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ABSTRACT

This module on home heating is one of six in a series intended for use as supplements to currently available materials on solar energy and energy conservation. Together with the recommended texts and references (sources are identified), these modules provide an effective introduction to energy conservation and solar energy technologies. The module is divided into these sections: (1) set of objectives; (2) programed instructional material, consisting of short readings describing ideas and techniques one step at a time, and a question or problem on each reading; (3) review questions and answers at intervals; and (4) posttest. Objectives for this module are for the student to be able to explain how heat is lost from buildings, describe methods for reducing rate of heat loss, and do basic computations involving building heat loss and heating system design. (YLB)

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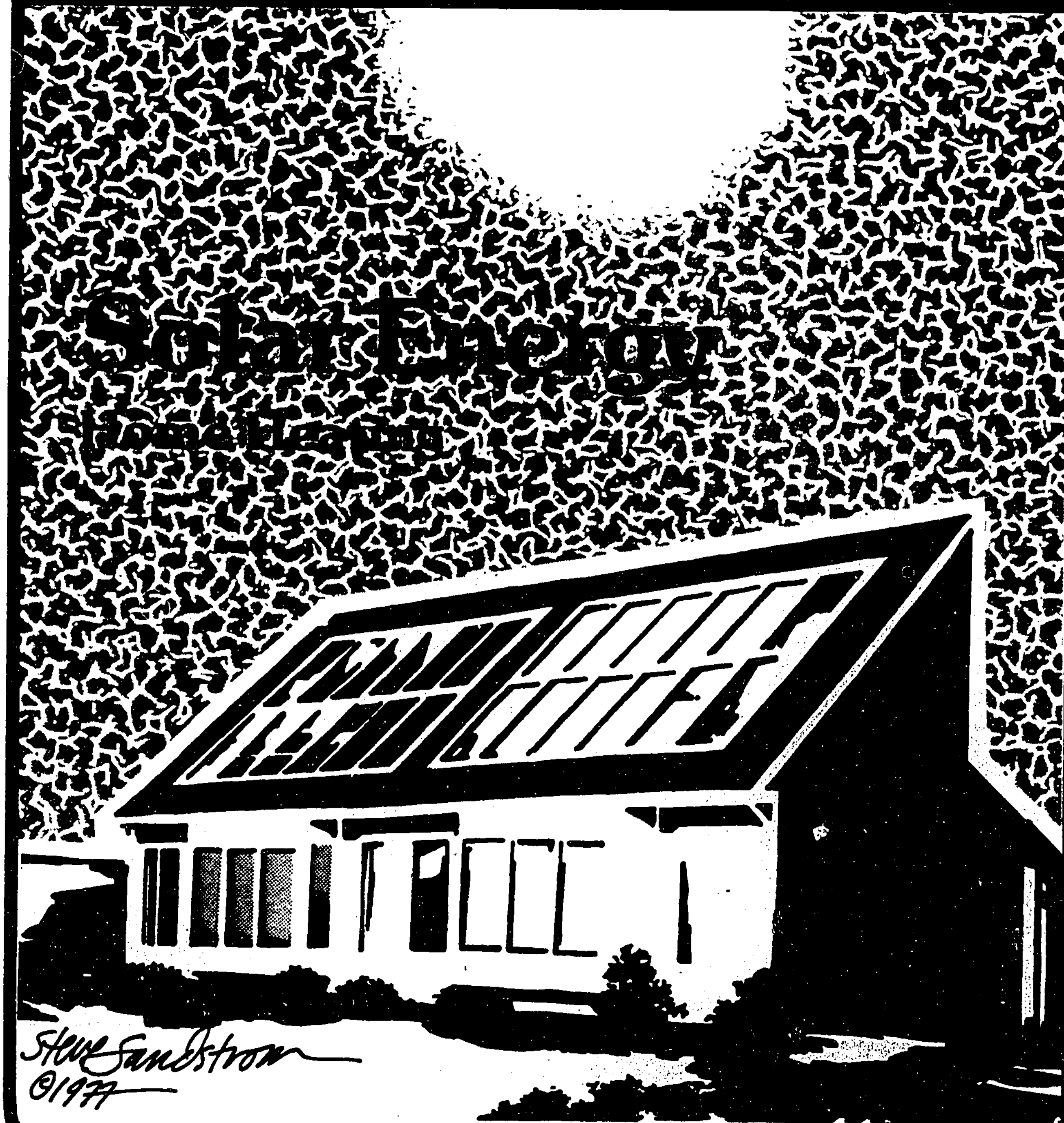
INDIVIDUALIZED LEARNING SYSTEMS

Solar Energy
Home Heating



INSTRUCTIONAL LEARNING SYSTEMS

Solar Energy

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Introduction

These modules are intended to be used as supplements to currently available materials on solar energy and energy conservation. The two best available texts are

Leckie, Masters, Whitehouse and Young; Other Homes and Garbage, Sierra Club Books, 1975

and

Anderson, The Solar Home Book, Cheshire Books, 1975.

There are several reference works that would also be very useful to have on hand. The three most useful ones are

ASHRAE Guide and Data Book, Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1977.

U.S. Department of Commerce, Climatic Atlas of the United States. Environmental Data Service, Reprinted by the National Oceanic and Atmospheric Administration, 1974.

U.S. Department of Commerce, Monthly Normal of Temperature, Precipitation and Heating and Cooling Degree-Days (1941-1970) National Oceanic and Atmospheric Administration, Climatography of the United States (by state).

The last two references can be obtained from the National Climatic Center, Environmental Data Service, Federal Building, Asheville, NC 28801. The most important data to have on hand are the per cent possible sunshine and heating degree-day records for locations in Oregon. They're available in the last two references. Some data are also available in the two texts and the modules themselves.

The modules are designed to simplify and supplement the treatment of some of the subjects discussed in the texts and references. In combination, the modules, texts, and references provide an effective introduction to energy conservation and solar energy technologies.

The technique you'll use to learn the skills presented in this module is called programmed instruction. It's a technique which we think will enable you to learn these new skills quickly and easily.

The module is divided into several sections:

1. A set of objectives, which tells you what you should expect to learn from this module.
2. Programmed instructional material which we'll describe later on in this introduction.
3. A post-test, which will help you find out what you were able to learn by using the module.
4. A student evaluation form which you can use to tell us what you liked and disliked about the module, so we can make it better for students who use it later on.

The programmed part of the module consists of short readings which show you the ideas and techniques you need a step at a time. Most are followed by a question or problem which gives you a chance to review what you just read. Depending on your answer to the question or problem, you'll be guided to another short reading which will either help you review a little more, or introduce you to a new idea or technique. Each short reading is called a frame.

To get the most out of the programmed part, you need to follow the directions exactly. Resist any temptations to skip around, and respond in the best way you can to the question in each frame before moving on to the frame you're told to read next.

It'll help to have pencil, paper, and a pocket calculator handy for some of the computations you're asked to do.

Don't forget about your instructor. You don't have to do it all by yourself. Ask for help with any part of the module that you can't get through by yourself. Good luck!

OBJECTIVES

Overall Objective 1:

The student will be able to explain how heat is lost from buildings and describe methods for reducing the rate of heat loss.

Sub-Objectives:

The student will be able to:

A. name each cause of heat loss.
B. describe each cause of heat loss, showing how the heat escapes from the building.
C. explain at least one method for reducing the rate of heat loss due to each cause.

Overall Objective 2:

The student will be able to do the basic computations involving building heat loss and heating system design.

Sub-Objectives:

The student will be able to compute

A. Building heat loss multipliers.
B. Rates of heat loss from buildings.
C. Required heating system capacities.
D. Amounts of heat required for entire heating seasons.
E. Heat capacities required for heat storage systems.

1. In module 2 you learned how to compute rates of heat transfer by conduction and convection. It's just a few short steps from doing that to computing the amount of heat required to heat an entire building.

In order to keep the air inside the building at a constant temperature, heat must be replaced at the same rate it's being lost from the building. If you know how rapidly heat is lost from a building, you know how fast heat must be generated inside it to keep it warm.

Buildings lose heat as a result of conductive heat transfer through their walls, foundation, and roofs. They lose heat by convective heat transfer in the air that leaks through cracks in windows, doors, and walls. They also lose heat due to radiation and conduction through windows.

You can use the convection and conduction heat transfer formulas you learned in module 2 to compute the rate of heat loss from air leaks and conduction through walls. The conduction formula can also be adapted to apply to windows. Finding the heat loss rate for the entire building just involves adding up all the loss rates using the formulas. Go on to frame 2.

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2. The heat loss due to conductive heat transfer through a wall can be computed by using the conductive heat transfer formula

$$\dot{Q} = UA\Delta T$$

Explain each symbol in the formula and give the units for the quantity it stands for. Check your answers in frame 3.

3. $\dot{Q}$ is the symbol for heat loss rate in BTU/Hr.

U is the symbol for the thermal conductivity of the wall in BTU/Ft.^{2}-Hr.-^{o}F.

A is the area of the wall in Ft.^{2}.

ΔT is the difference in temperature between the air inside the building and the air outside.

Make sure you have these straight before you go on to frame 4.

---

4. The heat loss due to air leaks through cracks in doors, windows, and walls can be computed using the convective heat transfer formula

$$\dot{Q} = \dot{V}C_v\Delta T$$

Explain each symbol in the formula and give the units of the quantity it stands for. Check your answers in frame 5.

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5. $\dot{Q}$ is the symbol for the heat loss in BTU/Hr.

$\dot{V}$ is the symbol for the flow rate of the fluid - in this case, air- in Ft.^{3}/Hr.

C_v is the symbol for the specific heat per unit volume of the fluid - air - in BTU/Ft.^{3}-^{o}F. For air it's .018 BTU/Ft.^{3}-^{o}F.

ΔT is the difference in temperature of the fluid in ^{o}F. In this case, it's the difference in temperature between indoor and outdoor air.

Make sure you have these straight before you go on to frame 6.

---

6. Both of the formulas for heat transfer rate or heat loss rate involve a relationship between $\dot{Q}$ and ΔT. In each formula, multiplying ΔT by a pair of other numbers results in a value for $\dot{Q}$.

In the conduction formula, the two numbers are U and A, and involve the heat transfer properties and the area of a wall. In the convection formula, they're $\dot{V}$ and C_v and involve the rate of air leaking into the building and the specific heat of air. For a particular building, none of those numbers will ever change unless the construction of the building is changed. In particular, the <u>products</u> UA and $\dot{V}C_v$ will stay the same.

So, the rate of heat loss can be found for both situations by multiplying ΔT, the difference between the inside and outside air temperatures, by one number — either the product UA or the product $\dot{V}C_v$. Neither number ever changes unless the construction of the building changes.

Let's call the number given by the product of U and A, H_W. The U stands for wall.

H_W = UA.

Let's call the number given by the product of $\dot{V}$ and C_v, H_I, with the I standing for infiltration, or leaking, of air. Infiltration is the commonly used term for the leakage of air through cracks in building walls.

$H_I = \dot{V}C_v$

The units of both H_W and H_I are BTU/Hr.-^{o}F.

Go on to frame 7.

---

7. We can now write simpler formulas for the rate of heat loss through a wall or due to air infiltration:

$\dot{Q}_W = H_W \Delta T$

$\dot{Q}_I = H_I \Delta T$

$\dot{Q}_W$ and $\dot{Q}_I$ stand for the rate of heat loss through the wall and the rate of heat loss due to air infiltration. What are the units of H_W, H_I, $\dot{Q}_W$ and $\dot{Q}_I$? Check your answer in frame 8.

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8. H_W and H_I have the units BTU/Hr.-^{o}F. $\dot{Q}_W$ and $\dot{Q}_I$ have the units BTU/Hr. Go on to frame 9.

---

9. You can find an H value for every part of a building. You can call UA for the ceiling H_C. You can call UA for the floor H_F. You can call UA for the windows H_G (G for glass - we've already used W.). You can look up the U values of various types of windows in tables. See <u>Other Homes and Garbage</u>, the reference given in the introduction.

All you need to know to find the H-value for any part of a building is its U-value and its area.

Here's an example:

What's the H-value of an R-20 wall with an area of 200 Ft.^{2}?

The R-value of the wall is 20 $^oF.$-Ft.^{2}-Hr./BTU, so its U-value is

$U = \frac{1}{R} = \frac{1}{20}$ BTU/Hr.-Ft.^{2}-^{o}F.

$U = .05$ BTU/Hr.-Ft.^{2}-^{o}F.

and

$H_W = UA$

H_W = (.05 BTU/Hr.-~~Ft.~~^{2}-^{o}F.) (200 ~~Ft.~~^{2})

H_W = 10 BTU/Hr.-^{o}F.

Try this one:

The total glass area of a building is 600 Ft.^{2}. The double pane insulating windows have a U-value of .69 BTU/Hr.-Ft.^{2}-^{o}F. What's H_G? Check your answer in frame 10.

---

10. You should have

H_G = 414 BTU/Hr.-^{o}F.

If you got it, go to frame 12.

If not, go to frame 11.

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11. Use $H_G = UA$

H_G = (.69 BTU/Hr.-Ft.^{2}-^{o}F.) (600 Ft.^{2})

H_G = 414 BTU/Hr.-^{o}F.

---

12. Suppose the rate of air infiltration into a building is 6000 $Ft.^3/Hr.$ You want to compute H_I. Here's how you'd do it.

$H_I = \dot{V}C_v$ with $C_v = .018\ BTU/^{o}F.-Ft.^3$ for air

$H_I = (6{,}000\ Ft.^3/Hr.)\ (.018\ BTU/^{o}F.-Ft.^3)$

$H_I = 108\ BTU/Hr.-^{o}F.$

Notice how the units /Hr. and $BTU/^{o}F.$ are combined into $BTU/Hr.-^{o}F.$

Try this one:

The air infiltration rate into a building is 1,500 $Ft.^3/Hr.$ What's H_I?

Check your answer in frame 13.

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13. $H_I = 27\ BTU/Hr.-^{o}F.$

If you got it, congratulations. If not, review the example given in frame 12 and go on to frame 14 when you can do it.

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14. To find H_I, you need to know $\dot{V}$. You can get it in either of two ways.

The easier way is to assume that there's enough air leaking through the cracks to completely replace all the air in the building each hour. Then, the rate of air flow, or infiltration, through the building per hour is equal to the volume of the building in cubic feet. For example, if the building volume is 12,000 $Ft.^3$, and there's one complete air change per hour, the rate of air flow is 12,000 $Ft.^3/Hr.$

That's the easier way of estimating the rate of air flow in $Ft.^3/Hr.$ It's not very accurate. You have to guess how many air changes occur each hour. Two air changes per hour is a pretty good guess for most buildings, but it could be less. In poorly sealed buildings, there may be as many as three or four air changes per hour.

Try this example problem:

A 1,250 Ft.^{2} house with a ceiling height of eight feet undergoes one complete air change per hour due to air infiltration through cracks. What's the rate of air flow $\dot{V}$ in Ft.^{3}/Hr.? Check your answer in frame 15.

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15. You should have $\dot{V}$ = 10,000 Ft.^{3}/Hr. If you got it, go to frame 17. If not, go to frame 16.

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16. O.K. The volume of the house is the ceiling height multiplied by the number of Ft.^{2} of floor area. Writing V (without a dot) for volume, we get

$V = (8 \text{ Ft.}) (1{,}250 \text{ Ft.}^2)$

$V = 10{,}000 \text{ Ft.}^3$

That volume of air is replaced each hour, so

$\dot{V} = 10{,}000 \text{ Ft.}^3/\text{Hr.}$

Go on to frame 18.

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17. Good. Go on to frame 18.

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18. Let's do another one:

A 1,600 Ft.^{2} house with a ceiling height of eight feet undergoes two complete air changes per hour due to infiltration. What's $\dot{V}$?

Check your answer in frame 19.

---

19. You should have

$\dot{V} = 25{,}600 \text{ Ft.}^3/\text{Hr.}$

If you got it, go to frame 21.

If not, go to frame 20.

12

---

20. The volume of the house is

$V = (8 \text{ Ft.}) (1600 \text{ Ft.}^3)$

$V = 12{,}800 \text{ Ft.}^3$

That volume is changed twice each hour.

$\dot{V} = 25{,}600 \text{ Ft.}^3/\text{Hr.}$

Review the two problems in frames 14 and 18, and then go to frame 21.

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21. O.K. You can compute $\dot{V}$. To get H_I, you just multiply $\dot{V}$ by C_v for air -- .018 BTU/Ft.^{3}-^{o}F. Find H_I for the problems in frames 14 and 18. Check your answers in frame 22.

---

22. You should have

$H_I = 180 \text{ BTU/Hr.-}^o\text{F.}$

and $H_I = 460.8 \text{ BTU/Hr.-}^o\text{F.}$

If you missed either one, go to frame 23.

If not, go to frame 24.

---

23. You use

$H_I = \dot{V}C_v$

The two answers for $\dot{V}$ were 10,000 Ft.^{3}/Hr., and 25,600 Ft.^{3}/Hr. C_v for air is .018 BTU/Ft.^{3}-^{o}F. The two Ft.^{3} symbols will cancel. Try them again.

Check your answers in frame 22.

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24. Now you can get H_I using a simple method for computing $\dot{V}$. The other method for computing $\dot{V}$ is more accurate, but takes longer.

It relies on tables which can be found in heating and air conditioning manuals and tell you how much air will leak into a house through cracks around various kinds of windows and doors. Such tables can also be found in the references given in the introduction. The rates of air flow given in the tables are in $Ft.^3/Hr.$-Ft.-cubic feet per hour per foot of crack length.

You must estimate the average outside wind velocity to use the tables. That can be done using either tables in the two main suggested texts or the Climatic Atlas of the United States.

After you've looked up the infiltration rate for a crack, you have to multiply it by the number of feet of crack to get the air infiltration rate in $Ft.^3/Hr.$ The formula is $\dot{V} = IL$. I is the symbol for the infiltration rate per foot of crack in $Ft.^3/Hr.$-Ft. L is the symbol for the crack length in Ft. If the infiltration rate is called Q in the tables, don't worry. It's the same as I. We just used I because we've already used Q as the symbol for heat.

The crack length is just the perimeter, or distance around, the window or door. To get it, you just add the length and width of the door or window, and multiply by two.

Suppose you have a four by five foot window. You look up the window type and outside wind speed in the table of infiltration rates (I or Q) and find that the infiltration rate through a typical crack around that type window is 25 $Ft.^3/Hr.$-Ft. for the wind speed you estimated. What's the infiltration rate for the entire window? Check your answer in frame 25.

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25. You should have

$\dot{V} = 450\ Ft.^3/Hr.$

If you didn't get it go to frame 26.

If you did, go to frame 27.

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26. The crack length is

$L = 2\ (5\ Ft. + 4\ Ft.) = 2\ (9\ Ft.)$

$L = 18\ Ft.$

$\dot{V} = (25\ Ft.^3/Hr.\text{-}Ft.)\ (18\ Ft.)$

$\dot{V} = 450\ Ft.^3/Hr.$

You can see that a single large window can leak a lot of air. Go to frame 27.

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27. Let's do another one:

A 4' x 7' door with an infiltration rate of 100 $Ft.^3/Hr.$-Ft. (from the tables). Check your answer in frame 28.

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28. You should have

$\dot{V} = 2200\ Ft.^3/Hr.$

If you missed it, look at frame 29.

If not, go to frame 30.

---

29. The length of the crack is

$L = 2\ (4\ Ft. + 7\ Ft.) = 2\ (11\ Ft.)$

$L = 22\ Ft.$

$\dot{V} = (100\ Ft.^3/Hr.\text{-}Ft.)\ (22\ Ft.)$

$\dot{V} = 2200\ Ft.^3/Hr.$

---

30. One more: a 3 by 4 foot window has an infiltration rate of 30 $Ft.^3/Hr.$-Ft. (from the table). What's $\dot{V}$? Check your answer in frame 31.

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31. $\dot{V}$ = 420 $Ft.^3/Hr.$

If you didn't get this one, review frames 24 through 30 until you do. Then, go to frame 32.

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32. Good. Now, you can compute $\dot{V}$ for single windows and doors using the crack method. Of course, you have to add up the $\dot{V}$'s for all the windows and doors in a building.

The actual $\dot{V}$ for the building is <u>half</u> the $\dot{V}$ you get when you do that. That's because air has to come in through one crack and go out through <u>another</u> in order to flow through the building. The air flow rate <u>through the building</u> is half the total air flow rate through the cracks. What's the total air flow rate through a building with the two windows and door of frames 24, 27, and 30? Check your answer in frame 33.

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33. $\dot{V}$ = 1535 $Ft.^3/Hr.$

Just add up the three answers and divide by 2. Go to frame 34.

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34. What's H_I for the building with the $\dot{V}$ of frame 33? Check your answer in frame 35.

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35. H_I = 27.63 BTU/Hr.-^oF.

You just use

$H_I = \dot{V}C_v$ with C_v = .018 BTU/Hr.-^oF. for air.

When you've got it, go on to frame 36.

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36. Good. Now, you can compute H_I in two different ways. The way you choose will depend on how much information you have about the building and how accurate your answer needs to be. To size a solar heating system, you should use the more accurate crack method.

The building air change method is usually used to size conventional heating systems. Go on to frame 37.

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37. You're now ready to compute the H value for an entire building. What you do is add up the values for H for the walls, windows, doors, floor and roof, together with H_I, the H for air infiltration. That gives you the H for the building. Then, you can use

$$\dot{Q} = H\Delta T$$

to find the rate of heat loss for the entire building.

ΔT is just the difference in temperature between the air inside the building and the outside air. As the outside air temperature changes, ΔT and $\dot{Q}$ change, but H doesn't change. H is only dependent on how the building is constructed.

Let's do an example.

Suppose you live in a 20 by 40 foot mobile home, with an eight foot ceiling. The walls are R-11, the floor is R-7, and the roof is R-19. There are five windows, each of which is 3 Ft. by 4 Ft. The windows have single-pane glass, and its U-value is 1.13 BTU/Hr.-Ft.^{2}-^{o}F. There are two 3 by 7 foot doors with R values of 5. The cracks around the windows have an infiltration rate of 20 Ft.^{3}/Hr.-Ft. The cracks around the doors have an air infiltration rate of 100 Ft.^{3}/Hr.-Ft.

First, we'll find the air infiltration rate $\dot{V}$ and H_I.

Total crack length for windows:

L = (5 windows) (2) (3 Ft. + 4 Ft.)

L = 70 Ft.

For the windows, $\dot{V}$ = IL

$\dot{V}$ = (20 Ft.^{3}/Hr.-Ft.) (70 Ft.)

$\dot{V}$ = 1400 Ft.^{3}/Hr.

Total crack length for doors:

L = (2 doors) (2) (3 ft. + 7 Ft.)

L = 40 Ft.

For the doors, $\dot{V}$ = (100 Ft.^{3}/Hr.-Ft.) (40 Ft.)

$\dot{V}$ = 4,000 Ft.^{3}/Hr.

The $\dot{V}$ for the mobile home is half the sum of the $\dot{V}$'s for the windows and doors:

$\dot{V}$ = 2700 Ft.^{3}/Hr.) (.018 BTU/Ft.^{3}-^{o}F.)

$H_I = \dot{V}C_v$

H_I = (2700 Ft.^{3}/Hr.) (.018 BTU/Ft.^{3}-^{o}F.)

H_I = 48.6 BTU/Hr.-^{o}F.

Now we'll find the H values for the walls, windows, doors, floor and roof. We need the areas.

The areas of the floor and roof are the same:

A = (20 Ft.) (40 Ft.) = 800 Ft.^{2}

The area of the windows is

A = (5 windows) (3 Ft.) (4 Ft.) = 60 Ft.^{2}

The area of the doors is

A = (2 doors) (3 Ft.) (7 Ft.) = 42 Ft.^{2}

The area of the walls is the distance around the mobile home times the ceiling height of 8 Ft., less the area of the doors and windows.

A = (8 Ft.) (2) (20 Ft. + 40 Ft.) - 60 Ft.^{2} - 42 Ft.^{2}

A = 960 Ft.^{2} - 102 Ft.^{2}

A = 858 Ft.^{2}

Now we can make a table to get the H values for the floor, roof, windows, doors, and walls. We'll include H_I at the bottom of the table.

	R (^{o}F.-Ft.^{2}-Hr./BTU)	1/R = U (BTU/Hr.-Ft.^{2}-^{o}F.)	A (Ft.^{2})	UA = H (BTU/Hr.-^{o}F.)
Walls	11	.091	858	78.1
Roof	19	.053	800	42.4
Floor	7	.143	800	114.4
Doors	5	.2	42	8.4
Windows	-	1.13	60	67.8
H_I				48.6
H				359.7

H = 359.7 BTU/Hr.-^{o}F.

More than 10% of the total H comes from H_I. You can see how important weatherstripping of cracks around doors and windows can be.

If the air temperature outside were 25 ^{o}F., ΔT would be 40 ^{o}F. The rate of heat loss would then be:

$\dot{Q} = H\Delta T$

$\dot{Q}$ = (359.7 BTU/Hr.-^{o}F.)

$\dot{Q}$ = (40 ^{o}F.)

$\dot{Q}$ = 14,388 BTU/Hr.

That number will mean more to you if you realize that an electric heater would use about 4.2 kilowatts of power to supply that heat, and it could cost as much as 11 cents an hour to heat the mobile home. In a cold month, the heating bill could go as high as $85.

The lesson here is that you can't change ΔT = that depends on the weather. You <u>can</u> change H, especially by sealing up cracks. Weatherstrip! The weatherstripping for this mobile home would pay for itself in one cold month. Go to frame 38.

---

38. Now you do one:

You have a 30 by 40 foot one-story conventional home with 8 foot ceilings. There are two 4 by 5 foot windows and four 3 by 4 foot windows. There are two 3 by 7 foot doors. The infiltration rate for the windows is 10 Ft.^{3}/Hr.-Ft. The infiltration rate for the doors is 100 Ft.^{3}/Hr.-Ft. The walls are R-19, the floor is R-11, and the roof is R-30. The windows are double-glazed (two panes of glass) with U = .69 BTU/Hr.-Ft.^{2}-^{o}F. The doors are R-8.

Find H. Use the outline below:

Total crack length for windows:

$\dot{V}$ for windows

Total crack length for doors

$\dot{V}$ for doors

$\dot{V}$ for the entire house:

H_I:

Areas:
Roof and floor:

Windows:

Doors:

Walls (don't forget the windows and doors):
Table:

	R ($^oF./Ft.^2$-Hr.-BTU)	$\frac{1}{R} = U$ (BTU/Hr.-Ft.^{2}-^{o}F.)	A (Ft.^{2})	UA=H (BTU/Hr.-^{o}F.)
Walls	19			
Roof	30			
Floor	11			
Doors	8			
Windows	—	.69		
H_I				—
H				

Check your work with ours in frame 39.

20

39. Total crack length for windows:

$L = (4 \text{ windows})\ (2)\ (3 \text{ Ft.} + 4 \text{ Ft.}) + (2 \text{ windows})\ (2)\ (4 \text{ Ft.} + 5 \text{ Ft.})$

$L = 56 \text{ Ft.} + 36 \text{ Ft.} = 92 \text{ Ft.}$

$\dot{V}$ for windows:

$\dot{V} = IL$

$\dot{V} = (10 \text{ Ft.}^3/\text{Hr.-Ft.})\ (92 \text{ Ft.})$

$\dot{V} = 920 \text{ Ft.}^3/\text{Hr.}$

Total crack length for doors:

$L = (2 \text{ doors})\ (2)\ (3 \text{ Ft.} + 7 \text{ Ft.})$

$L = 40 \text{ Ft.}$

$\dot{V} = (100 \text{ Ft.}^3/\text{Hr.-Ft.})\ (40 \text{ Ft.})$

$\dot{V} = 4{,}000 \text{ Ft.}^3/\text{Hr.}$

$\dot{V}$ for house:

$$\dot{V} = \frac{920 \text{ Ft.}^3/\text{Hr.} + 4{,}000 \text{ Ft.}^3/\text{Hr.}}{2}$$

$\dot{V} = 2{,}460 \text{ Ft.}^3/\text{Hr.}$

H_I:

$H_I = \dot{V}C_v$

$H_I = (2{,}460 \text{ Ft.}^3/\text{Hr.})\ (.018 \text{ BTU/Ft.}^3\text{-}^o\text{F.})$

$H_I = 44.28 \text{ BTU/Hr.-}^o\text{F.}$

Areas:

Roof and floor:

$A = 30 \text{ Ft.} \times 40 \text{ Ft.} = 1200 \text{ Ft.}^2$

Windows:

$A = (2 \text{ windows})\ (5 \text{ Ft.})\ (4 \text{ Ft.}) + (4 \text{ windows})\ 3 \text{ Ft.})\ (4 \text{ Ft.})$

$A = 40 \text{ Ft.}^2 + 48 \text{ Ft.}^2$

$A = 88 \text{ Ft.}^2$

Doors:

$A = (2 \text{ doors})\ (3 \text{ Ft.})\ (7 \text{ Ft.})$

$A = 42 \text{ Ft.}^2$

Walls:

$A = (8 \text{ Ft.})\ (30 \text{ Ft.} + 40 \text{ Ft.}) - 88 \text{ Ft.}^2 - 42 \text{ Ft.}^2$

$A = 1120 \text{ Ft.}^2 - 130 \text{ Ft.}^2$

$A = 990 \text{ Ft.}^2$

Table:

	R ($^oF./Ft.^2$-Hr.-BTU)	$\frac{1}{R} = U$ (BTU/Hr.-$Ft.^2$-$^oF.$)	A ($Ft.^2$)	UA = H (BTU/Hr.-$^oF.$)
Walls	19	.053	990	52.5
Roof	30	.033	1200	40.0
Floor	11	.091	1200	109.1
Doors	8	.125	42	5.3
Windows	—	.69	88	60.7
H_I				44.3
H				311.9

H = 311.9 BTU/Hr.-$^oF.$

Go over this one until you get the same answers we did. Then, go on to frame 40.

---

40. Congratulations! You've had your first taste of computing the heat loss multiplier, H, for a house.

22

The better insulated a house is, the more important it is to stop air leaks. Otherwise, the insulation won't save enough heat to make it worth the money. If the temperature outside the house in frames 39 and 40 were 30 ^{o}F., and it were heated to 65 ^{o}F. inside, what would its heat loss rate be in BTU/Hr.? Check your answer in frame 41.

---

41. $\dot{Q}$ = 10,916.5 BTU/Hr.

    Just use $\dot{Q} = H\Delta T$ with ΔT = 65 ^{o}F. - 30 ^{o}F. = 35 ^{o}F.

    Go on to frame 42.

---

42. O.K. Now you've had a taste of what it's like to compute the rate of heat loss from a house. Go on to the review questions on the next page and check your knowledge.

Review Questions:

1. You live in a 30 by 60 foot mobile home. It has two 3 by 5 foot windows and six 2-1/2 by 3 foot windows. It has two 3 by 7 foot exterior doors. The ceiling height is 8 feet. The infiltration rate around the doors is 140 $ft.^3$/Hr.-Ft. The infiltration rate around the windows is 25 $Ft.^3$/Hr.-Ft. The doors are R-7. The windows are single-glazed with U = 1.13 BTU/Hr.-$Ft.^2$-^oF. The walls are R-11, the roof is R-19, and the floor is R-11. Compute the heat loss multiplier for the building.

2. Compute the rate of heat loss from the mobile home on a day when the outside temperature is 10 ^{o}F. Assume the inside temperature is being maintained at 65 ^{o}F.

Answers to Review Questions

1. 614.3 BTU/Hr.-^{o}F.
2. 33,786 BTU/Hr.

   If you had difficulty with either of these questions, review frames 1 through 42 until you can get our answers. When you've worked them out, go on to frame 43.

43. Now that you know how to compute the heat loss factor H for a house, you can use the formula $\dot{Q} = H\Delta T$ to find the amount of heat required to heat the house for a day, a month, or even an entire year. You can use it to compute the amount of heat you need to store to heat a solar house on days without sunshine. And, you can use it to estimate the fuel and money savings possible by making changes in the design of a house, such as putting in additional insulation, weatherstripping, or a solar system. Go on to frame 44.

---

44. To estimate the amount of heat needed to keep a house warm, you have to know both H and ΔT. H is, of course, the result of how the house is constructed and will be the same no matter where the house is located, except for changes in H_I due to outside wind velocity differences. ΔT is entirely the result of the weather at the house location. To find ΔT, you have to find information about the outside temperatures that usually occur in the area around the house. There are tables of outside temperatures in both the main references for these modules and in the Climatic Atlas of the United States. In the formula $\dot{Q} = H\Delta T$, which symbol stands for the number that depends on the climate around the building? Check your answer in frame 45.

---

45. ΔT, the temperature difference between the air inside the building and the air outside, depends on the climate around the building. ΔT is, of course, also dependent on the inside temperature chosen for the building, but once you've chosen that temperature, ΔT will vary up and down as the outside temperature changes.

In the tables of weather information, you'll find two kinds of information about the lowest outside temperatures that occur in various locations, and you'll find information about the average ΔT between the outside air and the air in a building with an inside temperature of 65 ^{o}F. Go on to frame 46.

---

46. Information about the lowest outside temperatures in any area can be used to pick a minimum outside design temperature for a building. The minimum outside design temperature is an estimate of the lowest outside temperature the building will encounter. Its name is often shortened to design temperature.

The difference between the desired air temperature in the building and the design temperature is an estimate of the highest ΔT that will occur between the inside and outside of the building. The ΔT can be used in the formula $\dot{Q} = H\Delta T$ to get an estimate of the highest rate of heat loss the building will experience.

In order to keep a building warm inside, the building's heating system must have enough capacity to replace the heat the building loses on the coldest days. The design temperature and the ΔT that results from it enable a building designer to estimate the maximum heating capacity the building's heating system should have. Go to frame 47.

---

47. You can use various estimates of winter low temperatures to choose a design temperature. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) publishes a Handbook of Fundamentals that contains tables of winter low temperatures for locations all over the United States. You can get similar information for your local area from the National Oceanic and Atmospheric Administration Office (weather station) at your local airport. The Climatic Atlas of the United States also has such information.

Three estimates of low winter outside temperatures are the median of annual extremes, the 99 % winter low temperature, and the 97-1/2 % winter low temperature. The median of annual extremes is obtained by averaging together the lowest winter temperatures recorded every year for as long as they've been measured in a particular area. The winter temperature in an area goes below the median of annual extremes only a few times every 30 or 40 years.

The 99 % and 97-1/2 % winter low temperatures are the temperatures that are exceeded 99 % and 97-1/2% of the time during December, January and February. The outside temperature will be below the 99 % temperature only 1 % of the time during that period, and below the 97-1/2 % temperature only 2-1/2 % of the time.

The median of annual extremes is the safest temperature to use as a design temperature. The next safest is the 99 % winter low temperature.

The lower the design temperature you choose, the larger your estimate of the building's heating system capacity will be. If the building's occupants can put up with lower than average nighttime temperatures, you can probably use the 99 % or 97-1/2 % winter low temperature as your design temperature and reduce the size of the building's heating system.

What's the design temperature used to estimate? Check your answer in frame 48.

---

48. The design temperature, or minimum design outside temperature, is used to estimate the maximum ΔT and the maximum rate of heat loss a building will encounter. That estimate can be used to choose the heating capacity of the building's heating system and make changes in the building's design to reduce the heat loss rate. Go on to frame 49.

---

49. To estimate a building's maximum rate of heat loss, you first find ΔT by subtracting the design temperature from the desired temperature inside the building.

$$\Delta T = T_I - T_O$$

Then you just use

$$\dot{Q} = H\Delta T$$

to estimate the maximum heat loss rate.

Suppose you've designed a building with a heat loss multiplier H of 1000 BTU/Hr.-^{O}F. You've picked a design temperature of 20 ^{O}F. and the desired indoor temperature is 65 ^{O}F. What's your estimate of the building's maximum rate of heat loss? Check your answer in frame 50.

50. You should have

$$\Delta T = T_I - T_O$$

$$\Delta T = 65\ ^{O}F. - 20\ ^{O}F. = 45\ ^{O}F.$$

$$\dot{Q} = H\Delta T$$

$$\dot{Q} = (1000\ BTU/Hr.-^{O}F.)\ (45\ ^{O}F.)$$

$$\dot{Q} = 45{,}000\ BTU/Hr.$$

Go on to frame 51.

---

51. The heating system of the building in frames 49 and 50 should have a capacity of at least 45,000 BTU/Hr. Here's another exercise:

The minimum design temperature you've chosen is 25 ^{O}F. and you want the building's inside temperature to be 65 ^{O}F. The building's heat loss multiplier is 1600 BTU/Hr.-^{O}F. What should the capacity of the building's heating system be? Check your answer in frame 52.

---

52. The capacity of the building's heating system should be at least 64,000 BTU/Hr. If you didn't get that answer, review frames 49, 50, and 51 until you do. Get help if you need it. Then, go on to frame 53.

---

53. In addition to the maximum rate of building heat loss and the required capacity of its heating system, it's useful to know how much heat a building will need for an average day, a month, or an entire heating season. What you need to make such an estimate is a kind of average ΔT for a day, a month, or a heating season.

Information about average values of ΔT is contained in Heating Degree-Day tables. The ASHRAE Guide and Data Book has such tables, as do both the main references for these modules. You can also get degree-day information from local heating contractors, utilities and the weather bureau (National Oceanic and Atmospheric Administration).

The number of degree-days in a day is obtained by subtracting the average outside temperature on that day from 65 ^{o}F., so the number of degree-days in one day is a measure of ΔT for that day for a building with an inside temperature of 65 ^{o}F.

The number of degree-days in a month is obtained by adding up the number of degree-days for all the days in that month. It's equal to the ΔT for a 65 ^{o}F. building for an average day of that month, multiplied by the number of days in the month. For example, if the number of degree-days in December in a particular location is 620, the ΔT for an average day in December is 620 degree-days divided by the number of days in December -- 31. The ΔT for an average December day is 20 ^{o}F. The abbreviation for degree-day is ^{o}F.-day.

Suppose the ΔT for an average day in January for a 65 ^{o}F. building in a particular location is 25 ^{o}F. How many degree-days are there in January in that location? Check your answer in frame 54.

---

54. The number of days in January is 31. The number of degree-days is (31 days) (25 ^{o}F.) = 775 ^{o}F-day.

Go on to frame 55.

---

55. A building's average rate of heat loss $\dot{Q}$ is equal to the building heat loss multiplier H multiplied by the ΔT for an average day. The total amount of heat required to heat a building for a certain period of time is just the building's average rate of heat loss $\dot{Q}$ in BTU/Hr. multiplied by the number of hours in the period. So, the total amount of heat required to heat a building for a certain period of time is equal to the building's heat loss multiplier H, multiplied by the ΔT for an average day, multiplied by the number of hours in the time period.

The number of degree-days in a particular time period like a day, month or heating season is the ΔT for an average day multiplied by the number of days. To get the ΔT for an average day multiplied by the number of hours in the period, all you need to do is multiply the number of degree-days by 24. ΔT and the number of hours in the time period are combined automatically when you multiply the number of degree-days by 24 Hr./day.

To find the total amount of heat required for that period, all you have to do is multiply 24 Hr./day by the number of degree days (^{o}F.-day) and then multiply by H for the building in BTU/Hr.-^{o}F. Let's do an example:

The number of degree-days in a heating season in Eugene, Oregon is 4726. The total amount of heat required to heat a building in Eugene with a heat loss multiplier H of 500 BTU/Hr.-^{o}F. for an entire heating season is

$$Q = (500\ \text{BTU/Hr.-}^{o}\text{F.})\ (24\ \text{Hr./day})\ (4726\ ^{o}\text{F.-day})$$

$$Q = 56{,}712{,}000\ \text{BTU}$$

Notice we used Q for the total amount of heat required. We didn't use $\dot{Q}$, because $\dot{Q}$ stands for rate of heat loss in BTU/Hr. We wanted a total amount of heat.

Try this one: your house has a heat loss multiplier of 600 BTU/Hr.-^{o}F. You live in Portland, which has about 4600 degree-days in its heating season. What's the total amount of heat required to heat your house for a heating season? Check your answer in frame 56.

---

56. You should have

$$Q = 66{,}240{,}000\ \text{BTU.}$$

Did you remember to multiply by 24 Hr./day?

If you had trouble, go over the example in frame 55. When you get our answer, go on to frame 57.

---

57. You live in Eugene, which has 803 heating degree-days in January. Your house's heat loss multiplier H is 450 BTU/Hr.-^{o}F. How much heat will your house need to keep it warm in January? Check your answer in frame 58.

---

58. You should have

$Q = 8,672,400$ BTU

If you didn't get this one, go over frames 55 and 56 and get help from your instructor. When you've got it, move on to frame 59.

---

59. Good. Now, you can compute the total heat requirement for a month or a heating season if you know the degree-days and the heat loss multiplier for the building. Let's suppose now that you want to know the average amount of heat required for a shorter period of time, say several days. You might want to do that to pick the size of a heat storage system for a solar house.

What you need to know is the ΔT for an average day in the month you're interested in. That's easy. The number of degree-days in a month is just the ΔT for an average day multiplied by the number of days in the month. All you need to do is divide the number of degree-days in the month by the number of days in the month to find the ΔT for an average day in that month.

For example, if the number of degree-days in November in your location is 600 ^{o}F.-day, the ΔT for an average day in November is 20 ^{o}F.-600 ^{o}F.-day divided by 30 days.

What's the ΔT for an average day in December if there are 930 ^{o}F.-days in December in your location? Check your answer in frame 60.

---

60. ΔT = 30 ^{o}F. (There are 31 days in December. Go on to frame 61.

---

61. To find the amount of thermal storage required to heat a house for a certain number of days in a particular month, you just multiply the heat loss multiplier for the house by the ΔT for an average day in that month,

the number of days, and the conversion factor 24 Hr./day.

$Q = (24 \text{ Hr./day}) (\text{No. of Days}) H\Delta T$

Suppose you wanted to store 3 days' heat in December for a house with a heat loss multiplier H of 550 BTU/Hr.-^{o}F. There are 1240 ^{o}F.-Day in December where the house is located. How much heat would you need to store? Check your answer in frame 62.

---

62. The ΔT for an average December day in your location is 1240 ^{o}F.-day divided by 31 days or 40 ^{o}F.

The heat you need to store is

$Q = (24 \text{ Hr./day } (3 \text{ days}) H\Delta T$

$Q = (24 \text{ Hr./day}) (3 \text{ days}) (550 \text{ BTU/Hr.-}^{o}\text{F.}) (40 \ ^{o}\text{F.})$

$Q = 1,584,000 \text{ BTU}$

Go to frame 63.

---

63. Try this one: You want to store heat for 5 January days for a house with a heat loss multiplier of 400 BTU/Hr.-^{o}F. January has 620 ^{o}F.-day where the house is located. How much heat do you need to store? Check your answer in frame 64.

34

64. You need to store

$Q = 960{,}000$ BTU

If you didn't get that answer, review the example in frame 62 until you can. When you did, go to frame 65.

---

65. O.K. Now you can compute heating requirements for months, days, seasons, and the maximum required capacity of heating systems. Let's review a bit.

To get the required heating system capacity, you need to know the heat loss multiplier, H, for the building and an estimate of the maximum ΔT the building is likely to experience. You use weather data to find a minimum design outside temperature or design temperature. You can choose the median of the annual extremes, the 99 % temperature, or the 97-1/2 % temperature, or some temperature close to them for your design temperature.

You estimate the maximum ΔT by subtracting your design temperature from the desired indoor temperature. You find H by computing and adding up all the H values for the walls, roof, floor, windows, doors, and air leaks. Then you use

$\dot{Q} = H\Delta T$

To find the maximum rate of heat loss, the capacity of the heating system should be at least equal to the maximum rate of heat loss in BTU/Hr. Go to frame 66.

---

66. To find the total heat required for a month or a heating season, you need to know H and the number of degree-days in the month or season. You can look up the number of degree-days in weather tables. H you calculated when you estimated the maximum heating capacity of the system.

The total heat required is just 24 Hr./day multiplied by H and the number of degree-days. Go to frame 67.

---

67. To find the stored heat required for some number of days in a particular month, you need to know H and the ΔT for an average day of that month.

To find the ΔT for an average day in any month, you just divide the degree-days for that month by the number of days in the month. Then, you find the required amount of thermal storage using

$Q = (24\ \text{Hr./day})\ (\text{No. of days})\ H\Delta T$

Go to frame 68.

---

68. Suppose you're designing a solar heated house in Portland. You want enough heat storage for five days in November. You also want a conventional backup heating system that can supply all the heat the house needs on the coldest sunless days. The heat loss multiplier for the house is 650 BTU/Hr.-^{o}F. The median of the annual extremes is 21 ^{o}F., and you want to use that as your design temperature. The number of degree-days in November is 534 and the total for a heating season is 4109. You're going to maintain an inside temperature of 65 ^{o}F.

Estimate the total heat required, the amount of stored heat required, and the maximum required heating capacity of the backup heating system. Check your work in frame 69.

---

69. The maximum ΔT the house is likely to experience is 65 ^{o}F minus the design temperature of 21 ^{o}F., or 44 ^{o}F. The maximum required heating capacity of the backup heating system is

$\dot{Q} = H\Delta T$

$\dot{Q} = (650\ BTU/Hr.-^{o}F.)\ (44\ ^{o}F.)$

$\dot{Q} = 28,600\ BTU/Hr.$

The ΔT on an average November day is 534 ^{o}F.–day divided by 30 days, or 14.3 ^{o}F. For five November days you need a stored heat of

$Q = (24\ Hr./day)\ (5\ days)\ H\Delta T$

$Q = (24\ Hr./day)\ (5\ days)\ (650\ BTU/Hr.-^{o}F.)\ (14.3\ ^{o}F.)$

$Q = 1,115,400\ BTU$

The total amount of heat required for a heating season is

$Q = (24\ Hr./day)\ (H)\ (4190\ ^{o}F.-day)$

$Q = (24\ Hr./day)\ (650\ BTU/Hr.-^{o}F.)\ (4109\ ^{o}F.-day)$

$Q = 64,100,400\ BTU$

Review this section of the module until you feel you can do all three kinds of computations. Then go on to the review questions.

---

70. Learning how to compute heat loss has probably already given you some ideas about how to reduce it. Here are a few ideas:

1. Stop up all building air leaks.
2. Use insulating shutters or curtains on windows at night.
3. Make exterior doors open into small entry rooms instead of allowing them to open directly into the main areas of a building. Closing the exterior door before opening the inside door of the entry room prevents cold air from being blown directly into the building. Air leaks around doors are also lessened.
4. Use the maximum amount of insulation possible in walls, ceilings and floors.
5. Keep window area as small as you can without making the building unpleasantly dark. Eight to ten percent of floor area is good.
6. Make windows face south where possible to take advantage of winter sun. Use overhangs to shade them in summer.
7. Use a vapor barrier (thin plastic sheet) on interior walls to prevent air leaks and keep moisture in the inside air from condensing in walls and rotting the wood.

8. Plant shrubs around the windy sides of buildings to reduce wind velocity and air leaks through windows, doors, and walls.
9. Use insulated exterior doors to reduce conductive heat loss.
10. Store excess solar heat or excess heat from other sources inside the building to keep building temperatures even and prevent high heat loss.
11. Allow building temperatures to go below 65 °F. at night or when the building isn't in use.
12. Use double layers of glass on windows you can't insulate at night with curtains or shutters.

Go to frame 71.

---

71. Besides the heating system, there are several sources of heat in buildings which can be used to help keep it warm. One is direct sunlight through south windows. Another is the heat generated by people, machines, appliances and lighting. Using fans or natural convection to move the heat from overheated sections of the building to other sections can reclaim heat that would otherwise have to be provided by the heating system.

Massive walls or floors can store heat and keep temperatures even in rooms exposed to direct sunlight. Go to frame 72.

---

72. Well-sealed windows that don't open don't leak air. The building's ventilation requirements can be met by using natural convection through vents to the outside. The vents can be closed at night or when the building isn't in use. Consider underground ventilation tunnels to heat or cool the air to ground temperature before it enters the building. Also consider adjustable exhaust vents near the roof which allow warm air to leave the building by convection in summer and can be adjusted to prevent unnecessary ventilation in winter.

Forced convection can be used to get fresh air to poorly accessible portions of the building.

Go to frame 73.

---

73. When calculating required heating system size and total heat requirements, don't neglect _any_ source of heat inside the building. People produce about

400 BTU of heat per hour. Appliances and motors eventually give up all their input power as heat. Add up the heat produced in those ways and subtract it from the heating requirement. Lowering the building's interior temperature will reduce the heat loss by H BTU/Hr. for every ^{o}F. the temperature goes down. You should be in a position to compute the effects of all these things on your heat requirements.

Suppose, for example, you decide to lower a building's inside temperature by 2 ^{o}F. during the winter. The heat loss factor of the building is 1200 BTU/Hr.-^{o}F. How much heat energy will you save?

You'll save

$Q = (24\ \text{Hr./day})\ (1200\ \text{BTU/Hr.-}^{o}\text{F.})\ (2\ ^{o}\text{F.})$ each day.

$Q = 57{,}600\ \text{BTU/day}$

for the entire season. If the heating season is 180 days long, you'll save 10,368,000 BTU.

What you've done is reduced ΔT by 2 ^{o}F. and reduced $\dot{Q}$ by 2400 BTU/Hr. at no cost.

Go to frame 74.

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74. Congratulations! You've finished the programmed material. Go on to the review questions and post-test.

Review Questions

1. You've designed a house with a heat loss multiplier of 900 BTU/Hr.-^{o}F. You've chosen an internal temperature of 65 ^{o}F and a design minimum outside temperature of 10 ^{o}F. Compute the required heating system capacity in BTU/Hr.

2. The house of question 1 is located in an area which experiences 5500 heating degree-days during the heating season. Compute the total amount of heat necessary to maintain its interior temperature for the entire heating season.

3. There are 930 degree-days in January in the area occupied by the house in question 1. Compute the amount of stored heat required to maintain its interior temperature at 65 ^{o}F for 5 days in January.

Answers to Review Questions

1. 49,500 BTU/Hr.
2. 118,800,000 BTU
3. 3,348,000 BTU

If you had difficulty with any of these questions, review frames 41 through 74. When you feel confident, go on to the post-test.

Post Test

1. You own a house which has a floor area of 1600 $Ft.^2$. The total length of exterior wall is 200 ft. It's a single story house with a ceiling height of 8 feet. It has two exterior doors which are 3 feet by 7 feet. It has three 4 by 5 foot windows and five 3 by 3 foot windows. The air infiltration rate around is 125 $Ft.^3$/Hr. per foot of length around each window (40 $Ft.^3$/Hr.-Ft.) The windows are double glazed (two panes of glass) and have a U-value of 0.69 BTU/Hr.-$Ft.^2$-^oF. The doors are R-8, the walls are R-19, the roof is R-30, and the foundation is R-11. Find the heat loss multiplier for the house.

2. Your house has a heat loss multiplier of 1100 BTU/Hr.-^{o}F. You've chosen a design minimum outside temperature of 10 ^{o}F. You want to maintain the interior temperature of the house at 65 ^{o}F. Compute the required capacity of the heating system.

3. The house in question 2 is located in an area which has 6000 heating degree-days during its heating season. Compute the total amount of heat required to maintain the interior temperature at 65 ^{o}F for the entire season.

4. The house in question 2 is located in an area with an average December outside temperature of 25 ^{o}F. You intend to maintain the internal temperature at 65 ^{o}F. Compute the amount of stored heat necessary to maintain the interior temperature for 5 days in December.

5. Name three causes of heat loss from buildings and describe how and where the heat loss occurs for each cause.

6. List five ways to reduce heat loss from buildings, name the type(s) of heat loss reduced, and explain how the heat loss reduction is accomplished.