	1.04	0.81	1.10	0.83	0.83	1.23
Insulating Glass, Double[c]						
3/16 in. air space[d]	0.65	0.58	0.62	0.52	0.57	0.70
1/4 in. air space[d]	0.61	0.55	0.58	0.48	0.54	0.65
1/2 in. air space[e]	0.56	0.52	0.49	0.42	0.49	0.59
1/2 in. air space, low emittance coating[f]						
$\epsilon = 0.20$	0.38	0.37	0.32	0.30	0.36	0.48
$\epsilon = 0.40$	0.45	0.44	0.38	0.35	0.42	0.52
$\epsilon = 0.60$	0.51	0.48	0.43	0.38	0.46	0.56
Insulating Glass, Triple[c]						
1/4 in. air space[d]	0.44	0.40	0.39	0.31		
1/2 in. air space[e]	0.39	0.36	0.31	0.26		
Storm Windows						
1 in. to 4 in. air space[g]	0.50	0.48	0.50	0.42		
Plastic Bubbles[h]						
Single Walled					0.80	1.15
Double Walled					0.46	0.70

Table 3.14B Adjustment Factors for Various Window and Sliding Patio Door Types (Multiply *U*-Values in Part A by These Factors)

Description	Single Glass	Double or Triple Glass	Storm Windows
Windows			
All Glass[h]	1.00	1.00	1.00
Wood Sash; 80% Glass	0.90	0.95	0.90
Wood Sash; 60% Glass	0.80	0.85	0.80
Metal Sash; 80% Glass	1.00	1.20[m]	1.20[m]
Sliding Patio Doors			
Wood Frame	0.95	1.00	—
Metal Frame	1.00	1.10[m]	—

[a] See Table 3.14B for adjustments for various windows and sliding patio doors.

[b] Emittance of uncoated glass surface = 0.84.

[c] Double and triple refer to number of lights of glass.

[d] 0.125-in. glass.

[e] 0.25-in. glass

[f] Coating on either glass surface facing air space; all other glass surfaces uncoated.

[g] Window design. 0.25-in. glass, 0.125-in. glass, 0.25-in. glass

[h] Refers to windows with negligible opaque areas

[i] For heat flow up

[j] For heat flow down.

[k] Based on area of opening, not total surface area

[m] Values will be less than these when metal sash and frame incorporate thermal breaks. In some thermal break designs U values will be equal to or less than those for the glass. Window manufacturers should be consulted for specific data.

*15 mph outdoor air velocity; 0 F outdoor air; 70 F inside air temp natural convection.

**7.5 mph outdoor air velocity; 89 F outdoor air, 75 F inside air natural convection; solar radiation 248.3 Btu/(hr · ft^2)

***Values apply to tightly closed venetian and vertical blinds, draperies, and roller shades.

The reciprocal of the above *U*-factors is the thermal resistance, *R*, for each type of glazing. If tightly drawn drapes (heavy close weave), closed Venetian blinds, or closely fitted roller shades are used internally, the additional *R* is approximately 0.29 (hr · ft^2 · F)/Btu. If miniature louvered solar screens are used in close proximity to the outer fenestration surface, the additional *R* is approximately 0.24 (hr · ft^2 · F)/Btu

TABLE XIII. COEFFICIENTS OF TRANSMISSION (U) THROUGH DOORS, Btu per (hr·ft^2·F)

Thickness[a]	Winter			Summer
	Solid Wood, No Storm Door	Storm Door[b]		No Storm Door
		Wood	Metal	
1-in.	0.64	0.30	0.39	0.61
1.25-in.	0.55	0.28	0.34	0.53
1.5-in.	0.49	0.27	0.33	0.47
2-in.	0.43	0.24	0.29	0.42
	Steel Door			
1.75 in.				
A[c]	0.59	—	—	0.58
B[d]	0.19	—	—	0.18
C[e]	0.47	—	—	0.46

[a] Nominal thickness.

[b] Values for wood storm doors are for approximately 50% glass; for metal storm door values apply for any percent of glass.

[c] A = Mineral fiber core (2 lb/ft^3).

[d] B = Solid urethane foam core with thermal break.

[e] C = Solid polystyrene core with thermal break

TABLE XIV. CORRECTION FACTORS FOR HEAT LOSS VS. DEGREE DAYS INTERIM FACTOR C_D[a] (Reference Systems Handbook, ASHRAE, 1976, Page 43.8)

Outdoor Design Temp. F	-20	-10	0	+10	+20
Factor C_D	0.57	0.64	0.71	0.79	0.89

[a] The multipliers in Table 2 which are high for mild climates and low for cold regions, are not in error as might appear. For equivalent buildings, those in warm climates have a greater portion of their heating requirements on days when the mean temperature is close to 65 F. and thus the actual heat loss is not reflected.

TABLE XV. PART LOAD CORRECTION FACTOR (C_F) FOR FUEL-FIRED EQUIPMENT (Reference, Systems Handbook, ASHRAE, 1976, Page 43.8)

Percent oversizing	0	20	40	60	80
Factor C_f	1.36	1.56	1.79	2.04	2.32

[a] Because equipment performance at extremely low loads is highly variable, it is strongly recommended that the values in Table 3 not be extrapolated

TABLE XVI. DESIGN EQUIVALENT TEMPERATURE DIFFERENCES (ETD) FOR WALLS, CEILINGS AND FLOORS (Reference, Cooling and Heating Load Calculation Manual, ASHRAE, 1979, Table 7.8, Page 7.22)

Design Temperature, deg F	85		90			95			100		105	110
Daily Temperature Range *	L	M	L	M	H	L	M	H	M	H	H	H
WALLS AND DOORS												
1. Frame and veneer-on-frame	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
2. Masonry walls, 8-in. block or brick	10.3	6.3	15.3	11.3	6.3	20.3	16.3	11.3	21.3	16.3	21.3	26.3
3. Partitions, frame	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
masonry	2.5	0	7.5	3.5	0	12.5	8.5	3.5	13.5	8.5	13.5	18.5
4. Wood doors	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
CEILINGS AND ROOFS[b]												
1. Ceilings under naturally vented attic or vented flat roof—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
2. Built-up roof, no ceiling—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
3. Ceilings under unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
FLOORS												
1. Over unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
2. Over basement, enclosed crawl space or concrete slab on ground	0	0	0	0	0	0	0	0	0	0	0	0
3. Over open crawl space	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0

[a] Daily Temperature Range
L (Low) Calculation Value, 12 deg F. Applicable Range, Less than 15 deg F.
M (Medium) Calculation Value: 20 deg F. Applicable Range, 15 to 25 deg F.
H (High) Calculation Value: 30 deg F. Applicable Range: More than 25 deg F.

[b] Ceiling and Roofs. For roofs in shade, 18-hr average = 11 deg temperature differential. At 90 deg F design and medium daily range, equivalent temperature differential for light-colored roof equals 11 + (0.71)(39 − 11) = 31 deg F.

TABLE XVII. DESIGN COOLING LOAD FACTORS THROUGH GLASS (ETD)
(Reference, Cooling and Heating Load Calculation Manual,
ASHRAE, 1979, Table 7.6, Page 7.21)

Outdoor	Regular Single Glass						Regular Double Glass						Heat Absorbing Double Glass						Clear Triple Glass		
Design Temp	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95
No Awnings or inside Shading																					
North	23	27	31	35	39	44	19	21	24	26	28	30	12	14	17	19	21	23	17	19	20
NE and NW	56	60	64	68	72	77	46	48	51	53	55	57	27	29	32	34	36	38	42	43	44
East and West	81	85	89	93	97	102	68	70	73	75	77	79	42	44	47	49	51	53	62	63	64
SE and SW	70	74	78	82	86	91	59	61	64	66	68	70	35	37	40	42	44	46	53	55	56
South	40	44	48	52	56	61	33	35	38	40	42	44	19	21	24	26	28	30	30	31	33
Horiz. Skylight	160	164	168	172	176	181	139	141	144	146	148	150	89	91	94	96	98	100	126	127	129
Draperies or Venetian Blinds																					
North	15	19	23	27	31	36	12	14	17	19	21	23	9	11	14	16	18	20	11	12	14
NE and NW	32	36	40	44	48	53	27	29	32	34	36	38	20	22	25	27	29	31	24	26	27
East and West	48	52	56	60	64	69	42	44	47	49	51	53	30	32	35	37	39	41	38	39	41
SE and SW	40	44	48	52	56	61	35	37	40	42	44	46	24	26	29	31	33	35	32	33	34
South	23	27	31	35	39	44	20	22	25	27	29	31	15	17	20	22	24	26	18	19	21
Roller Shades Half-Drawn																					
North	18	22	26	30	34	39	15	17	20	22	24	26	10	12	15	17	19	21	13	14	15
NE and NW	40	44	48	52	56	61	38	40	43	45	47	49	24	26	29	31	33	35	34	35	35
East and West	61	65	69	73	77	82	54	56	59	61	63	65	35	37	40	42	44	46	49	49	50
SE and SW	52	56	60	64	68	73	46	48	51	53	55	57	30	32	35	37	39	41	41	42	43
South	29	33	37	41	45	50	27	29	32	34	36	38	18	20	23	25	27	29	25	26	26
Awnings																					
North	20	24	28	32	36	41	13	15	18	20	22	24	10	12	15	17	19	21	11	12	13
NE and NW	21	25	29	33	37	42	14	16	19	21	23	25	11	13	16	18	20	22	12	13	14
East and West	22	26	30	34	38	43	14	16	19	21	23	25	12	14	17	19	21	23	12	13	14
SE and SW	21	25	29	33	37	42	14	16	19	21	23	25	11	13	16	18	20	22	12	13	14
South	21	24	28	32	36	41	13	15	18	20	22	24	11	13	16	18	20	22	11	12	13

TABLE XVIII. SHADE LINE FACTORS FOR WINDOWS

(Reference, Cooling and Heating Load Calculation Manual, Table 7.7, Page 7.20)

Direction Window Faces	N Latitude, Deg						
	25	30	35	40	45	50	55
E/W	0.8	0.8	0.8	0.8	0.8	0.8	0.8
SE/SW	1.9	1.6	1.4	1.3	1.1	1.0	0.9
S	10.1	5.4	3.6	2.6	2.0	1.7	1.4

Note: Distance shadow line falls below the edge of the overhang equals shade line factor multiplied by width of overhang. Values are averages for 5 hr of greatest solar intensity on August 1.

TABLE XIX. SENSIBLE COOLING LOAD DUE TO INFILTRATION AND VENTILATION

(Reference, Fundamentals Handbook, ASHRAE, 1977, Table 38, Page 25.41)

Design Temperature, F	85	90	95	100	105	110
Infiltration, Btuh/ft^2 of gross exposed wall area	0.7	1.1	1.5	1.9	2.2	2.6
Mechanical ventilation, Btuh/cfm	11.0	16.0	22.0	27.0	32.0	38.0

TABLE XX. ESTIMATED EQUIVALENT RATED FULL-LOAD HOURS OF OPERATION FOR COOLING EQUIPMENT

(Reference, Systems Handbook, 1976, Table 5, Page 43.9)

Albuquerque, NM	800-2200	Indianapolis, IN	600-1600
Atlantic City, NJ	500-800	Little Rock, AR	1400-2400
Birmingham, AL	1200-2200	Minneapolis, MN	400-800
Boston, MA	400-1200	New Orleans, LA	1400-2800
Burlington, VT	200-600	New York, NY	500-1000
Charlotte, NC	700-1100	Newark, NJ	400-900
Chicago, IL	500-1000	Oklahoma City, OK	1100-2000
Cleveland, OH	400-800	Pittsburgh, PA	900-1200
Cincinnati, OH	1000-1500	Rapid City, SD	800-1000
Columbia, SC	1200-1400	St. Joseph, MO	1000-1600
Corpus Christi, TX	2000-2500	St. Petersburg, FL	1500-2700
Dallas, TX	1200-1600	San Diego, CA	800-1700
Denver, CO	400-800	Savannah, GA	1200-1400
Des Moines, IA	600-1000	Seattle, WA	400-1200
Detroit, MI	700-1000	Syracuse, NY	200-1000
Duluth, MN	300-500	Trenton, NJ	800-1000
El Paso, TX	1000-1400	Tulsa, OK	1500-2200
Honolulu, HI	1500-3500	Washington, DC	700-1200

TABLE XXI. UNIFORM PRESENT VALUE DISCOUNT FACTORS FOR ENERGY PRICE ESCALATION RATES FROM 0% TO 10% (BASED ON A 10% DISCOUNT RATE)

(Reference, Life Cycle Costing, NBS, 1978)

	Energy Price Escalation Rates										
Year	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9091	0.9182	0.9273	0.9364	0.9455	0.9546	0.9636	0.9727	0.9818	0.9909	1.0000
2	1.7355	1.7612	1.7871	1.8131	1.8393	1.8657	1.8921	1.9188	1.9457	1.9727	2.0000
3	2.4868	2.5353	2.5844	2.6340	2.6844	2.7354	2.7869	2.8391	2.8921	2.9456	3.0000
4	3.1698	3.2460	3.3237	3.4027	3.4834	3.5656	3.6492	3.7344	3.8213	3.9097	4.0000
5	3.7907	3.8986	4.0092	4.1225	4.2388	4.3581	4.4801	4.6053	4.7336	4.8650	5.0000
6	4.3552	4.4978	4.6449	4.7966	4.9531	5.1146	5.2808	5.4524	5.6294	5.8117	6.0000
7	4.8684	5.0480	5.2344	5.4278	5.6284	5.8367	6.0524	6.2765	6.5089	6.7498	7.0000
8	5.3449	5.5521	5.7810	6.0188	6.2669	6.5260	6.7959	7.0780	7.3723	7.6793	8.0000
9	5.7590	6.0159	6.2878	6.5722	6.8705	7.1839	7.5124	7.8577	8.2201	8.6004	9.0000
10	6.1445	6.4417	6.7577	7.0903	7.4411	7.8118	8.2028	8.6161	9.0524	9.5130	10.0000
11	6.4930	6.8328	7.1935	7.5755	7.9807	8.4113	8.8682	9.3539	9.8696	10.4174	11.0000
12	6.8137	7.1919	7.5977	8.0299	8.4909	8.9837	9.5095	10.0717	10.6722	11.3138	12.0000
13	7.1034	7.5216	7.9725	8.4553	8.9733	9.5300	10.1274	10.7698	11.4601	12.2020	13.0000
14	7.3667	7.8243	8.3199	8.8536	9.4293	10.0513	10.7227	11.4487	12.2335	13.0819	14.0000
15	7.6061	8.1022	8.6421	9.2266	9.8604	10.5490	11.2964	12.1092	12.9929	13.9539	15.0000
16	7.8238	8.3574	8.9408	9.5758	10.2680	11.0240	11.8492	12.7516	13.7384	14.8178	16.0000
17	8.0216	8.5918	9.2179	9.9029	10.6535	11.4776	12.3821	13.3767	14.4706	15.6742	17.0000
18	8.2014	8.8069	9.4747	10.2090	11.0177	11.9103	12.8953	13.9844	15.1891	16.5223	18.0000
19	8.3649	9.0044	9.7129	10.4957	11.3622	12.3235	13.3900	14.5757	15.8947	17.3630	19.0000
20	8.5135	9.1857	9.9337	10.7641	11.6878	12.7178	13.8666	15.1507	16.5873	18.1958	20.0000
21	8.6486	9.3512	10.1385	11.0154	11.9957	13.0942	14.3259	15.7101	17.2674	19.0211	21.0000
22	8.7715	9.5042	10.3285	11.2509	12.2870	13.4537	14.7688	16.2546	17.9355	19.8394	22.0000
23	8.8832	9.6446	10.5046	11.4714	12.5623	13.7968	15.1955	16.7841	18.5913	20.6501	23.0000
24	8.9847	9.7735	10.6679	11.6777	12.8225	14.1241	15.6065	17.2989	19.2349	21.4531	24.0000
25	9.0770	9.8919	10.8193	11.8710	13.0686	14.4367	16.0026	17.7998	19.8670	22.2490	25.0000

TABLE XXII. COMPARISON OF BENEFIT/COST RATIOS FOR SEVERAL EXPECTED LIVES OF ENERGY CONSERVATION PRACTICES

(Discount Rate = 10%; Fuel Price Escalation Rate = 10%)

Expected Life (yrs)	Net Annual Savings (NAS) $	Present Worth Factor	Present Value of NAS	Benefit/Cost Ratio %
1	$445	1.0	$ 445	0.57
3		3.0	1335	1.71
5		5.0	2225	2.85
7		7.0	3115	3.99
10		10.0	4450	5.70
15		15.0	6675	8.55
20		20.0	8900	11.40
25		25.0	11125	14.24
(Discount Rate = 10%; Fuel Price Escalation Rate = 5%)				
1	$445	0.9546	$ 425	0.54
3		2.7354	1217	1.56
5		4.3581	1939	2.48
7		5.8367	2597	3.33
10		7.8118	3476	4.45
15		10.5490	4694	6.01
20		12.7178	5659	7.25
25		14.4367	6424	8.23

TABLE XXIII. COMPARISON OF BENEFIT/COST RATIOS FOR VARYING RATES OF ESCALATION IN FUEL COSTS

(Expected Life = 7 years; Discount Rate = 10%; First Cost = $781; NAS (1st year) = $445)

Annual Escalation Rate in Fuel Price (%)	Net Annual Savings $	Present Worth Factor	Present Value of NAS	Benefit/Cost Ratio %
0	$445	4.8684	2,166	2.77
2		5.2344	2,329	2.98
4		5.6285	2,505	3.21
6		6.0524	2,693	3.45
8		6.5089	2,896	3.71
10		7.0000	3,115	3.99

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