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ABSTRACT

This manual contains fifteen energy activities suitable for high school physical and environmental science and mathematics classrooms. The activities are independent, each having its own objectives, introduction, and background information. A special section of each activity is written for the instructor and contains limits, sample data, and suggestions for follow-up activities. Most of the activities are analytical or empirical and require students to have completed a second year of high school algebra. (Author/RE)

ENERGY AND ENERGY CONSERVATION ACTIVITIES FOR HIGH SCHOOL STUDENTS

Prepared by the Project Staff and Participants of the WORKSHOP ON ENERGY CONSERVATION, University of Colorado, School of Engineering, and supported by the National Science Foundation (Project #SPI 78-04527, 1978)

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Abstract

This manual contains fifteen energy and energy conservation activities suitable for integration into high school physical and environmental science and math classrooms. The activities are independent, each being self-contained with its own objectives, introduction and background information. A special section of each activity (Teacher's Guide) is written for the instructor and contains helpful hints, sample data and suggestions for follow-up activities.

Most of the activities are analytical or empirical and require a second year high school algebra capability. Others may require some background in trigonometry and computer programming. Effort was made to insure a quantitative approach and, where possible, to relate activity results to the social, economic and environmental ramifications of energy conservation. Among the topics included are thermocouples, heat content of fuels, heat storage mechanisms, wind machines, solar geometry, illumination, exponential growth, insulating characteristics of various materials, electrical consumption of appliances, solar greenhouses and passive solar design. Both theoretical and practical engineering concepts are illustrated and demonstrated by the activities.

Student pages can be detached from the manual and reproduced in class sets. Additionally, the materials needed to implement these activities are inexpensive and can be found at home and in high school stockrooms or they may be purchased locally at hardware stores.

Preface

From July 31 to August 18, 1978, seventeen selected high school physical science and mathematics instructors convened at the Engineering Center, University of Colorado, to participate in a National Science Foundation supported "Workshop on Energy Conservation". One of the project goals was to produce a self-contained set of activity modules for infusion and integration into high school physical science and math classes.

The rationale for this project is straightforward: Although many fine energy educational materials have been produced by public and private organizations in the years following the OPEC embargo, much of what is available is suitable for the non-technical student. It was felt that little exists currently to challenge and to encourage the above average student to pursue technical careers related to new energy technologies and oriented to energy engineering. This volume is a contribution to that effort.

Chuan C. Feng
Project Director

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#1. IMPACTS OF EXPONENTIAL GROWTH

PURPOSE: The purpose of this activity is to focus your attention on the relationship between rates of population growth and consumption of finite resources. Our industrialized systems which support our contemporary lifestyles function on an energy base derived principally from the fossil fuels (coal, oil, natural gas). While the unused quantities of these material resources may seem very great to us, the fact remains that they are being consumed very rapidly. Some of these resources will be depleted in our lifetime, causing profound changes in our lifestyles.

All of us need to understand and practice ways we can use our energy and other finite resources more conservatively and intelligently. Some of you may wish to consider pursuing energy management careers in order that you may become closely involved in helping to solve our energy problems. It is, perhaps, one of the greatest challenges ever to be faced by our world societies.

INTRODUCTION:

1. Definitions:
    a. Finite resources - resources such as coal, oil, gas and minerals, which are limited; they are not being replenished or renewed.
    b. Exponential growth - the growth of a quantity (such as population) which increases by a fixed percentage of itself in equal time intervals.
    c. Fossil fuels - those finite, natural resources which provide the energy (1) to generate our electricity, (2) to run our industrial systems, (3) to heat our homes, (4) to run our

automobiles.

d. Doubling time - the time required for a quantity growing at a constant rate to double in size.

e. Extrapolation - a type of prediction in which what has happened in the past is extended into the future.

2. Applications: The concept of applying exponential consumption rates can be applied to situations other than energy. For example, if we can determine the population growth rate for Denver, we can extrapolate the future requirements for water, food and clothing.

3. History: Perhaps modern man has more information available about his resources and their consumption than at any time in the past. What we do with this information may have profound implications for the future.

OVERVIEW OF ACTIVITIES:

1. First Day: A review of mathematics and problem solving.
2. Second Day: A simulation exercise to compare the space occupied by two populations having different exponential growth rates.
3. Third Day: A simulation exercise to compare consumption rates.
4. Fourth Day: Fossil fuels and problem solving.
5. Fifth Day: General review and test.

FIRST DAY: A Review of Mathematics and Problem Solving

PURPOSE: As a result of today's activity, you will understand and be able to work problems involving:

(1) exponents, (2) exponential growth rates, and (3) doubling time. ($T_2 \cong 70/P$).

MATERIALS: Paper and pencil

PROCEDURE: Problem solving

1. Exponent: the power to which a number is raised.

Examples: 5^2 means 5 x 5 = 25

5^3 means 5 x 5 x 5 = 125

5^4 means 5 x 5 x 5 x 5 = 625

Problems: 8^2 = ______________________

8^3 = ______________________

8^4 = ______________________

2. Scientific Notation: When using very large numbers, it is much easier to express the number in terms of powers of ten.

Examples:

$10 = 1 \times 10^1$

$100 = 1 \times 10^2$

$1000 = 1 \times 10^3$

$1000000 = 1 \times 10^6$

Problems: 1. Express in powers of ten:

a. $27 = 2.7 \times 10$ ____?

b. 876 = ______________

c. 1390 = ______________

d. 27,100,000 = ______________

2. In 1970 the United States produced 3.29 billion barrels of oil. Express this quantity in powers of ten.

____

3. Exponential Growth Rate: When a quantity grows by a fixed percent per year, the growth is exponential. This is represented by Equation (1): $N=N_0e^{kt}$ (1) where N_0 is the size of the growing quantity at time, $t=0$; N is the final size of the quantity; k is the fractional change in N per time unit and e is the base of natural logarithms. Exponential growth is characterized by doubling. When the

growth rate is constant, Equation (2) can be used to determine the time for the quantity to double. That equation is:

$$T_2 \cong 70/P \qquad (2)$$

where;

T_2 = the time required to double and,

P = the percent growth per year.

Problems:

1. Assume that in 1958 the population of Denver, Colorado was 500,000 (5×10^5). If the growth rate for Denver has been 3.5% per year, how many years are required for Denver's population to double?

   $T_2 \cong 70/P \cong 70/3.5 \cong 20$ years.

   Therefore, Denver's population in 1978 =

   ____

   Denver's population in 1998 = ____________________

2. If each person consumes a quart of milk per day in Denver, how many gallons of milk would be consumed per day:

   in 1958? ______________________________

   in 1978? ______________________________

   in 1998? ______________________________

3. If each dairy cow gives four gallons of milk/day, how many cows would be required to provide milk to Denver's population?

   in 1958 ? ______________________________

   in 1978 ? ______________________________

   in 1998 ? ______________________________

4. Assume that there were 250,000 (2.5×10^5) automobiles in Denver in 1958 and that the number of autos will increase in direct proportion to population increase. How many autos would we expect:

   In 1978? ______________________________

   In 1998? ______________________________

5. Assume that each automobile uses three gallons of gasoline per day. Compute the number of gallons of gasoline consumed per day.

   In 1958? ______________________________

   In 1978? ______________________________

   In 1998? ______________________________

6. Assume that each person in Denver uses 100 gallons of water per day. Compute the number of gallons of water used per day.

   In 1958? ______________________________

   In 1978? ______________________________

   In 1998? ______________________________

CONCLUSIONS:

1. What effect does an exponential growth rate have on a population?

2. What effect does an exponential growth rate have on a population's consumption of resources?

SECOND DAY: A Simulation Exercise to Compare the Space Occupied by Two Populations Having Different Growth Rates

PURPOSE: As a result of this exercise, the student will: (1) observe, calculate and compare the rates at which space is occupied by two populations growing at different rates; (2) gain an appreciation for the impact which population growth rates have on space availability.

MATERIALS: 1-150 ml bottle/student
300 ml beans/pair of students

PROCEDURE: Using beans as units of a population, students place them in the two bottles at different rates. The first population doubles every minute; the second population doubles every five minutes. The simulation will continue until one bottle becomes full.

DATA: In the space provided, record the number of population units placed in each bottle for every minute interval.

Time (minutes)	Number of Population Units (T_2 = 1 min)	Number of Population Units (T_2 = 5 min)
1		
2		
3		
4		
5		
6		
7		
8		

Time (minutes)	Number of Population Units (T_2 = 1 min)	Number of Population Units (T_2 = 5 min)
9		
10		
11		
12		
13		
14		
15		
Total:		

RESULTS:

1. Did either population fill its bottle? __________

   Which one? __________

   How many minutes were required for this to occur?

   ____

2. How many units of population were placed in the first bottle?

   ____

   The second bottle? __________

3. If the simulation had continued for the full fifteen minutes, how many population units would have occupied the first bottle?

   ____

   The second? __________

CONCLUSIONS:

1. How is available space affected by population growth rates?

   ____

   ____

   ____

2. The world population today is estimated to be 4 billion people. It is growing at the rate of 1.6 percent per year. In how many years can we expect the world population to double to 8 billion people? ________ years. ($T_2 \cong 70/P$)

What affect will this have on the number of:

a) hospitals? ________________________________

b) power generating plants? ________________________________

c) farms? ________________________________

d) reservoirs of water? ________________________________

Now name 5 other needs which will be affected by this doubling.

________________________ ________________________

________________________ ________________________

____

THIRD DAY: A Simulation Exercise Comparing Consumption at Zero and Exponential Rates

PURPOSE: As a result of today's activity, you will be able: (1) to compare mathematically the consumption of a resource by two populations--one at zero growth rate and one at an exponential growth rate and; (2) to develop a greater appreciation for the significance of resource consumption by populations growing at exponential rates.

MATERIALS: 12 liters of popcorn (popped)

Two 6-liter bowls

PROCEDURE: Two large bowls of popcorn will each represent a finite resource. (Note: Each bowl could represent the world reserves of coal, crude oil, natural gas, food, water, etc.) One will be consumed by a non-growing population (i.e., ZPG); the second will be consumed by a population which doubles every minute. (Note: The minute interval could represent any interval of time, a day, month, year, century.).

One member of the class will represent a zero-growth population. (Note: Each person can represent a thousand, a million, or any number of people.) This person will eat one piece of popcorn every minute from the first bowl. The remaining members of the class will compose the growing population. They, too, begin consuming with only one person eating one piece the first minute. They continue doubling their consumption rate every minute until all remaining students are eating.

In order to continue the exponential rate of consumption, the larger population will now simulate greater numbers by simply doubling the quantity it consumes at each minute interval. The simulation will continue until one bowl is empty.

DATA: In the space provided, record the quantity of the resource consumed by each population group for every minute interval.

Time (minutes)	Quantity Consumed by Zero Growth Population	Quantity Consumed by Growing Population
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Time (minutes)	Quantity Consumed by Zero Growth Population	Quantity Consumed By Growing Population
13		
14		
15		
Total:		

RESULTS:

1. Did either population consume all of its resource? ____________

   Which one? ____________

2. How many intervals of time (minutes) were required for the resource to be consumed?

   ____

3. During this period of time, how many pieces of the resource were consumed by the zero growth rate population?

   ____

   By the exponentially growing population? ____________

4. If the simulation could have continued for twenty-five minutes, how many pieces would have been consumed by the zero growth population?

   ____

   By the exponentially growing population?

   ____

CONCLUSION: How does population growth rate affect the consumption of a resource?

____

____

____

____

FOURTH DAY: How Long Will Our Fossil Fuels Last?

PURPOSE: As a result of this exercise, you will: (1) be able to calculate the lifetime for certain fossil fuels; (2) gain a better understanding of when we may expect these resources to be depleted; (3) understand the importance of conservation; and, (4) give some thought to pursuing careers in science.

MATERIALS: Paper, pencil and calculator

PROCEDURE: Problem solving

DATA:

Problems: 1. It is estimated that the ultimately recoverable resources of oil from just the continental United States will be 190 BB (billion barrels). By 1972, 96.6 BB had been produced. How many BB of oil remain to be receovered?________
What percent of the total oil was produced by 1972?________

2. In 1970 the annual production of oil from reserves in the continental United States was 3.29 BB. Assume that the consumption rate remains constant. (Is that really likely?) How many years of oil production remains? (This number is the static reserve index for domestic petroleum.)

____

At what year may we expect U.S. oil production to be exhausted?

____

3. The Alaskan oil reserves are estimated to be approximately 10 BB. Assume that the 1970 production rate of 3.29 BB could be maintained. How many years of additional production will this give us? ________________________________

4. It is estimated that there may be 103.4 BB of U.S. oil shale. Assuming the 1970 production rate of 3.29 BB, how many additional years might this add to our oil production?

5. It has been calculated that with a 3% growth rate all of these reserves will have been consumed in 35.3 years. At a 3% growth rate factor, calculate how many years would be required for production (and consumption) to double.

6. Why is the price of gasoline increasing steadily?

Do you expect the price to increase, decrease, or remain the same in the future?

Why?

7. The ultimate world crude oil production is estimated to be 1952 BB. By 1972 we had consumed 261 BB, leaving a world reserve of 1691 BB. The world consumption rate in 1970 was 16.7 BB. Assuming a zero growth rate, how many years will be required to consume the world's remaining reserves of oil?

8. Can we realistically expect the world consumption of oil to remain at a zero growth rate? Why or why not?

The "developing third world nations" are demanding more oil to improve their productivity and standard of living. If the world consumption growth rate is only 5% per year, in how many years could we expect the world reserve of 1691 BB to be depleted?

Hint: Use the following equation:

$$T = \frac{1}{k} \ln \left[\frac{Rk}{r_o} + 1 \right]$$

where: k = growth rate, 1970

R = remaining reserves

r_o = production rate, 1970

CONCLUSIONS:

1. How do production growth rates affect the lifetimes of finite resources?

2. Some people say that "growth is good--bigger is better." What do you think about this statement?

3. Through "planned obsolescence" many manufacturers maintain high production rates. Should we outlaw "planned obsolescence?" Why or why not?

4. Except for the continuous input of sunlight, the human race must finish the trip with the supplies that were aboard when the "spaceship earth" was launched. What impact does this statement have on the concept of recycling?

5. Many raw chemicals (used to make medicines, fertilizers, and plastics) are made from petroleum products. Should we save our petroleum for these important chemicals or use the oil for fuels? Why or why not?

6. Is there any weakness in the argument that we should promote ever-increasing rates of consumption of resources in the hope that science and technology will rescue us from the consequences of doing so?

7. What is of critical importance in this statement: "At current levels of output and recovery, coal reserves can be expected to last more than 500 years."

8. With great challenges there also are great opportunities. What opportunities do you see for careers in science?

TEACHER'S GUIDE

OBJECTIVE: Students will understand the impact of the exponential growth rate of population on the consumption of finite resources such as the fossil fuels, water and food.

BACKGROUND:

1. On Finite Resources: Professor Albert A. Bartlett, Department of Physics and Astrophysics, University of Colorado has stated, "The question of how long our resources will last is perhaps the most important question that can be asked in a modern industrial society."

Modern industrial and technological developments coupled with the voracious public appetite for the use of consumable resources enables us "to see the light at the end of the resource tunnel." The light, in this case, means the end of those resources, for all practical purposes.

The fossil fuels (coal, oil, gas) serve as the primary energy base for most of our industrial productivity. By practicing conservation techniques, we can prolong the use of but not prevent the exhaustion of these resources.

2. Exponential Growth Rates of Human Populations: In very general terms, we may assume the premise that a direct quantitative correlation exists between the number of people and the consumption of finite resources. Since population tends to grow exponentially, we can assume, therefore, that finite resources also will be depleted at an exponential rate.

3. Exponential Math: The classic equation for exponential growth is: $N = N_0 e^{kt}$ (1)

where N = the size of the quantity at time t,

N_0 = the initial size of the quantity at time $t = 0$,

e = the base of natural logarithyms (2.71828),

k = the fractional change in the quantity per given time interval (the growth rate) and

t = time.

If the quantity doubles in size ($N=2N_o$) during an amount of time t_2, then

$$2 = e^{kt_2}$$

and t_2 (the doubling time) $= \frac{.69}{k} \simeq \frac{70}{100k} \simeq \frac{70}{P}$

where P is k expressed as a percentage.

If Equation (1) is applied to resource production, integrated and solved for t, an expression termed the exponential reserve index is obtained:

$$t = \frac{1}{k} \ln \left[\frac{Rk}{r_o} + 1\right] \quad (2)$$

where t = the resource expiration time; i.e., the time it will take from t_o to consume all of the resource,

R = an estimate of remaining reserves of the resource,

k = the fractional rate of growth,

r_o = the production rate at t=0 and

ln = the natural logarithym.

4. Summary Statement: This activity is not intended to be an exhaustive or comprehensive treatment of the subject of energy or resource consumption. Rather, it is intended to focus the student's attention on the relationship between rates of population growth and resource consumption. This relationship is having and will continue to have profound implications on all aspects of our lives.

TIME REQUIRED: This activity can be accomplished in five teaching periods of 45 minutes each.

MATERIALS:

Regular graph paper
300 ml of rice per pair of students

3. One 250 ml beaker or bottle per student
4. 2 lbs. of unpopped popcorn (for 175 students)
5. Two 6 liter bowls
6. Notebook paper

Suggestion for popcorn conservation: Save the remaining zero growth materials for other classes.

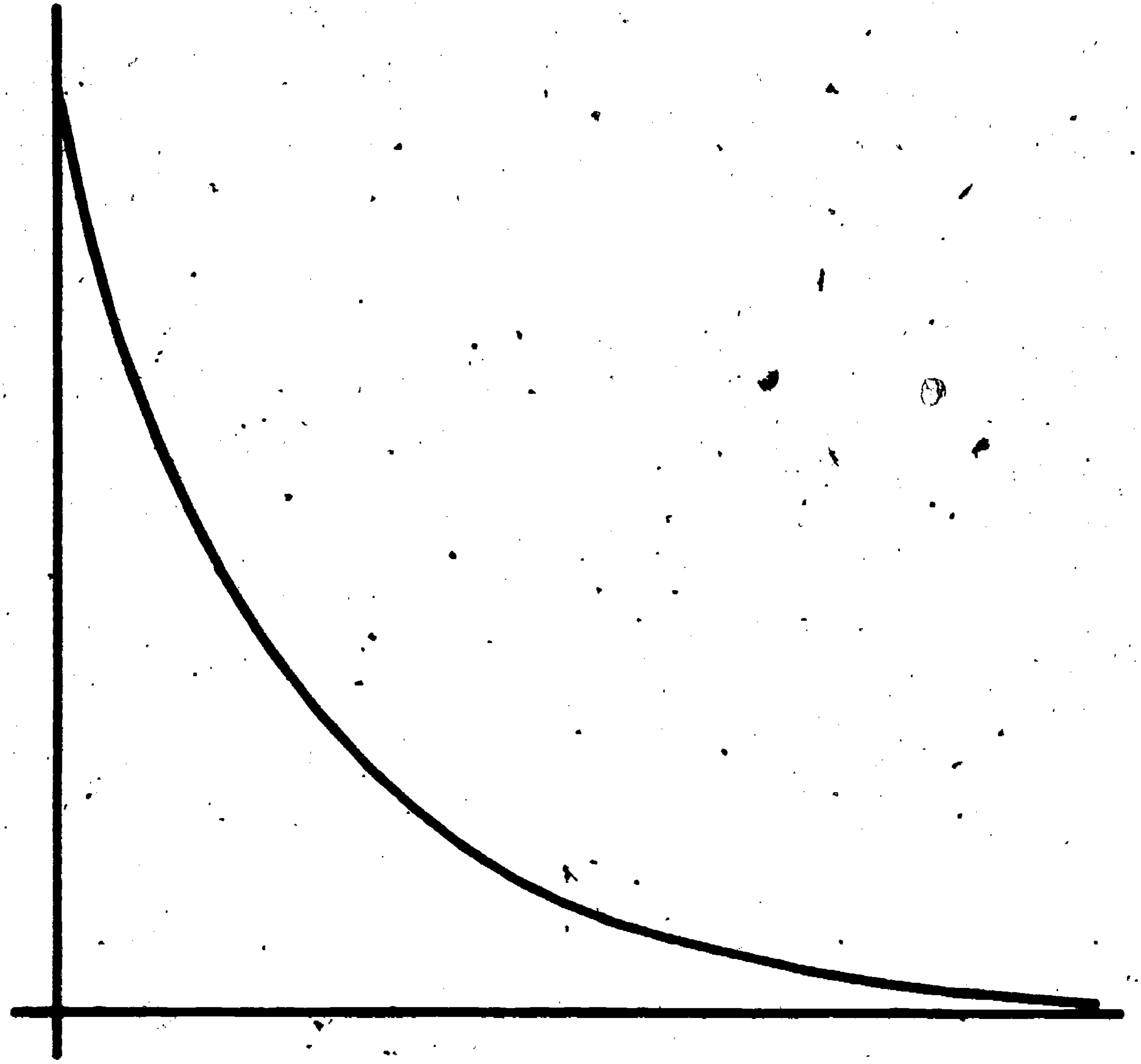
SUGGESTED FOLLOW-UP ACTIVITIES:

1. Construct exponential growth graphs for varying rates of growth.
2. Repeat the above using semilog graph paper.
3. Show and discuss other types of exponential growth graphs using the graphs on the following pages.

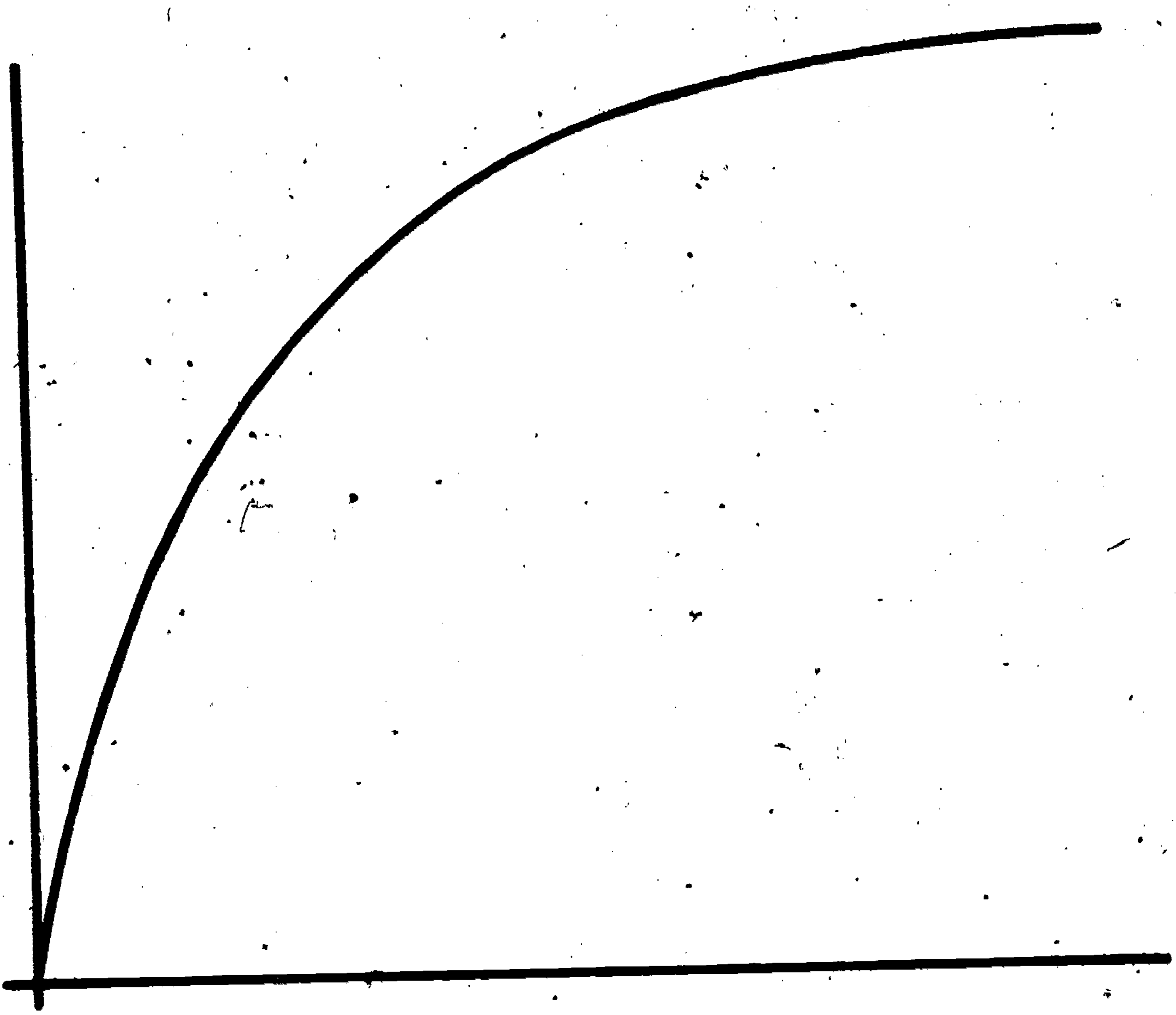
REFERENCES:

1. The Poverty of Power, Barry Commoner, Knopf, Inc., 1978.
2. The Man-Made World, Polytechnic Institute of Brooklyn, McGraw-Hill, 1971.
3. "The Forgotten Fundamentals of the Energy Crisis," by Dr. Albert A. Bartlett, Department of Physics and Astrophysics, University of Colorado, Boulder, Colorado.
4. "U.S. Energy Resources, A Review as of 1972; a National Fuels and Energy Policy Study, Serial 93-40 (92-75) Part I," by M. King Hubbert. U.S. Government Printing Office, Washington, D.C. 20402. $2.35, 267 pages.

Exponential Curve, $y = ce^{kx}$ (k positive)



Exponential Curve, $y = ce^{kx}$ (k negative)



Exponential Curve, $y = 1 - ce^{kx}$ (k negative)

#2. CALIBRATION OF A THERMOCOUPLE

PURPOSE: To calibrate a thermocouple for convenient temperature measurements.

INTRODUCTION: Society has always needed some form of measurement to be able to trade goods and build cities. It becomes increasingly important that we adopt standard units to insure that everyone is talking about the same quantity.

Scientists have accepted the freezing point and the boiling point of water (at one atmosphere of pressure) as the two reproducible points for temperature measurement. You will be calibrating a thermocouple against these same reference points by comparing the voltage output of the thermocouple against various water temperatures as measured with a thermometer.

Basically, a thermocouple is a device, composed of two dissimilar metal wires joined at two points, which converts heat into electrical energy by virtue of the potential difference or electromotive force (EMF) between the two metals.

This EMF is dependent upon temperature, allowing us to use thermocouples as temperature-sensing devices.

MATERIALS: Thermocouple, millivolt meter, thermometer, 250 ml beaker, heat source, ice, ring stand and graph paper.

PROCEDURE:

1. Prepare the ice-water bath by placing ice and cold water in a 250 ml beaker. Stir to bring the temperature down to 0^oC. Assemble your apparatus as shown in Fig. 1.

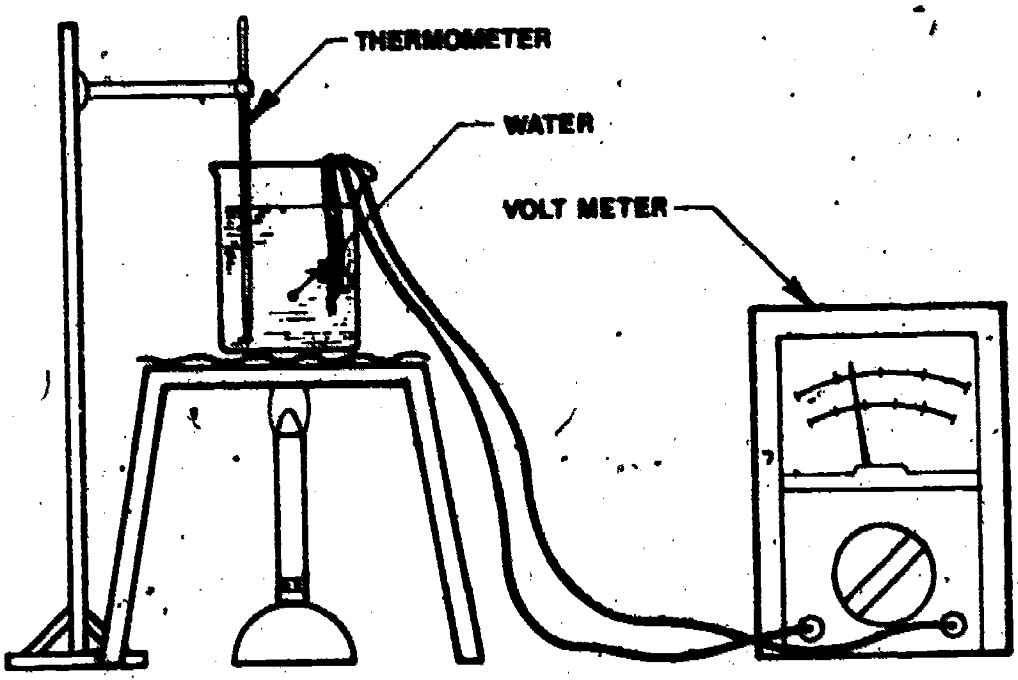


Fig. 1 Apparatus

2. Wait until the bath temperature is at $0^{o}C$ before taking any measurements. Record the voltage output at $0^{o}C$ on your Data Sheet.
3. Begin heating the water bath and record both the water bath temperature and the voltage output every minute, until the water boils. Continue for two more minutes after the water boils. (Be sure to read both the voltage and water bath temperature simultaneously.)
4. Construct a graph of voltage as a function of temperature.
5. Determine the slope of the line and use a dotted line to extrapolate the curve to $300^{o}C$.

DATA SHEET

Time, in minutes	Temperature ($^{\circ}C$)	Voltage (millivolts)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

CALCULATIONS AND RESULTS:

1. Graph the voltage on the "y" axis and the temperature on the "x" axis.
2. Determine the slope and record it here: ______________________
   (What are the units for the slope?)
3. Graphically, determine the voltage for the following temperatures:

$0^{\circ}C$ = ________________ (what units?) ________________________

$20^{\circ}C$ = ________________ ________________________

$50^{\circ}C$ = ________________ ________________________

100° C = ______________ (what units?) ______________

150° C = ______________ ______________

300° C = ______________ ______________

Be sure to label and save your graph for further use with this thermocouple.

QUESTIONS:

1. Give three reasons for the need for accurate measuring tools. ______________

2. Why are at least two points needed to calibrate a scale? ______________

3. What voltage corresponds to 75°C? ______________

4. What is the corresponding temperature at 10 millivolts? ______________

5. Is there any difference in the slope between 10° C and 30° C and the slope between 80° C and 100° C? ______________

6. Using the slope, determine the voltage at 75° C? ______________

7. What information can you obtain from the slope? ______________

8. What is one advantage of a thermocouple over a thermometer? ______________

9. What is one advantage of a thermometer over a thermocouple? ______________

10. Where could a thermocouple be used in your home? ______________

TEACHER'S GUIDE

OBJECTIVE: The student will:

1. Understand how to calibrate a thermocouple using a water bath, a voltmeter and a thermometer.
2. Record and graph the data for future use.
3. Demonstrate an understanding of graph reading by determining the slope and extrapolating to 150° C (302° F).
4. Show an awareness of measurement by discussing the concept of scale calibration.

BACKGROUND: Thermocouples are a very convenient form of temperature measurement since their output can be monitored with a millivolt meter, thus keeping system disturbance at a minimum.

The operation of a thermocouple is based on the fact that a small electric current will flow between two dissimilar metal wires if their junctions are maintained at different temperatures. One junction, called the reference, is normally kept at 0^oC while the second junction serves as the sensor. However, acceptable results are available without maintaining the reference junction at 0^o C, provided that the reference junction is always at the same temperature for each use.

This activity utilizes the meter itself as the reference junction while also completing the circuit. The best thermocouple for classroom use is the copper-constantan (type T) since its effective range is -60^oC to 300^oC. Its accuracy is $\pm .8^o$ C up to 100^o C, increasing to $\pm 2.25^oC$ at 300^oC.[1] One shortcoming, however, is the rapid oxidation of copper at high temperatures over 400^oC.

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[1] Thermocouple Temperature Measurement, P.A. Kinzie, 1973, John Wiley & Sons, Inc., p. 122.

TIME REQUIRED:

1. One period for actual measurements.
2. Two to three periods if the teacher wishes to include more about measurement and measuring skills.

MATERIALS (per group)

Thermocouple (see suggestions for sources)
Millivolt meter
Water bath (with ice)
Thermometer
Heat source
Ring stand and clamps

SUGGESTIONS: The simplest method of thermocouple construction is to buy type T thermocouple wire available in any city or from Instrument Service Co., at 4241 Jason, Denver, Colorado at about 8¢ per foot. The second choice is to buy equal guage copper and constantan wire or to try hardware stores for either wire or thermocouples.

The joint can be twisted, but is better if soldered or clamped.

This activity can be used as a replacement of the traditional blank thermometer calibration lab . It can be practically applied in some of the solar energ activities outlined in this manual. Additionally, it can serve as a source of discussion regarding measurement and graphing applications.

SUGGESTIONS FOR FOLLOW-UP: The thermocouple is almost a requirement for solar lab activities as thermometers need to be read by opening the system while thermocouples can be monitored without disturbing the system. Secondly, thermocouples can read higher temperatures than the standard classroom thermometers can safely attain.

The thermocouples produced in this activity can be used later in the following activities found in this manual:

Save That Ice, Activity #4

The Insulating Qualities of Various Fibers, Activity #5

The Efficacy of Light Sources, Activity #9

Constructing a Model Greenhouse, Activity #13

Solar Energy Storage in Gravel, Activity #15

REFERENCES:

1. Thermocouple Temperature Measurement, P.A. Kinzie, 1973, John Wiley & Sons, Inc.
2. The Theory and Properties of Thermocouple Elements, P.D. Pollock, 1971, American Society for Testing and Materials.
3. Source: Instrument Service Company, 4241 Jason, Denver, Colorado, (303) 458-7302.

#3. A TIME AND COST COMPARISON OF HEAT SOURCES

PURPOSE: In this experiment, you will: 1) use several different heat sources to raise the temperature of a known quantity of water, 2) calculate the quantity of heat required to heat the water, 3) calculate the relative costs for using each of these fuels, and 4) correlate the experimental data with home heating data.

INTRODUCTION: In our technological society, we obtain our energy from many different sources. In this country, homes are heated using a variety of methods including oil, natural gas, wood, electricity, and solar energy.

This particular experiment will focus on the use of several fuels and a hot plate as heat sources. Some of the fuels that will be used are petroleum based; e.g., propane, butane and paraffin. Other fuels are distilled from wood products; e.g., alcohol and sterno. You will experimentally determine the cheapest method of providing heat. Upon completion of the experiment, other considerations such as efficiency, pollution, and fuel availability will be discussed. It is important for all Americans to understand the implications of using a particular fuel.

MATERIALS: (per team)

250 ml beaker

Various heat sources including candles, sterno, alcohol lamp, hot plate, propane torch

Water

Graduated cylinder, 100 ml

Clock or watch with second hand

Thermometer

PROCEDURE: For this experiment, you will be using several of the heat sources listed above. In order to compare the various heat sources, calculations of the amount of fuel must be done for each heat source. These calculations will vary depending on the heat source. Below, you will find the steps involved in calculating the amount of fuel used for each heat source.

1. Add exactly 200 grams of water to a 250 ml beaker.
2. Record the temperature of the water in the data table.
3. A. For sterno, alcohol lamp, propane burner: Determine the mass of the source before heating.

   B. For hot plate: Record the watt rating given on the hot plate identification plate and turn the hot plate to the highest setting.
4. Place the beaker just above the hottest part of the source.
5. Record the starting time.
6. Continue heating until the temperature has been raised by exactly 50°C.
7. Record the time when the desired temperature has been reached.
8. Turn the heat source off.
9. For sterno, alcohol lamp, propane burner: Determine the mass of the source after heating.
10. Repeat 1-9 for each of the other heat sources.

DATA:

Fuel	Starting Mass, g	Final Mass, g	Starting Temp., °C	Final Temp., °C	Starting Time	Ending Time
Candle						
Sterno						
Alcohol Lamp						
Propane Burner						
Hot Plate						
	Wattage Rating:					

FINAL RESULTS:

Fuel	B Units Used	C Cost/Unit	D Cost to Heat 200 ml H_2O to 50°C	E Cost/Calorie	F Time Needed
Candle	g	¢/g			
Sterno	g	¢/g			
Alcohol Lamp	g	¢/g			
Propane Burner	g	¢/g			
Hot Plate	KWH	¢/KWH			

CALCULATION:

A. Heat used = (specific heat) (mass) (change in temperature) = calories

specific heat of water = 1 cal/gram °C

mass of water used = 200 g

change in temperature = 50°C

heat used = $(1 \frac{\text{cal}}{\text{g}\,^{\circ}\text{C}})$ (200 g) (50°C) = ______ calories

HEAT IN KILOCALORIES = $\frac{\text{calories}}{1000\ \text{cal/Kcal}}$ = ______ Kcal or Calories

B. Amount of "fuel" used = Mass before - Mass after = _____ grams

for hot plate: $\frac{\text{(number of watts) (time in minutes)}}{\text{(1000 w/kw) (60 min/hr)}}$ = _____ KWH

C. Obtain cost per unit from your instructor.

D. Cost to heat 200 ml of water 50°C:

$\underset{(C)}{\text{(cost per unit)}} \times \underset{(B)}{\text{(number of units used)}}$

E. Cost per kilocalorie = $\frac{\text{cost calculated in D}}{\text{number of kilocalories in A}}$

F. Time needed = Ending Time - Starting Time

CONCLUSION: ____________________

____

____

QUESTIONS:

1. Which heat source was the most expensive? ____________

least expensive? ____________

2. Which heat source was the fastest? ____________

the slowest? ____________

3. Other than time and cost, what other factors might be considered in choosing a heat source?

4. Check with local heating contractors, electric companies and solar installation companies in order to complete the chart below:

HOME HEATING SOURCES --UNITED STATES

	Unit	No. of Calories per Unit	Cost per Unit	Cost per Calorie	Installation of Equipment Average Home	Pollution Level
Oil	gallon	36,000				medium
Natural gas	1000/cubic ft	260,000				low
Wood	cord	5,300,000				high
Coal	ton	6,200,000				high
Electricity	Kwh	860				variable
Solar	langley	$\frac{1200 \text{ cal}}{m^2/\text{hr}}$				none

5. For each of the sources listed above, list the advantages and disadvantages, including any factors which are not included in the table.

6. Now, the choice is yours. Make a list of your 1st, 2nd, 3rd, 4th and 5th choices for heating systems.

TEACHER'S GUIDE

OBJECTIVES: Upon completion of this activity, the student will be able to:

1. Demonstrate proficiency in measurements of temperature and time in comparing heat sources.
2. Understand the source of each of the fuels encountered.
3. Make calculations of heat, amount of fuel consumed, cost of each heating source, and cost per calorie of heat delivered.
4. List several factors in choosing a fuel.
5. List five common methods of heating a building.
6. Research current prices for both installation and fuel, and make calculations necessary to compare the methods of heating.
7. Make an educated judgment as to the type of heating system most appropriate for his (her) needs.

BACKGROUND: Most students have heard about the different methods of heating a house or building. In this activity, they will be able to directly observe the efficiency of various laboratory heat sources and relate the knowledge to actual heating systems in buildings. This particular activity could be used in a variety of scientific disciplines: the physics teacher could implement the activity when discussing energy and heat; the chemistry teacher could use it when specific heat is studied. It would be best utilized after students have had some background in fuel production and use.

TIME REQUIRED: 1 laboratory period for data collection

2 regular class periods for calculation and discussion

MATERIALS (per group): Heat sources can be rotated so that in a class of 30 students working in groups of 2, you would need 3 of each heat source.

- 3 - candles
- 3 - sterno cans
- 3 - alcohol lamps
- 3 - propane burner (stove)
- 3 - hot plates
- 15 - beakers
- 15 - thermometers
- 1 - clock with second hand
- 15 - graduated cylinders

SAMPLE DATA:

Fuel	Units Used	Cost Per Unit	Cost to Heat 200 ml H_2O 50°C	Cost/KCAL	Time Needed (min)
Sterno	10.2 g	.31¢/g	3.17¢	.317¢	7.6
Alcohol Lamp	6.4 g	5.5¢/g	35.2¢	3.52¢	8.2
Propane	4.4 g	.37¢/g	1.65¢	.165¢	5.3
Butane	5.3 g	.78¢/g	4.12¢	.412¢	3.5
Hot Plate (750 watt)	.083 Kwh	4.4¢/Kwh	.37¢	.037¢	6.7

SUGGESTIONS:

1. Caution students in the proper use of all heat sources. Safety goggles must be worn. Exercise care with hot beakers.
2. Other heat sources, such as a Bunsen burner or butane camp stove could be substituted or added.
3. In calculating the mass of fuel used for sterno, alcohol lamp, and propane stove, it is important to subtract the mass of the container when calculating the cost per gram.
4. Have ready a quantity of water at room temperature.

SUGGESTED FOLLOW-UP ACTIVITIES:

1. Discuss the use of fuels in producing electricity.
2. Demonstrate the use of the sun's energy for heating water.
3. Discuss heat loss in houses and methods for reducing fuel consumption.
4. Demonstrate the use of fuels in transportation.

REFERENCES:

Energy - Environment Source Book, John Fowler, 1975; by National Science Teachers Association.

Energy - Environment Mini-Unit Guide, Stephen Smith, et al., 1975, by National Science Teachers Association.

#4. SAVE THAT ICE

PURPOSE: In this activity you will:

1. Evaluate the comparative value of the insulating ability of several different materials.
2. Calculate the heat loss (or gain) in Btu's.
3. Determine the R factor of your insulating material.
4. Propose a revision to the activity so that you can make the ice last 10% longer than your first attempt.

INTRODUCTION: Whether you are trying to keep heat out of a container or keep it in, the problem is still the same - how can you resist the transfer of heat from the hot region to the cooler one. The material that you use will accomplish this in varying degrees depending on its ability to resist that flow. This is known as the R-value of the insulating material, with the higher number indicating a greater insulating ability.

Your problem in this activity is to use any one material commonly available to you to wrap a known quantity of ice so that the least amount of ice will have melted in 24 hours. You will determine the percentage of ice lost to melting, and will compare the relative values of insulating properties of each of the substances used by the various teams in your class. In addition, you will calculate the amount of heat energy transferred into your ice "package".

MATERIALS (per group)

2 - styrofoam cups or 1/2 pint milk cartons
Balance
Insulating materials (your choice)
Thermometer (-10 to 120° C)

PROCEDURE:

Day 1:

1. Determine the mass of a styrofoam cup (or milk carton). Fill it with water and find the mass of water and container. Record in appropriate space on Data Sheet.
2. Determine and record the mass of the water (Data Sheet, #3).
3. Collect the insulating material that you will use.
4. Overnight, freeze the container of water.

Day 2:

5. In the next class period, remove ice from freezer and wrap it in your insulating material (not to exceed 2 feet in circumference along any of its three axes.
6. Label your team's package and place it in the same location as all the others as directed by the teacher.

Day 3:

7. During the next class period, unwrap the container of ice, being careful not to spill any melt water.
8. Determine the temperature of the melt water. (Data Sheet, #4)
9. Quickly determine the mass of the remaining ice and record. Subtract to find the mass of melt water. (Data Sheet, #5, 6 & 7)
10. Calculate the number of calories absorbed by the ice. This is the energy necessary to melt that mass of ice.
11. Determine the number of calories of heat that was used only in warming the water (#11).
12. Determine the total amount of heat energy absorbed by this system (#9 and #11).
13. Determine by calculation the number of Btu's of energy to melt the ice (#13). (1 Btu = 252 calories)

DATA

Day 1:

1. Mass of container ________ g
2. Mass of container and water ________ g
3. Mass of water (#2 - #1) ________ g

Day 2:

4. Temperature of melted water ________ °C
5. Mass of water after 24 hours (pour off into a separate container) ________ g
6. Mass of ice at end of 24 hours ________ g
7. Mass of ice that melted (see #5) ________ g
8. Percent of ice that remained after 24 hours (#6/#3 x 100) ________ %
9. Number of calories of heat absorbed by the ice (each gram of ice that melts absorbs 80 calories of heat) $\left(\frac{80\ \text{cal}}{\text{g}}\right) \times \#7$ ________ calories
10. Temperature rise of melt water at end of 24 hours (Final temperature #4 - 0°C) ________ C°
11. Number of calories of heat absorbed by the melt water (#5 x #10) ________ calories
12. Total amount of energy absorbed by the melting of the ice and warming of the melt water (#9 + #11) ________ calories
13. Number of Btu's absorbed $\left(\#12 \times \frac{1\ \text{Btu}}{252\ \text{calories}}\right)$ ________ Btu's

CONCLUSIONS AND QUESTIONS:

1. Of all the projects done in class, which insulating material allowed the least amount of ice to melt? ______________________

2. What experimental errors might have been encountered in this activity?

3. How would you change this activity so that your remaining ice will be at least 10% larger? ______________________

4. Rank in order from the most expensive to the least expensive, the relative cost of each of the materials. ______________________

5. Compared to the relative cost of each, which material would be the most economical to use considering its insulating value? ________

6. If you were to place any of these insulating materials in your house, what problems might you encounter? ______________________

7. Do any of the materials suggest difficulty in installation? Consider labor costs in installing each of the materials. How does this affect the overall cost of insulating your home?

TEACHER'S GUIDE

OBJECTIVES: After completing this activity the students will be able to:

1. Compare the relative value of the various types of insulating materials.
2. Discuss insulating materials in terms of R-value.

BACKGROUND: Heat flow depends on area, time, thickness and temperature difference. The flow of heat occurs only when there is a temperature difference (the "driving force"). Regardless of how much insulation you use, there will be no heat lost or gained if the inside temperature is the same as the outside temperature. The greater the difference in temperature, the greater is the heat flow. The direction of heat flow or transfer is always from the warmer side to the cooler side.

The resistance to heat flow of a material, the R-factor, is determined by laboratory testing. The test results are expressed usually as "U-factors" rather than R-factors. A U-value is the transmission rate of a material expressed as the rate of flow (British Thermal Units, Btu) per square foot of area, per stated thickness, per hour of time subject to a temperature difference. This is often stated as $Btu/hr/ft^2/^oF$ for specific thickness. Rather than writing $Btu/hr/ft^2/^oF$ every time, the symbol U is used to express this value. The resistance to this flow rate is expressed as R, which is equal to 1/U.

One Btu is the amount of heat energy required to raise the temperature of one pound of water one degree F. All furnaces and air-conditioners are rated in terms of Btu's.

TIME REQUIRED:

4 class periods

- 1 - planning of approach and assigning of groups
- 1 - preparing insulating package
- 1 - measuring and recording data
- 1 - discussion and comparative evaluation

MATERIALS (per group):

2 - water containers (1/2 pint milk cartons or large styrofoam cups)
1 - freezer
1 - thermometer
6 - balances (several groups could share)

SUGGESTIONS:

1. Avoid starting the activity such that the melting process will occur over a weekend or holiday. Twenty-four hours is about the limit to expect ice to last except under the most ideal conditions.
2. Have each team or group summarize its data and type of insulating material used on the board so that the rest of the class can arrive at conclusions.
3. Suggested insulating materials:
   - a. spun fiberglass
   - b. styrofoam sheets
   - c. cellulose fiber (shredded newspapers)
   - d. urethane foam
   - e. rock wool
   - f. wood shavings

   All of these may have varying thickness and density of packing.

4. Compare the R-value ratings of the various materials to their costs. A local lumber yard can give you current prices. Which material is the least expensive for a given R-value?
5. Experience has shown that using larger blocks of ice and having insulating material on hand makes for a more successful experience.

SUGGESTED FOLLOW-UP ACTIVITIES:

1. Have the entire class discuss the ideas elicited by Question #3. Have a group carry it out to quantify any improvements.
2. Discuss how retarding heat flow from our homes during the winter or into our homes during the summer is a real-world application of the principles demonstrated in this activity.

SAMPLE DATA:

1. Mass of container 14 g
2. Mass of container and water 250 g
3. Mass of water (#2 - #1) 236 g
4. Temperature of melted water 8 °C
5. Mass of water after 24 hours (pour off into a separate container) 200 g
6. Mass of ice at end of 24 hours 36 g
7. Mass of ice that melted (see #5) 200 g
8. Percent of ice that remained after 24 hours (#5/#3 x 100) 15.25 %
9. Number of calories of heat absorbed by the ice (each gram of ice that melts absorbs 80 calories of heat) 16,000 calories

   $\left(\frac{80\text{ cal}}{g}\right) \times \# 7$
10. Temperature rise of melt water at end of 24 hours assume $T_1=0^oC$, $T_2=8^oC$, $T_2-T_1=8C^o$ 8.0 C^o

11. Number of calories of heat absorbed by the water (#5 x #10) 1,600 calories

12. Total amount of energy absorbed by the melting of the ice and heating of the water (#9 + #11) 17,600 calories

(If $T_2 - T_1 = 0^{o}C$ then 16,000 + 0 = 16,000 calories)

13. Number of Btu's absorbed 69.8 Btu's

REFERENCE:

Solar Experiments for High School and College Students, Norton, Hunter and Cheng. 1977 Rodale Press. p. 16.

NOTES:

Latent heat of fusion = 80 calories per gram.

80 calories of heat energy are required to melt 1 gram of ice to water at 0 °C.

1 Btu = 252 gram-calories

#5. THE INSULATING QUALITIES OF VARIOUS FIBERS

PURPOSE: The student will perform an experiment to collect data on the insulating capability of various cloth fibers used in clothing manufacture.

INTRODUCTION: One of the ways that man has protected himself from the forces of nature is through the use of proper clothing. He has learned to use the correct type of fiber or, in some cases, combinations of fibers to reduce the rapid loss of his body heat.

The purpose of the clothing we wear is to reduce heat loss to a reasonable level in order that we can remain comfortable under most weather conditions. Generally, the body's heat is lost by the three methods of heat transfer: convection, conduction, and/or radiation. Convection is heat transfer via moving fluids; conduction involves loss of heat through molecular motion in solids, and radiation is the transfer of heat via electromagnetic waves from a source through a separating medium.

We will determine in the following activity why certain types of clothing seem to keep us more comfortable in cold conditions than others.

MATERIALS: Several pieces of cloth (various weights of wool, cotton, nylon ~~shell, down). Two~~ "heat" boxes/student group, thermocouple or thermometer for each "heat" box, source of wind (fan), wind guage (hand held). See Figure 1

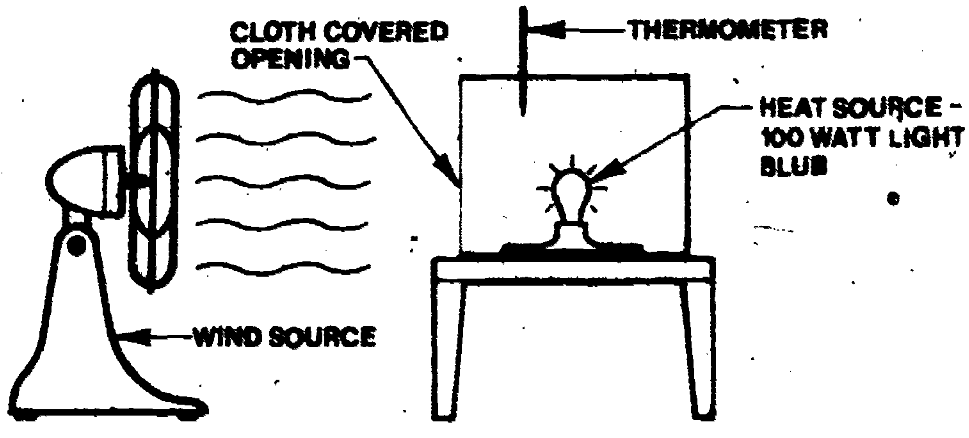


Figure 1. Apparatus

Two heat boxes are needed so that the one without the wind passing over it would be the "control".

PROCEDURE:

1. The heat boxes should be set up to begin generating heat at the start of the class period with the cloth removed to allow time for heat to accumulate and the temperature to stabilize in the boxes.
2. Place a piece of the selected material over the open sides of both heat boxes (masking tape should work well for this), completely covering the opening.
3. Direct a steady flow of air at the test cloth from a fan.
4. Begin 1 minute observations of temperature change, recording results in the data table.

DATA: In the following data table record the type of cloth being tested, the time and the heat box temperature. Continue the experiment, taking temperature readings each minute for approximately 20 minutes.

DATA TABLE

Cloth Sample ____________________

Time, minutes	Temperature of Heat Box, °C
0	
1	
2	
3	
4	
5	
6	
7	

DATA TABLE (Continued)

Cloth Sample ________________

Time, minutes	Temperature of Heat Box
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

CALCULATIONS AND RESULTS:

1. From your data plot a graph of temperature as a function of time.
2. Determine the slope of the line on your graph; i.e., find the number of degrees change in temperature per minute of "exposure."
3. Compare your results with those of students who used different samples of cloth.

CONCLUSIONS AND QUESTIONS:

Use class data to answer the following:

1. Which fiber has the highest insulating property in this experiment?
2. Can you suggest why some fibers are used in combination with other fibers?

3. Which of the natural fibers (wool or cotton) would you prefer for winter clothing?
4. Can you think of weather conditions that would alter the insulating qualities of cloth fibers? Explain.

TEACHER'S GUIDE

OBJECTIVE: Students will learn how to determine what effect various clothing has on retarding the loss of body heat.

BACKGROUND: This activity is designed to illustrate the resistance of clothing material to heat transfer.

Building insulation (or R-factor) is discussed in another activity in this manual, but the purpose of this activity is to aquaint students with some of the principles of heat energy conservation even though it is dealing with heat conservation in the human body and not a building or home.

TIME REQUIRED: This activity should take no more than two class periods. One period may be required to gather the data.

MATERIALS (per class or group): The teacher has the option of demonstrating this activity or assigning it to student groups. The materials required are: two "heat boxes/group; thermocouple or thermometer; cardboard box; wind guage; wind source (fan). One or two fans will probably accommodate all of the students' test boxes. Suggested samples of cloth to use are wool, cotton, nylon, other natural and man-made fibers.

The use of "down" (a combination of fibers) can lead to a discussion of proper "layering" of clothes. Wool may also vary as to weight and tightness of weave.

SUGGESTIONS: This activity is appropriate for independent study in the following classes: energy, meterology, home economics, physics, earth science and biology. You may wish to check an ASHRAE manual for further studies on values of clothing insulation.

FOLLOW-UP: A related activity involves the use of the following equation to determine wind chill:

$$H = (0.14 + 0.47\, v^{1/2})\ (36.5 - T), \text{ where}$$

H is the wind chill factor, v is the velocity of wind in m/sec and T is the ambient temperature in °C.

You may also wish to define Clo units for your classes. These units are used by the clothing industry and engineers to determine comfort under varying environmental conditions--particularly wind speed and humidity. One Clo is defined as the amount of insulation necessary to maintain comfort and mean skin temperature at 92°F in a room at 70°F with air movement not over 10 ft/min, humidity not over 50% (metabolism of 50 calories/square meter/hour).

REFERENCES: ASHRAE Manual 1977, American Society of Heating, Refrigerating and Air Conditioning Engineers.

#6. HOME HEAT LOSS STUDY

PURPOSE: You will learn the concepts of heat flow and infiltration and will gain a practical knowledge about heat transfer in homes and their construction.

INTRODUCTION: Most exciting about this activity is its potential for studying heat flow in your own house. We will study an example of a 1000 ft^2, two-story house to observe what effects various construction materials and building techniques have on its thermal properties.

This activity is based on the derived expression for conductive heat loss:

$$q_k = kA \frac{\Delta T}{w} \qquad (1)$$

where q_k is the rate of heat transfer in $\frac{Btu}{hr}$ (Btuh),

k is the thermal conductivity of the surface material in

$$\frac{Btu - in.}{hr \cdot ft^2 {}^oF} \text{ or } \frac{Btu - ft.}{hr \cdot ft^2 {}^oF},$$

A is the area of the surface in ft^2,

ΔT is the temperature difference across the surface in ^oF and

w is the surface thickness in feet or inches.

In the process of using Eq. (1), we will be introduced to thermal conductivity, R- and U-values and the calculations of area for the house.

We will also study infiltration, using the density and specific heat of air, the number of air changes per hour, the volume of air in the house and the inside and outside design temperatures.

MATERIALS:

A 4K computer, programmed in BASIC

Graph paper

Activity sheet

PROCEDURE:

1. Choose the house transmission area you wish to study: floors, ceilings, walls, wall on buffer space, windows and doors.
2. Brainstorm for various types of constructions for your transmission area. (See Appendix C.)
3. List 5 or more different types of constructions for your transmission area.
4. Draw or describe each type of construction.
5. Input construction materials, and their R-values (or their k-values and their thicknesses). (See Appendix C.)
6. Get heat flow results in Btu/hr for each transmission area.
7. Get heat flow in Btu/hr for total house.
8. Find the gain or loss in Btu/hr for your change.

DATA:

Transmission Area ______________________

Construction #1

Layers of Materials	R-value
1. ______________________	______
2. ______________________	______
3. ______________________	______
4. ______________________	______
5. ______________________	______
6. ______________________	______
7. ______________________	______
8. ______________________	______
Total R-value	______

Construction #2

Layers of Materials	R-value
1. ______________________	______
2. ______________________	______
3. ______________________	______
4. ______________________	______
5. ______________________	______
6. ______________________	______
7. ______________________	______
8. ______________________	______
Total R-value	______

Construction #3

Layers of Materials	
1. ______________________	______
2. ______________________	______
3. ______________________	______
4. ______________________	______
5. ______________________	______
6. ______________________	______
7. ______________________	______
8. ______________________	______
Total R-value	______

Construction #4

Layers of Materials	
1. ______________________	______
2. ______________________	______
3. ______________________	______
4. ______________________	______
5. ______________________	______
6. ______________________	______
7. ______________________	______
8. ______________________	______
Total R-value	______

Construction #5

Layers of Materials R-value

1. ________________________________ ________
2. ________________________________ ________
3. ________________________________ ________
4. ________________________________ ________
5. ________________________________ ________
6. ________________________________ ________
7. ________________________________ ________
8. ________________________________ ________

Total R-value ________

Construction #6

Layers of Materials

1. ________________________________ ________
2. ________________________________ ________
3. ________________________________ ________
4. ________________________________ ________
5. ________________________________ ________
6. ________________________________ ________
7. ________________________________ ________
8. ________________________________ ________

Total R-value ________

Construction #7

Layers of Materials

1. ________________________________ ________
2. ________________________________ ________
3. ________________________________ ________
4. ________________________________ ________
5. ________________________________ ________
6. ________________________________ ________
7. ________________________________ ________
8. ________________________________ ________

Total R-value ________

Construction #8

Layers of Materials	R-value
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
Total R-value	

Table of Results

Run #	Total R-value of Area	Area Heat Loss (Btu/hr)	Total Heat Loss (Btu/hr)	Difference in Gain or Loss
Control				
1				
2				
3				
4				
5				
6				
7				
8				

QUESTIONS:

1. Which transmission area shows the lowest total heat loss? ______
2. Your transmission area contributed what per cent of the total heat loss of the house, in control run ______ %. With your optimal "construction": ______ %.
3. If natural gas costs $1.50 per million Btu's in Denver, how much would one pay per day with the original system? $ ______ The new system? $ ______ How much is saved? $ ______

4. What is the relationship between heat flow and R-value? ______________________

____

Between heat flow and construction materials? ______________________

____

5. What factors would influence your choice of construction materials for a new house? ______________________

____

____

6. How could you change your existing house to reflect these conclusions?

____

____

____

TEACHER'S GUIDE

OBJECTIVES: Students will:

1. Gain a practical knowledge of a house's thermal system.
2. Study the derived expressions for heat flow and infiltration.
3. Make a graph of heat loss as a function of R-value.
4. List ways to decrease heat loss.
5. Use the computer to gather data.

BACKGROUND: To analyze a home's heat loss, one must use several concepts such as conductive, convective and radiative heat flow. Only heat loss by conduction, the transfer of heat through solid materials, is considered in this activity.

If given a surface which separates two spaces having different air temperatures, heat will flow (be conducted) through the surface from the warmer to the colder space. Conductive heat transfer is described by EQ (1):

$$q_k = \frac{kA}{w} \Delta T \quad (1)$$

where q_k is the rate of heat transfer in $\frac{\text{Btu}}{\text{hr}}$ (Btuh),

k is the thermal conductivity of the surface material in

$$\frac{\text{Btu}\cdot\text{in.}}{\text{hr}\cdot\text{ft}^2\,{}^\circ\text{F}} \quad \text{or} \quad \frac{\text{Btu}\cdot\text{ft.}}{\text{hr}\cdot\text{ft}^2\,{}^\circ\text{F}}$$

A is the area of the surface in ft^2,

ΔT is the temperature difference across the surface in °F and

w is the surface thickness in feet or inches.

EQ (1) indicates that q_k is directly proportional to the thermal conductivity, the surface area and the temperature difference; it is inversely proportional to the material's thickness.

In general, the rate at which most physical processes occur is directly proportional to a "driving" potential and inversely proportional to a resistance.

In conductive heat transfer, the "driving" potential is the temperature difference; therefore, by EQ (1), the thermal resistance, R_s, of the surface must be

$$R_s = \frac{w}{kA} \quad (2)$$

and EQ (1) can be rewritten as

$$q_k = \frac{\Delta T}{R_s} \quad (3)$$

However, most tables listing thermal properties of construction materials and insulation do so in terms of one or more of the following:

a) the thermal conductivity, k, in $\frac{\text{Btu - in.}}{\text{hr ft}^{2}\,{}^{o}\text{F}}$;

b) the reciprocal of the thermal conductivity, $\frac{1}{k}$ in $\frac{\text{hr ft}^{2}\,{}^{o}\text{F}}{\text{Btu - in.}}$;

c) the "R-value" for one ft^2 of material of a given thickness, w, in $\frac{\text{hr ft}^{2}\,{}^{o}\text{F}}{\text{Btu}}$;

d) the thermal conductance, $C = \frac{1}{\text{R-value}}$, in $\frac{\text{Btu}}{\text{hr ft}^{2}\,{}^{o}\text{F}}$

Using the units for k and w, it can be shown that $\frac{w}{k}$ = R-value for one ft^2 and a given thickness of material:

$$\frac{\text{in}}{\frac{\text{Btu - in.}}{\text{hr}\cdot\text{ft}^{2}\cdot{}^{o}\text{F}}} = \frac{\text{hr ft}^{2}\,{}^{o}\text{F}}{\text{Btu}} = \text{R-value}$$

Substitution of R-value for $\frac{w}{k}$ into EQ (2) yields

$$R_s = \frac{\text{R-value}}{A},$$

and substitution of R_s into EQ (3) gives

$$q_k \text{ (for a surface)} = \frac{1}{\text{R-value}} \times \Delta T \times A \quad (4)$$

Since $C = \frac{1}{\text{R-value}}$,

$$\dot{q}_k \text{ (for a surface)} = C \times \Delta T \times A \quad (5)$$

(The reader should verify that the units do check.)

Depending on how thermal information is tabled, Equations (1), (4) and (5) will yield the same rate of heat flow (within rounding errors) through a surface composed of one material with a thickness, w, and area, A.

For a given heat barrier (wall, floor, ceiling, etc.) composed of two or more layers of building materials, it is necessary to define U, the overall coefficient of heat transmission (commonly called the U-value) for n-layers of materials:

$$U = \frac{1}{R_T} \qquad (6)$$

where $R_T = R_1 + R_2 + \ldots\ldots\ldots + R_n$ is the total thermal resistance for the multi-layered surface, and R_1, R_2 ....R_n are the resistances of layer_1, layer_2....layer_n.

The heat loss (or gain) through the multi-layered barrier is then expressed by

$$q_k = U \times \Delta T \times A \quad (7)$$

It can be seen from EQ (6) that the higher the U-value, the lower the thermal insulating value of the composite surface.

Appropriate units for U are $\frac{\text{Btu}}{\text{ft}^2\ \text{hr}^0\text{F}}$.

EXAMPLE 1: Using Equations (1), (4) and (5), determine q_k for a wall (30 ft x 8 ft) of 4-inch face brick with inside and outside temperatures of 65^0F and $+10^0$F, respectively, (k for face brick is $\frac{9 \text{ Btu - in.}}{\text{hr ft}^{2\,0}\text{F}}$)

Neglect air films and wind. Are your answers the same (within rounding error)?

SOLUTION:

a) By EQ (1): $q_k = \frac{k}{w} \times A \times \Delta T$

$$q_k = \frac{9 \text{ Btu - in.}}{\text{hr ft}^2 \text{ }^{o}\text{F}} \times \frac{1}{4 \text{ in.}} \times 240 \text{ ft}^2 \times 55^{o}\text{F} = \frac{29{,}700}{} \frac{\text{Btu}}{\text{hr}}$$

b) By EQ (2): $q_k = \frac{1}{\text{R-value}} \times A \times \Delta T$

$$\text{R-value} = \frac{1}{k} \times w = \frac{1}{9 \frac{\text{Btu - in.}}{\text{hr ft}^2 \text{ }^{o}\text{F}}} \times 4 \text{ in.} = \frac{.11 \text{ hr ft}^2 \text{ }^{o}\text{F}}{\text{Btu - in.}} \times 4 \text{ in.} =$$

$$.444 \frac{\text{hr ft}^2 \text{ }^{o}\text{F}}{\text{Btu}}$$

$$q_k = \frac{1}{.444} \frac{\text{Btu}}{\text{hr ft}^2 \text{ }^{o}\text{F}} \times 240 \text{ ft}^2 \times 55^{o}\text{F} = \frac{29{,}730}{} \frac{\text{Btu}}{\text{hr}}$$

c) By EQ (5): $q_k = C \times A \times \Delta T$

$$\text{Since } C = \frac{1}{\text{R-value}} = \frac{1}{.444} = 2.252 \frac{\text{Btu}}{\text{hr ft}^2 \text{ }^{o}\text{F}} \text{, then}$$

$$q_k = 2.252 \frac{\text{Btu}}{\text{hr ft}^2 \text{ }^{o}\text{F}} \times 240 \text{ ft}^2 \times 55^{o}\text{F} = \frac{29{,}700}{} \frac{\text{Btu}}{\text{hr}}$$

EXAMPLE 2: Determine U and q_k for a composite "wall" (10' x 10') made of 3/4 inch plywood backed by 2 inches of blanket/batt insulation. Inside and outside temperatures are 65^{o}F and -10^{o}F, respectively.

SOLUTION: From Tables:

k for plywood is $.802 \frac{\text{Btu - in.}}{\text{hr ft}^2 \text{ }^{o}\text{F}}$;

$\frac{1}{k}$ for blanket/batts is $3.5 \frac{\text{hr ft}^2 \text{ }^{o}\text{F}}{\text{Btu - in.}}$.

R-value for plywood of this thickness is

$$\text{R-value} = \frac{1}{k} \times w = \frac{1}{.802} \frac{\text{hr ft}^2 \text{ }^{o}\text{F}}{\text{Btu - in.}} \times .75 \text{ in.} = .935 \frac{\text{hr ft}^2 \text{ }^{o}\text{F}}{\text{Btu}}$$

R-value for blanket/batt insulation of given thickness is:

$$\text{R-value} = \frac{1}{k} \times w = 3.5 \frac{\text{hr ft}^2 \text{ oF}}{\text{Btu - in.}} \times 2 \text{ in.} = 7 \frac{\text{hr ft}^2 \text{ }^{o}\text{F}}{\text{Btu}}$$

By EQ (6) $\qquad U = \frac{1}{R_T}$

$$U = \frac{1}{7.935} = .126 \quad \frac{\text{Btu}}{\text{hr ft}^2\ {}^{o}\text{F}}$$

By EQ (7) $q_k = U \times A \times \Delta T$

$$q_k = .126 \frac{\text{Btu}}{\text{hr ft}^2\ {}^{o}\text{F}} \times 100 \text{ ft}^2 \times 75^{o}\text{F}$$

$$q_k = \frac{945.2}{} \ \frac{\text{Btu}}{\text{hr}}$$

Another expression used in the computer program relates to infiltration. Infiltration is expressed by EQ (8):

$$q_i = V \cdot a_H \cdot \rho \cdot C_a \cdot \Delta T \qquad (8)$$

where q_i = rate of heat loss due to infiltration

V = volume of air in the house, ft^3

a_H = air changes in the house per hour, usually between .5 and 1.5; (.7 used in the program)

ρ = the density of air (lb/ft^3)

C_a = the specific heat of air ($\text{Btu/lb}^{o}\text{F}$)

ΔT = difference in temperature between inside and outside, ^{o}F

Example:

For a house with 1000 sq. ft. and 8 ft. ceilings, determine the heat required to maintain an inside air temperature of 65^{o}F with an outside temperature of 15^{o}F; $\rho = .075 \text{ lbs/ft}^3$

$$q_i = V \cdot a_H \cdot C_a \cdot \rho \cdot \Delta T$$

$$= 8000 \text{ ft}^3 \cdot .7 \text{ changes/hr} \cdot .24 \text{ Btu/lb}^{o}\text{F} \cdot .075 \text{ lbs/ft}^3 \cdot 50^{o}\text{F}^{o}$$

$$= 5040 \text{ Btu/h or Btuh}$$

TIME REQUIRED: One to two hours, depending on availability of computers

MATERIALS:

- Activity sheet
- Computer
- Graph paper

SUGGESTIONS: Students working in groups of two or three is suggested, allowing more construction combinations to be used. Encourage wall constructions of cement block, cement form, brick and wood siding; for ceilings: glass fiber, rock wool, cellulose fiber; for floors: wood with and without insulation underneath, carpet, tiles; for windows: with storm windows, double-paned, triple-paned; for doors: with and without storm doors.

It is suggested that you group your students to share their data with others so that they may see the relative importance of their results in respect to the total house.

In the computer program there may be two sources of difficulty with your BASIC system. On line 710 two LET statements are combined on one line with a colon. If you can't use the colons, use 710 LET R = R(9), 715 LET R(1) = R(9) as substitutes. In a few lines the LET statement in an equation has been omitted. For lines 202, 280, 315, 689, and 695 you may add them if necessary.

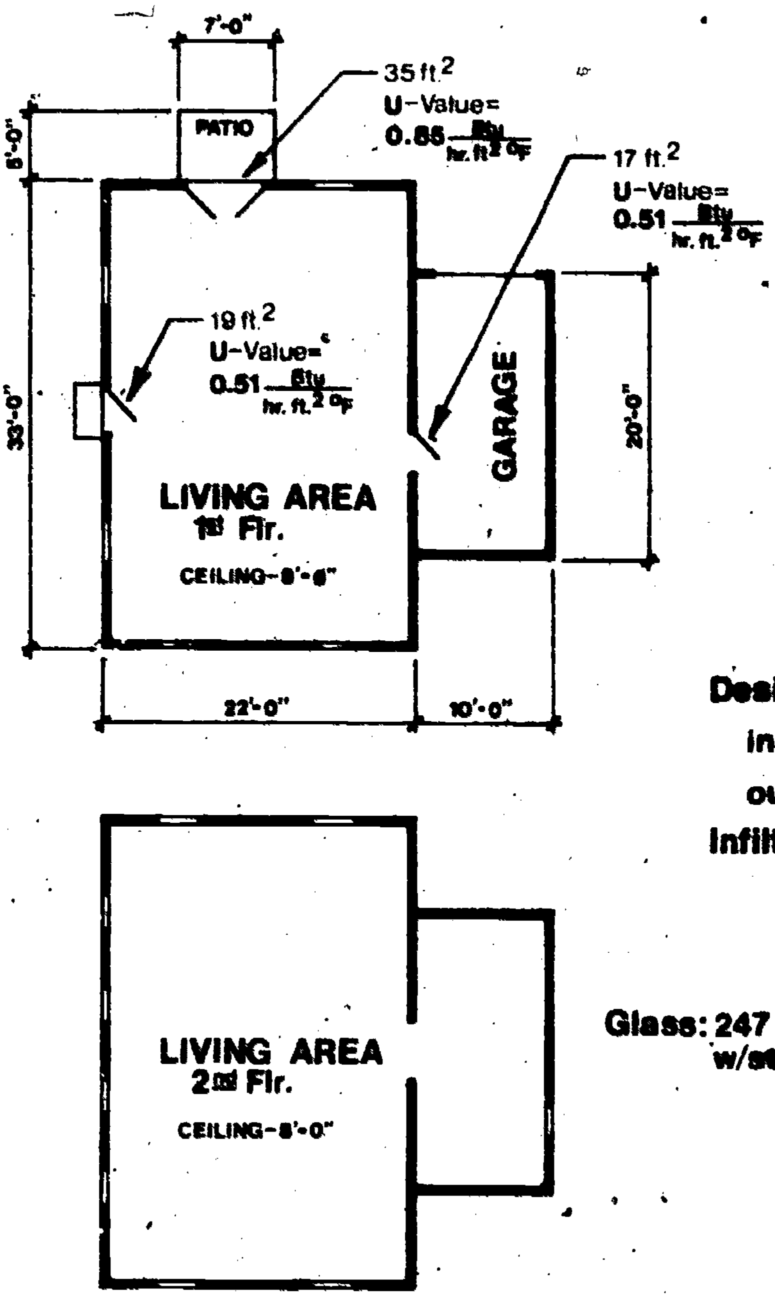
Also lines 750 to 830 may be a problem in some systems. The logic would require two additional statements for each IF THEN.

EXAMPLE:

```
750 IF I = 1 THEN A = W1 + W2 - W3 = W9 - D1 - D2 - D3
```

You should substitute:

```
750 IF I = 1 THEN 831
831 LET A = W1 + W2 - W3 - W9 - D1 - D2 - D3
832 GO TO 840
```



Design Temp:

inside -15°F

outside 65°F

Infiltration Rate: 0.7/hr.

Glass: 247 ft²
w/storm windows

FLOOR PLAN FOR STANDARD RUN HOUSE

Walls: brick veneer 4", wood sheathing 3/4"; stud wall with fiberglass insulation 3-1/2" and wallboard 1/2". R = 11.72

2nd floor ceiling wallboard and fiberglass ball insulation (6")

1st floor floor hardwood flooring 1/2" on plywood subflooring 3/4" (uninsulated)

Fig. 1

SAMPLE DATA

TRANSMISSION AREA 1st Floor	R-values
Layers of materials	
1. Hardwood flooring 1/2"	.48
2. Plywood subflooring 3/4"	.93
TOTAL R-values	1.41

TRANSMISSION AREA Ceiling	
Layers of materials	
1. Wallboard 1"	.45
2. Fiberglass batt 5"	16.67
TOTAL R-values	17.12

TRANSMISSION AREA Walls	
Layers of materials	
1. Brick veneer 4"	5.99
2. Wood sheathing 3/4"	.93
3. Studwall with fiberglass insulation 3 1/2"	11.83
4. Wallboard 1/2"	.23
TOTAL R-values	18.98

TRANSMISSION AREA Windows	
Layers of materials	
1. Windows with storm windows	2.00
TOTAL R-values	2.00

TRANSMISSION AREA Door	
Layers of materials	
1. Single doors	1.96
TOTAL R-values	1.96

TRANSMISSION AREA French Doors	
Layers of materials	
1. French doors	1.18
TOTAL R-values	1.18

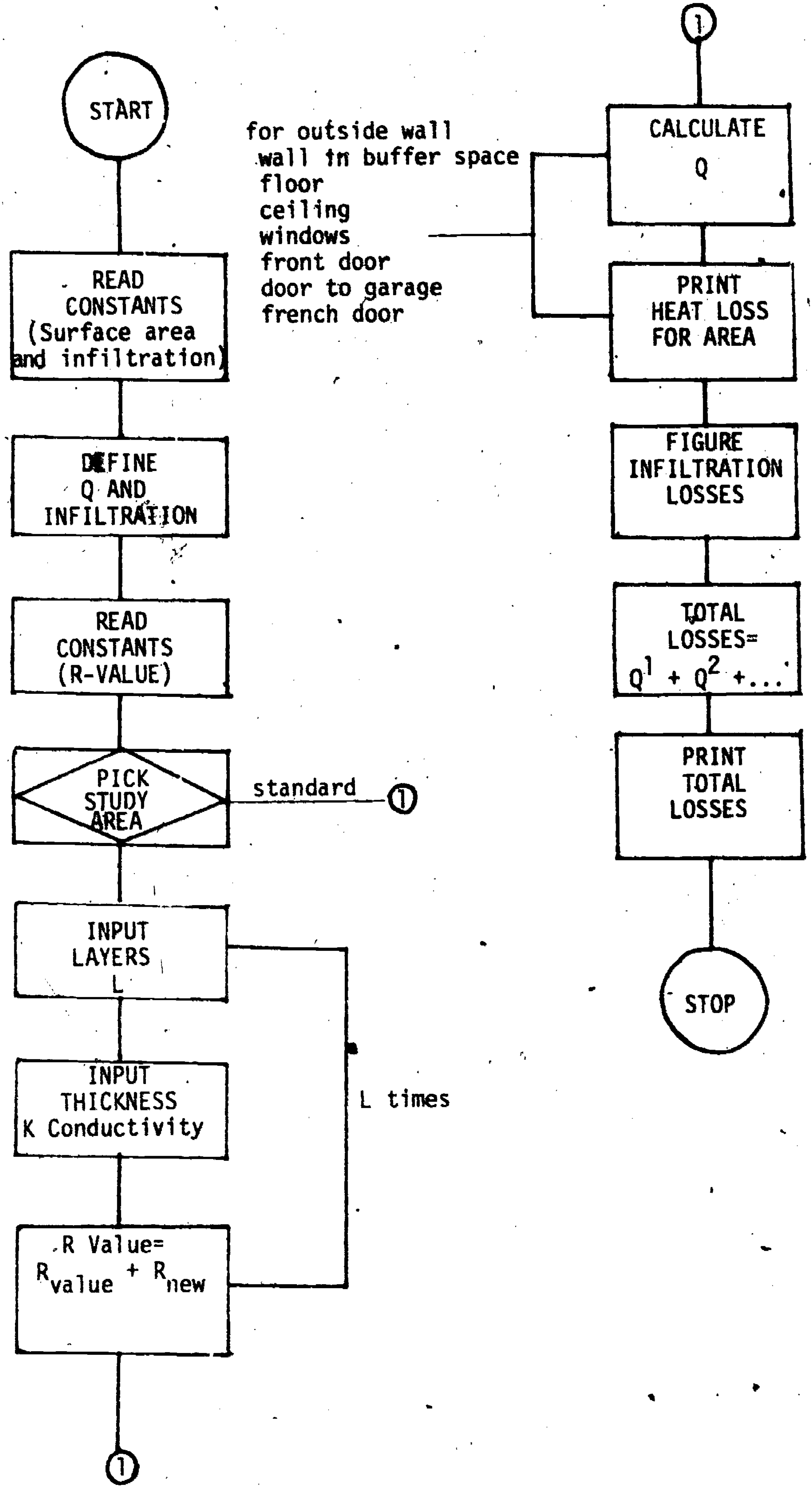


Fig. 2. Programming Flow Chart

PROGRAM

```
10 REM  THIS PROGRAM IS DESIGNED TO STUDY HEAT FLOW THROUGH
20 REM  DIFFERENT MATERIALS IN A HOUSE
30 REM  WRITTEN 8, 13, 78 BY DENNIS COLE REVISED 9.1.78
40 REM  THE FIRST READ INPUTS THE CONSTANTS FOR THE
50 REM  HOUSE'S  SURFACE AREAS. THE SECOND READ ADDS
60 REM  THE CONSTANTS FOR INFLITRATION, THE THIRD INPUTS
70 REM  R VALUES FOR THE SURFACE AREAS.
80 READW1, W2,W9,D1,D2,W3,D3,F1,C1
90 READV,C,T1,T2
92 PRINT "ENTER YOUR DESIGN TEMPERATURES FOR YOUR HOUSE"
93 PRINT"(INSIDE TEMPERATURE COMMA OUTSIDE TEMPERATURE)";
94 INPUTT1,T2
100 DATA935,1040,247,19,17,153,35,926,926,13579,17,65,-15
130 FORI=1TO8
135 READR(I)
140 NEXT.
150 DATA11.72,11.72,.74,17.12,2,1.96,1.96,1.18
160 PRINT"WHICH TRANSMISSION AREA DO YOU WANT TO STUDY":PRINT
165 PRINT"1,WALLS", "2.WALL OF BUFFER SPACE","3. FLOORS"
170 PRINT"4. CEILING", "5. WINDOWS","6. DOORS","7. CONTROL RUN"
180 INPUTX
190 IFX=7THENT360
200 PRINT"DO YOU KNOW THE TOTAL R VALUE OF YOUR MATERIALS"
201 PRINT" (YES OR NO)";
202 R=0
210 INPUTB$
220 IFB$="YES"THEN232
221 PRINT"DO YOU KNOW THE R VALUE OF EACH OF YOUR MATERIALS";
222 INPUTC$
223 IFC$="NO"THEN260
224 PRINT"HOW MANY LAYERS ARE THERE INCLUDING AIR SPACES";
225 INPUTZ
226 FORJ=ITOZ
227 PRINT"WHAT IS THE R VALUE OF MATERIAL NO. ";J;
228 INPUTRR
229 LETR=R+RR
230 NEXTJ
231 GOTO360
232 PRINT"WHAT IS THE R VALUE";
240 INPUTR
250 GOTO360
260 PRINT"HOW MANY LAYERS ARE THERE INCLUDING AIR SPACES";
270 INPUTZ
280 R=0
290 FORJ=ITOZ
300 PRINT"HOW THICK IS LAYER";J;"IN INCHES";
310 INPUTM
```

PROGRAM (continued)

```
315 M=M/12
320 PRINT"WHAT IS THE THERMAL CONDUCTIVITY CONSTANT K"
321 PRINT" (IN BTU.-FT./HR.SQ.FT.DEGREES F.)";
330 INPUTK
340 LETR=R+(M/K)
350 NEXTJ
360 LETR(9)=R
380 GOSUB700
400 LETQ(9)=V*C*.075*.24* (T1-T2)
405 DIMA$(20)
410 FORI-1TO9
420 READA$(I)
430 NEXTI
440 DATA"OUTSIDE WALL","WALL ON GARAGE AREA", "FLOOR","CEILING"
450 DATA"WINDOWS","FRONT DOOR","GARAGE DOOR","FRENCH DOORS"
460 DATA"INFLITRATION"
610 PRINT:PRINTTAB(25); "HEAT LOSSES":PRINT:PRINT
630 PRINT"TRANSMISSION AREA";TAB(25); "R-VALUE";TAB(40); "HEAT LOSS"
635 PRINTTAB(41);"BTU/HR."
640 FORI=1TO8
650 PRINTA$(I); TAB(27);R(I);TAB(42);Q(I)
660 NEXTI
670 PRINTA$(9);TAB(42);Q(9)
680 PRINT:PRINT"TOTAL LOSSES";TAB(42);
689 Q=0
690 FORI-1TO9
695 Q=Q+Q(I)
696 NEXTI
697 PRINTQ
699 END
700 FORI=1TO8
701 IFI-7THEN703
702 IFI<>8THEN705
703 LETR(I)=R(6)
704 GOTO750
705 IFX<>1THEN740
710 R-R(9):R(I)=R(9)
720 GOTO750
740 R-R(I)
750 IFI-1THENA-W1+W2-W3-W9-D1-D2-D3
760 IFI-2THENA=W3/2
770 IFI-3THENA-F1/2
780 IFI-4THENA=C1/2
790 IFI-5THENA=W9
800 IFI=6THENA=D1
805 IFI=7ANDX=6THENR=R(6)
806 IFI=8ANDX=6THENR=R(6)
810 IFI=7THENA=D2/2
830 IFI=8THENA=D3
840 LETQ(I)=A*(T-T2)/R
850 NEXTI
860 RETURN
OK
```

SAMPLE PRINTOUTS

1. CONTROL

```
RUN
ENTER YOUR DESIGN TEMPERATURES FOR YOUR HOUSE
(OUTSIDE TEMPERATURE COMMA INSIDE TEMPERATURE)? 65,-2
WHICH TRANSMISSION AREA DO YOU WANT TO STUDY

1. WALLS         2. WALL OF BUFFER SPACE        3. FLOORS
4. CEILING       5. WINDOWS   6.  DOORS         7. CONTROL RUN
?7
                           HEAT LOSSES

TRANSMISSION AREA              R-VALUE              HEAT LOSS
                                                    BTU/HR.

OUTSIDE WALL                    11.72               8597.95
WALL ON GAME AREA               11.72               437.329
FLOOR                           .74                 41920.3
CEILING                         17.12               1811.97
WINDOWS                         2                   8274.5
FRONT DOOR                      1.96                649.49
GARAGE DOOR                     1.96                290.561
FRENCH DOORS                    1.18                1987.29
INFLITRATION                                        11463.4

TOTAL LOSSES                                        75432.8

OK
```

2. WALLS

```
OK
RUN
ENTER YOUR DESIGN TEMPERATURES FOR YOUR HOUSE
(OUTSIDE TEMPERATURE COMMA INSIDE TEMPERATUR)? 65,-10
WHICH TRANSMISSION AREA DO YOU WANT TO STUDY

1. WALLS          2. WALL OF BUFFER SPACE          3. FLOORS
4. CEILING        5. WINDOWS      6. DOORS         7. CONTROL RUN
?1
DO YOU KNOW THE R VALUE OF YOUR MATERIALS (YES OR NO)
?NO
HOW MANY LAYERS ARE THERE INCLUDING AIR SPACES? 2
HOW THICK IS LAYER 1 IN INCHES? .75
WHAT IS THE THERMAL CONDUCTIVITY CONSTANT K
 (IN BUT.-FT./HR.SQ.FT.DEGREES F.)? .14
HOW THICK IS LAYER 2 IN INCHES? 2
WHAT IS THE THERMAL CONDUCTIVITY CONSTANT K
 (IN BUT.-FT/HR.SQ.FT.DEGREES F.)? .025
```

SAMPLE PRINTOUTS (continued)

2. WALLS(continued)

```
                                   HEAT LOSSES

TRANSMISSION AREA                   R-VALUE          HEAT LOSS
                                                     BTU/HR.

OUTSIDE WALL                        7.1131           15858.1
WALL ON GARAGE AREA                 11.72            489.548
FLOOR                               .74              46925.7
CEILING                             17.12            2028.33
WINDOWS                             2                9262.5
FRONT DOOR                          1.96             727.041
GARAGE DOOR                         1.96             325.255
FRENCH DOORS                        1.18             2224.58
INFLITRATION                                         12832.2

TOTAL LOSSES                                         90673.2
OK
```

3. CEILING

```
RUN
ENTER YOUR DESIGN TEMPERATURES FOR YOUR HOUSE
(OUTSIDE TEMPERATURE COMMA INSIDE TEMPERATURE)? 65,-10
WHICH TRANSMISSION AREA DO YOU WANT TO STUDY

1. WALLS          2. WALL OF BUFFER SPACE          3. FLOORS
4. CEILING        5. WINDOWS       6. DOORS         7. CONTROL RUN
?4
DO YOU KNOW THE R VALUE OF YOUR MATERIALS (YES OR NO)
?NO
HOW MANY LAYERS ARE THERE INCLUDING AIR SPACES? 2
HOW THICK IS LAYER 1 IN INCHES? .5
WHAT IS THE THERMAL CONDUCTIVITY CONSTANT K
 (IN BTU.-FT./HR.SQ.FT.DEGREES F.)? .0925
HOW THICK IS LAYER 2 IN INCHES? 12
WHAT IS THE THERMAL CONDUCTIVITY CONSTANT K
 (IN BTU.-FT./HR.SQ.FT.DEGREES F.)? .024
```

SAMPLE PRINTOUTS (continued)

3. CEILING (continued)

```
                              HEAT LOSSES

TRANSMISSION AREA             R-VALUE             HEAT LOSS
                                                  BTU/HR.

OUTSIDE WALL                  11.72               9624.57
WALL ON GARAGE AREA           11.72               489.548
FLOOR                         .74                 46925.7
CEILING                       42.1171             824.487
WINDOWS                       2                   9262.5
FRONT DOOR                    1.96                727.041
GARAGE DOOR                   1.96                325.255
FRENCH DOORS                  1.18                2224.58
INFLITRATION                                      12832.2

TOTAL LOSSES                                      83235.8

-OK
```

SUGGESTED FOLLOW-UP ACTIVITIES:

1. Have students do heat flow analyses for their houses. This may be done by "cranking it out" or by changing these components of the computer program. (All the changes would be made in Lines 80 through 150):

   W1 = wall area of 1st floor
   = perimeter · height of ceiling
   W2 = wall area of 2nd floor
   = perimeter · height of ceiling
   W3 = wall facing buffer space
   = length · height
   W9 = Area of windows
   D1, D2, D3 = area of doors (you must be particular about door placement)
   F1 = area of first floor
   C1 = area of ceiling or roof surface area
   For simplification, treat basements like attics. (Temp = $\frac{1}{2}\Delta T$.)

   R1 through 8 are the R-values of the areas.

2. The computer program was designed especially for use with all BASIC computers. A student could be assigned to change the program. Fig. 1 is the floor plan used to create the standard run.

3. Discuss the topic of insulation payback at current fuel cost. Using degree days, compute the heating bill with and without the new insulation. One might also consider a house-design activity.

4. Further studies of heat flow by convection and radiation, infiltration and insulation materials, might be pursued.

5. Other programming activities are thermostat operation and set-back efforts, passive and active solar design, monitoring home consumption,

computerized home environmental control, buildings and energy codes, efficiency, and heat content of fuels.

REFERENCES:

ASHRAE Fundamentals, Chapters 19, 21, 23, 24, 22, 25, 26

Solar Heating and Cooling, Chapters 1 and 2. Jan F. Kreider and Frank Kreith. McGraw-Hill, 1977.

Energy Conservation in the Home. U.S. Dept. of Energy. Oct., 1977.

"Simulation of Temperature Within a Building Space" by Wai-Bui Zee for NSF Workshop, 1978.

Lectures 16 and 17 by Dr. John Dow for NSF Workshop

#7. HOW MUCH HEAT DO WE LOSE THROUGH A TYPICAL DOORWAY?

PURPOSE: In this activity, you will examine various options for doorway design in a model house. You will determine the minimum amount of heat necessary to keep the model house at a desired temperature.

INTRODUCTION: All of our lives, we have heard the words "Close that door. Do you want us to freeze to death?" or some variation of that statement. But what you may not know is just how much heat is lost through an open door. In addition, there are simple ways to reduce that heat loss considerably.

There are several factors which will affect the amount of heat lost through a doorway. Obviously, the outside temperature is important, and the speed and direction of the wind must be considered. The design of the doorway, however, is probably the most critical aspect of heat loss through it. If the door is set back from the rest of the house, this may reduce heat loss. Another idea to consider is the addition of a vestibule, which makes it necessary to enter the house by opening and closing an outside door followed by opening and closing a second door into the house from the vestibule. In this activity, we will use a model house to compare different doorway designs.

MATERIALS: Two styrofoam model houses - one with a flush door, the other with a vestibule.

Heat source for model house (40-watt light bulb)

Thermostat

Thermometer

Clock (with second hand)

PROCEDURE: In this experiment, you will be comparing the amount of time that the light bulb "heater" is actually on in order to calculate the amount of energy necessary to heat your model house.

1. Control "house":
    a. Set-up your house with the door closed.
    b. Record the temperature.
    c. Set the thermostat at the setting determined by your instructor.
    d. Turn on the light. Record the starting time.
    e. For each minute, record whether the light was on or off for that minute. If the light was on for more than half of a minute, record "on", less than half a minute record "off".
    f. Record the temperature at 1 minute intervals throughout the experiment.
    g. Continue the experiment for ten minutes after the house has reached the thermostat temperature. Continue to record temperatures and on-times of the bulb.
2. House with door opening every 2 minutes for 5 seconds:
    a. Set up your house with the door closed.
    b. Record the temperature.
    c. Keep the thermostat at the same setting.
    d. Turn on the light and take readings as before.
    e. When the temperature has reached your thermostat setting, open the door and leave it open for exactly 5 seconds. Continue to do this at 2 minute intervals.
    f. Record the time and temperature readings as before as well as the bulb on-time.

3. House with door opening every minute for 5 seconds:
   a. Repeat the above steps, only this time open the door every minute for 5 seconds.
4. House with vestibule and door opening every 2 minutes for 5 seconds:
   a. Repeat the above except that when opening the doors, follow these instructions:
      - Open outside door for 5 seconds, then close.
      - Open inside door for 5 seconds, then close.
5. House with vestibule and door opening every minute for five seconds:
   a. Repeat step 4; only this time open the vestibule and door every minute.

	Control House		House w/Door opening every 2 minutes		House w/Door opening every 1 minute		House with Vestibule & Door opening every 2 min		House with Vestibule & Door opening every 1 min	
Time (min)	Temp (^{o}C)	Light On/Off	Temp (^{o}C)	Light On/Off	Time (^{o}C)	Light On/Off	Temp (^{o}C)	Light On/Off	Temp (^{o}C)	Light On/Off
0										
1										
2										
3										
4										
5										
6										
7										
8										

9

10

11

12

13

1[illegible]

15

16

17

18

19

20

21

22

CALCULATIONS:

A. Make graphs of the data you have collected for each of the models. The graphs should be temperature as a function of time. Indicate on each graph whether the light was on or off by showing a solid line for "on" and a dotted line for "off".

B. Calculate the amount of time that the light was on for each condition after the temperature had reached the thermostat setting. This can be done by simply checking your data and adding up the minutes that the light was on. Record your results below.

C. Calculate the amount of energy used during the ten minute period of each condition by following the sample below.

$$\text{NUMBER OF KILOWATT HOURS} = \text{WATT RATING OF LIGHT BULB} \times \frac{1\ \text{KILOWATT}}{1000\ \text{WATTS}} \times \text{NUMBER OF MINUTES THE LIGHT WAS ON} \times \frac{1\ \text{HOUR}}{60\ \text{MIN}}$$

Record your results below.

D. Calculate the percent increase in energy use due to the opening of the doors and/or vestibule. (Hint: See the sample calculation below.)

$$\% \text{ Increase} = \frac{\text{Amount of Energy Used (KWH)} - \text{Amount of Energy Used in Control House (KWH)}}{\text{Amount of Energy Used in Control House (KWH)}} \times 100$$

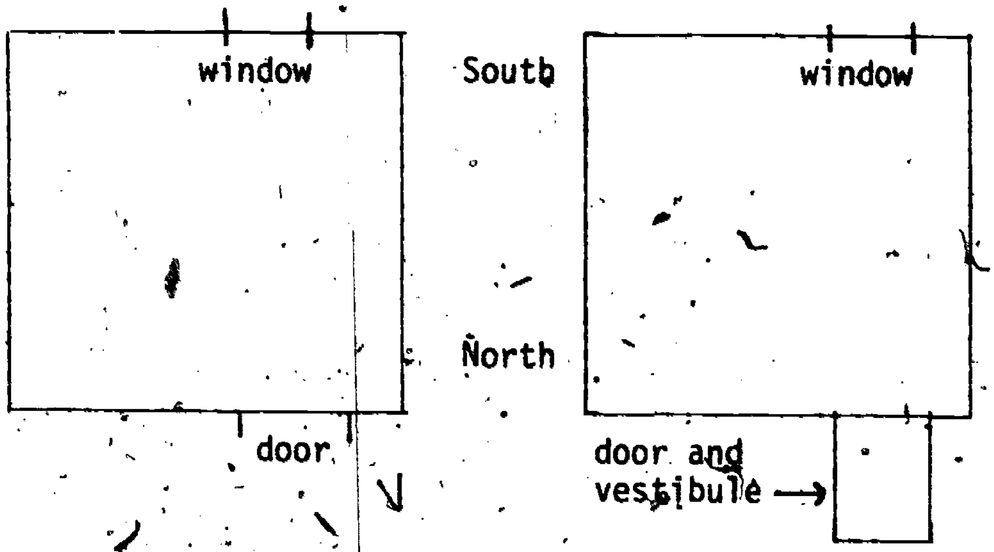
Summarize the results below.

Results

	Amount of Time Light Was On (min)	Number of KWH Used	% Increase in Energy Use
Control House			
House with Door Opening Every 2 Min			
House with Door Opening Every 1 Min			
House with Vestibule Opening Every 2 Min			
House with Vestibule Opening Every 1 Min			

QUESTIONS:

1. Which house used the most energy to maintain the designated temperature?
2. Which house used the least energy?
3. Consider houses which are set up as follows:



If the houses above were to be operated under the same conditions as the houses in which you opened the door every 2 minutes for 5 seconds, predict whether there would be <u>more</u>, <u>less</u>, or the <u>same</u> amount of energy used under the following conditions:

	Door Only	Door and Vestibule
a. Window slightly open (no wind).		
b. Window closed (north wind).		
c. Window closed (south wind).		
d. Window slightly open (east wind).		
e. Window closed (east wind).		

4. A vestibule is only <u>one</u> way of reducing heat losses through doors in both residential and commercial buildings. List several other methods which are used to reduce heat loss through doorways.

a. ______________________

b. ______________________

c. ______________________

d. ______________________

e. ______________________

TEACHER'S GUIDE

OBJECTIVES: Upon completion of this activity, the student will be able to:

1. Take accurate data of temperature and time in a model house heated by a light bulb.
2. Calculate the amount of energy in kilowatt-hours required to heat the model house.
3. Explain the effects of opening and closing doors on building heat loss.
4. Calculate the percent increase in energy consumption as a result of opening doors.
5. List several methods of reducing heat losses through doorways.

BACKGROUND: In the energy-conscious society in which we live, much has been written and said about conservation of energy. In this activity, students will focus on one single aspect of conserving energy; i.e., reducing heat loss through doorways. Comparisons will be made among a closed house, a house with a conventional doorway opened at regular intervals, and a house with a vestibule doorway opened at regular intervals. Students will be able to calculate the percent increase in energy use due to door openings.

TIME REQUIRED: Two 45 minute periods for data collection
One-two 45 minute periods for calculations and questions

MATERIALS (per group): For a class of 30 working in pairs, you will need 15 model houses, 6 with vestibules and 9 with conventional doors. These model houses can be constructed using small styrofoam coolers which have been fitted with a small window on top (Saran wrap or plastic will work) and appropriate doors. It is suggested that the door be designed so that a string will pull the door up, allowing it to easily fall back into place when the string is released. Be sure to have a way to close the door securely.

The styrofoam cooler would be placed upside-down on a piece of wood onto which has been mounted a light bulb, socket and thermostat. Putty may be used to make a tight seal between the wood and the styrofoam. In addition, there must be a small hole for a thermometer. The thermostat should be located near the thermometer.

Thermostats are available at a nominal cost from heating companies and hardware stores. Many people have installed new clock thermostats, which leaves many old conventional types available.

These model houses could also be used for other empirical applications such as determining effects of insulation and stratification of temperature in houses.

SUGGESTIONS:

1. Be sure to set up each house with identical conditions, including door size, type of thermostat, type of bulb, accurate thermometers and the same initial temperature.
2. If necessary, calibrate each thermostat to be standard with the control houses.
3. If you wish to reduce the amount of time spent in lab, split the data collection between the lab teams and pool data at the end of one period.

4. Make sure that the students understand that they are not really measuring the amount of heat, since a light bulb is not an efficient source of heat.
5. Make sure that the thermostat setting that you choose is high enough to cause a reasonable heat demand. If the activity is done in a classroom at 65^{0}F (18^{0}C), a suggested thermostat setting would be 95^{0}F (35^{0}C).

SUGGESTED FOLLOW-UP ACTIVITIES:

1. This activity could be lengthened by testing the effect of wind (electric fan) on different housing orientations.
2. A calculation of heat loss in a normal house is an exercise which can point out the other heat loss causes.
3. A similar activity with these model houses could illustrate the effectiveness of various types of insulation.

REFERENCES:

University Physics, Sears and Zemansky, Addison Wesley.

Physics for Students of Science and Engineering, R. Resnick and D. Halliday, John Wiley and Sons.

ASHRAE Fundamentals, 1977

Solar Heating and Cooling, J.F. Kreider and F. Kreith, McGraw-Hill Book Co.

#8. CALCULATING ELECTRICAL CONSUMPTION IN YOUR HOME

PURPOSE: The purposes of this activity are: 1) to do a home survey of electrical appliances; 2) to calculate the number of kilowatt hours of electricity consumed annually by these appliances and; 3) to calculate the approximate annual cost of operating these appliances.

INTRODUCTION: Most people are not aware of the number of electrical appliances found in their homes. We would probably tend to guess we have fewer appliances than we actually possess. Few of us have any concept of the quantities of electricity consumed by our appliances. Each appliance will consume a certain quantity of electricity during the course of a year and few of us co[illegible]der the collective effect or cost of operating our home appliances.

There are two methods by which one can attach a price tag to the usage of electricity in your home. One method is to read the electric meter each day. This will (by subtraction), tell you the number of kilowatt hours used per day. The problem with using this method is that it does not allow one to determine or analyze which appliances are consuming the greatest amounts of electrical energy.

The second method is to calculate the electricity consumed by each appliance and add the individual calculations to attain a total daily usage. This method entails a great number of calculations and a consideration of the time each appliance was operating.

Electric power is measured in watts. Power in watts is determined by multiplying electrical pressure in volts by current flow in amperes. If a one-watt appliance is run continuously for one hour, it will consume one watt-hour of electricity. A 100-watt light bulb will use 100 watt-hours of electricity every hour it is on. Your electric meter measures kilowatt-hours of electricity. One kilowatt-hour is equal to 1000 watt-hours, so ten 100-watt light bulbs turned on for one hour will consume one kilowatt-hour of electricity. Kilowatt-hours are units of energy.

The cost of electricity is calculated by multiplying the number of kilowatt-hours used by the rate per kilowatt-hour. Assuming the electric rate is 5 cents per kilowatt-hour, it would cost 0.6¢ to play records on a 120-watt solid-state stereo for each hour.

MATERIALS: "Estimated Annual Energy Consumption of Appliances" (Appendix D)
Home Data Sheets

PROCEDURE: (1) Survey your home for electrical appliances. Write the number of each appliance found in your home on the data sheet.

(2) Multiply the number of each appliance by the average number of kilowatt-hours used by each appliance annually.

(3) Multiply the number of kilowatt-hours used by your electric rate.

(4) Add the costs to find the total annual electric bill.

QUESTIONS:

1. Does your home have more or fewer electrical appliances than you might have guessed before conducting the survey? ____________

____

2. In your opinion, is your home above average, average, or below average in regard to the number of electrical appliances? _______

____

Data Sheet

Appliance	Number	Average Annual Consumption in KWH	Total KWH Used Annually	Annual Cost @ 5¢ KWH
Major:				
Air Conditioner (room)		860		
Air Conditioner (central)		1240		
Clothes dryer		993		
TOTALS				

Additional Appliances:	Number	Watts	Estimated Hours Used per Year	Total KWH Used Annually	Annual Cost @ 5¢ per KWH

3. If an electric hair-curling iron is rated at .75 amps, and is used an average of 15 minutes per day 6 days per week, calculate the annual cost using your local utility rate. ______________________

4. Of the electrical appliances found in your home, which five consume the greatest amounts of electricity annually? ______________

5. If a federal law were enacted that would allow each home to have only five electrical appliances, which five would you keep? Briefly explain why you would keep those five. ______________________

6. If your home were to be allotted a limit of 6000 Kwh per year with substantial penalties for exceeding the limit, which appliances would you keep? ______________________

7. What effects would the doubling of electric rates have in your home? Why? What effects would occur to people on fixed incomes?

8. Calculate the percentage of your family's annual income that is spent on electrical power. ______________________

9. Calculate the difference in annual cost of operating a tube-type radio (125 watts) and a solid-state radio (25 watts) if both are used six hours per day. ______________________

TEACHER'S GUIDE

OBJECTIVES: Students will be able to: (1) survey their own homes for electrical appliances, (2) calculate the energy (in kilowatt-hours) consumed by their electrical appliances individually and collectively, (3) calculate the cost of operating their electrical appliances, (4) develop an awareness of electricity consumption and costs.

BACKGROUND: Electrical consumption due to home appliances has increased dramatically in the past few years. National studies indicate that consumption is increasing at 7% annually. This represents a doubling of consumption every 10 years.

Most are not aware of the number of electrical appliances found in their homes, the amounts of energy consumed by these appliances, or the cost of operating these appliances individually or collectively.

Some basic equations used in this activity are:

Power, Watts = Electrical Pressure, Volts x Current Flow, Amps

One kilowatt = 1000 watts

Energy, kilowatt-hours = watts x time (in hours)/1000

Cost = Energy kilowatt-hours x electric rate, cents/kilowatt-hour

TIME REQUIRED. Two class periods (55 minutes each); homework time

MATERIALS: Data sheets.

SUGGESTIONS: 1) Electric rates vary according to region. Call your electric company and get the actual rate.

2) Preview the data sheet with students, show how to calculate annual consumption and cost and allow students

several days to complete their surveys.

3) Give students the opportunity to add appliances to the data sheets. They will have to calculate kilowatt-hours used annually by these appliances.

4) Note: "furnace fan" is listed on the data sheet.

5) You might anticipate the five appliances selected to keep will be: range, clothes washer, furnace fan, TV, and refrigerator. If six are selected, the clock will probably be sixth.

ANSWER TO QUESTION #3: (Based on 5¢/kwh)

watts = volts x amps

120 v x .75 a = 90 watts

kilowatts = 90 watts/1000 = .09 kw

time = 15 min/day x 6 days/week x 1 hr/60 min x 52 weeks/yr

= 78 hrs/year

kwh/year = 78 hrs/year x .09 kw = 7.02 kwh/year

cost = 7.02 kwh/year x .05 =$.351 per year

ANSWER TO QUESTION #9: (Based on 5¢/kwh)

Tube type:

125 watts x 6 hrs/day = 750 watt-hours/day

750 watt-hours/1000 = .75 kilowatt-hour/day

.75 kwh/day x 365 days = 273.75 kwh/yr =

273.75 x .05 = $13.69

Solid State:

25 watts x 6 hrs/day = 150 watt-hours/day

150 watt-hours/day/1000 = .15 kilowatt-hours/day

.15 kwh/day x 365 days = 54.75 kwh

54.75 x .05 = $2.74

Difference = $13.69 - $2.74 = $10.95

Note: The following may be of interest:

U.S. Households with Major Appliances, 1973 (percent)*

- Clothes washer - 78
  - Nonautomatic - 10
  - Automatic - 70
- Dishwasher - 25
- TV - 97
  - Black & white - 64
  - Color - 53
- Clothes Dryer - 53
  - Gas - 16
  - Electric - 38
- Refrigerator - 99
  - Manual defrost - 48
  - Frostless - 51
- Stove - 97
  - Gas - 52
  - Electric - 46
- Freezer - 34

*The American Energy Consumer, Dorothy K. Newman & Dawn Day, Ballinger Publishing Company, Cambridge, Massachusetts, 1975.

REFERENCES:

1. The American Energy Consumer, D. Newman and D. Day, Ballinger Publishing, 1975.
2. Tips for Energy Savers, Federal Energy Administration, August, 1977.
3. The Home Energy Guide, J. Rothchild and F. Tenney, Ballantine Books, 1978.
4. Energy Conservation in the Home, U.S. Department of Energy, October, 1977.

#9. THE EFFICACY OF LIGHT SOURCES

PURPOSE: To determine the efficacy of various light sources.

INTRODUCTION: The lighting efficiency of lamps and other light sources is termed EFFICACY and is determined by dividing the light output in lumens by the power used by the light source in watts. Therefore, efficacy units are lumens/watt. In this activity different lamps will be tested to determine their efficacies as well as each lamp's desirable and undesirable characteristics.

MATERIALS: (each group)

Graph paper

1 - photometer and associated equipment

1 - incandescent lamp fixture

1 - 15 watt fluorescent fixture

2 - cardboard boxes, insides painted black and large enough to cover the fixtures

3 - low wattage lamps, incandescent. Example: 15 watt, 60 watt, none greater than 100 watts

2 or more different - 15 watt fluorescent lamps

PROCEDURE:

1) Place a known standard light source at one end of a photometer. Place a box with one open side over the bulb. The interior should be black and the open side facing the photometer.

2) On the other side of the photometer set up the unknown light source in the same way.

3) Slide the photometer until the light is the same intensity on both sides of the meter stick. Measure the distances of light sources to photometer.

4) Using $E = \frac{I}{d^2}$, where

E is the light intensity falling on the photometer in lumens/meter^2.

I is the light output in lumens (I_{known} found from bulb cartons)

d is the distance from the photometer to the light source in meters.

If $E_{known} = E_{unknown}$

then $\frac{I_{known}}{d^2_{known}} = \frac{I_{unknown}}{d^2_{unknown}}$

$$\therefore \quad \frac{I_{known}}{d^2_{known}} \times d^2_{unknown} = I_{unknown}$$

Find $I_{unknown}$ in lumens and record on the data page.

5) Find the EFFICACY of light source

$$\text{EFFICACY} = \frac{I}{\text{power}}$$

where I is light output in lumens and the power input (found on bulb) is in watts.

6) Repeat steps 3 through 5 for two more incandescent lamps and record results on the data page.

7) Replace the unknown incandescent lamp fixture with the fluorescent fixture and put in a fluorescent lamp.

8) Repeat steps 3 through 5 and record on data page.

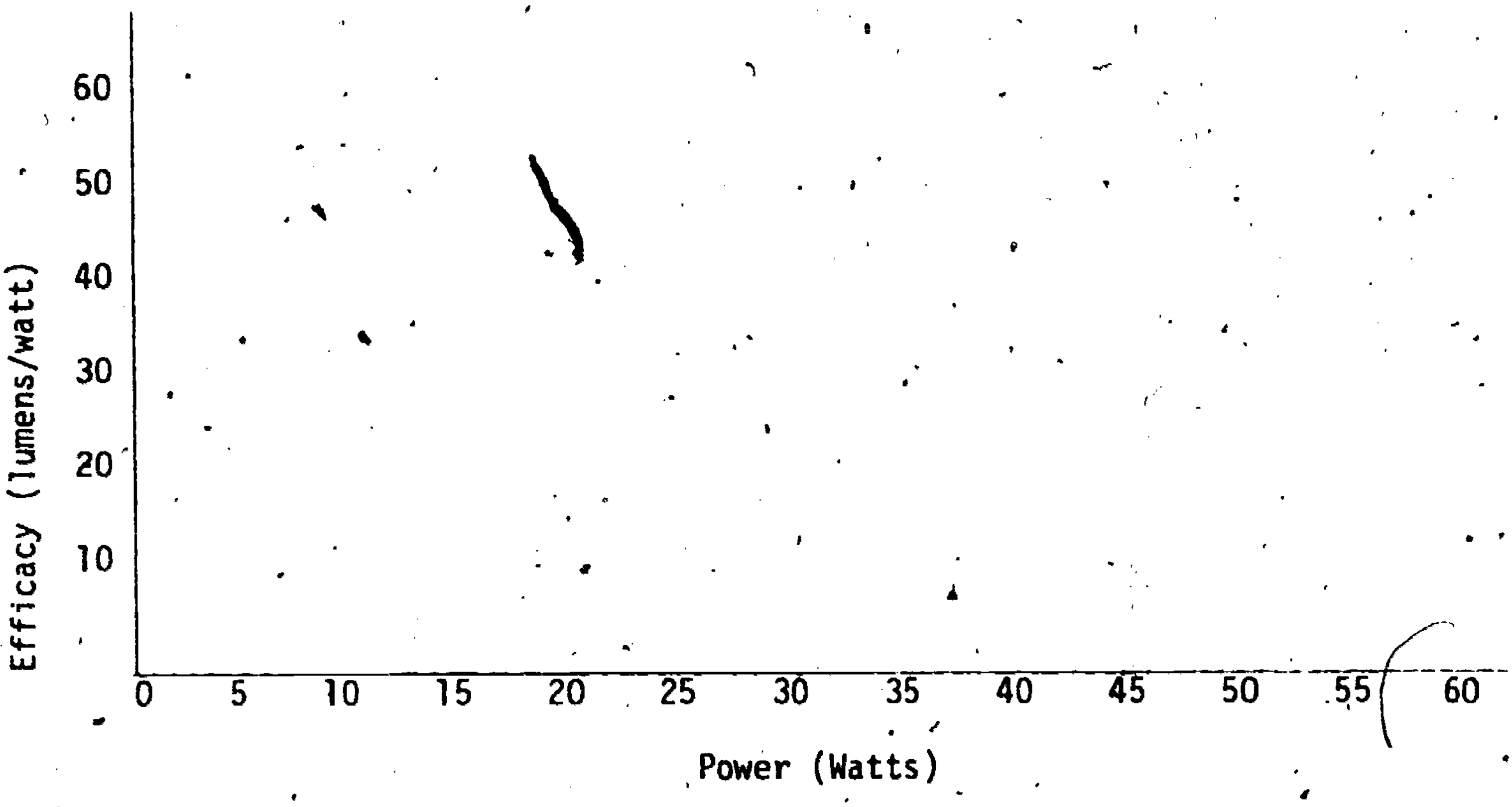
9) If your teacher has any other special bulbs to test, then repeat steps 3 through 5 and record on data page.

10) Make a dual histogram of power in watts as a function of efficacy in lumens/watt. Distinguish the two lamp types with different colors.

DATA

Lamp	Illumination (lumens)	Distance (meters)	Power (watts)	Efficacy (lumens/watt)
Known Incandescent				
1)				
2)				
3)				
4) Known Fluorescent				
5)				
6)				
7)				
8)				

HISTOGRAM



CONCLUSIONS:

1) What conclusions can be drawn from the histogram?

2) How does the fluorescent lamp compare with the incandescent lamp?

3) Give some of the advantages and disadvantages of:

   a) fluorescent lamps.

   b) incandescent lamps.

4) When installing light fixtures in the home, where would you locate the different types of lamps? Give your reasons.

TEACHER'S GUIDE

OBJECTIVE: Students will be able to apply a standard photometric method in the determination of efficacies for several light sources.

BACKGROUND: This is a consumer education activity that will increase the understanding of the positive and negative energy consumption aspects of typical lamps found in the home and school.

TIME REQUIRED: One 50 minute period is recommended for this activity; however, several follow-up activities listed below could be added to help the student enhance his understanding of efficacy.

MATERIALS: The basic materials are listed on the student activity pages. It is recommended that the teacher have 3 different incandescent lamps; e.g., 25-, 60-, 75- or 100-watts. More lamps of different wattages could be used if you desire. When purchasing fluorescent lamps, the suggested wattage to use is 15 watts.

There are several special lamps that can be found in schools, including projection lamps, for example. Check with your custodian or audio-visual staff.

SUGGESTIONS: This activity should work well as a follow-up to the standard photometer experiment found in most physical science or physics sources. Students seem to enjoy determining the efficacy of unknown light sources.

FOLLOW-UP ACTIVITIES:

1) Try asking the student to determine the efficacies of some special light sources such as high intensity, halogen, mercury and projection bulbs.
2) Determine the effect of reflectors with the use of lamps. (This may be done by placing aluminum foil inside the box.)
3) Have students check the wattage, lumens and efficacy of the lifetime (5 year) light bulbs. (They will generally be low.)
4) Over the open side of the box place a cover and insert a thermometer into the top of the cardboard box. Turn on the lamp and take temperature readings over a period of time (5 or 10 minutes); then grapn temperature as a function of time.

SAMPLE DATA*:

Incandescent (all frosted):

Power (watts)	Illumination (lumens)	Efficacy (lumens/watt)
15	125	8.3
25	235	9.4
40	455	11.4
60	870	11.4
75	1190	15.9
100	1750	17.5

Fluorescent lamps: *

Power (watts	Name	Illumination (lumens)	Efficacy (lumens/watt)
15	cool white	870	58
"	deluxe cool white	610	40
"	warm white	600	40
"	warm	870	58

* For GE bulbs only, others will show lower efficacy.

REFERENCES:
<u>IES Lighting Handbook</u>
Illuminating Engineering Society
Standard Lighting Guide
3rd Ed. 1962

<u>G.E. Lamp Catalog</u>, 1977 Ed.
Form 9200

#10. USING WIND POWER TO PRODUCE MECHANICAL WORK

PURPOSE: To demonstrate the conversion of wind energy into work and the effect of wind velocity and aeroturbine diameter on the conversion.

MATERIALS: Fan with variable speed; wind tunnel, anemometer or other wind-speed measuring device; ring stand and clamp for holding wind machine; 20- and 50-gram mass standards; classroom set of wind machine heads; cardboard, acetate, or metal for fins; string.

INTRODUCTION: Wind power, derived from solar radiation, is an obvious force acting in our physical world. Winds can range from light cooling breezes of 1-7 mph to destructive hurricanes with speeds above 50 mph. Harnessing wind power has been a challenge for centuries, but the name of the man who discovered that wind could be used to turn a wheel has long been forgotten.

Wind machines have been called windmills (used to grind grain), wind pumps (used to pump water) and wind generators (used to generate electricity). Any device used to capture wind power by the rotation of a wheel is called an aeroturbine. It can be made in a variety of shapes, but the most familiar type consists of a circular head with two or more fins attached.

The power of the wind can be determined from the kinetic energy of a moving mass of air:

$$KE = \frac{1}{2}MV^2$$

where M = mass of air in kg, V = velocity of air in meters/sec

By finding the mass of air passing through the aeroturbine per unit time, we can arrive at power (energy per unit time).

The mass of air passing through an aeroturbine during a given time period is a product of the density of air, the area of the aeroturbine facing the wind and the velocity of the wind:

$$M = \rho AV$$

where ρ = density of air in kg/m^3

A = the area of the aeroturbine in m^2

V = the velocity of the wind in m/sec

Substituting:

Power input (P_i) = KE/unit time = $\frac{1}{2}(\rho AV)\,V^2$

Therefore,

$$P_i = \frac{1}{2}\rho AV^3 \qquad (1)$$

From Eq(1) it can be seen that the power of the wind is directly proportional to the square of the diameter of the aeroturbine ($A = \pi \frac{d^2}{4}$) and to the cube of the wind velocity.

The power of the wind obviously cannot be completely coverted to usable power by a wind machine. A. Betz of Germany determined that the theoretical efficiency can be as high as 59.3%, but the actual efficiency of a well-built machine is about 40%.

In this experiment you will measure the power output of a model wind machine by having it lift a weight. The kinetic energy resulting from a vertical linear motion is the mass times the acceleration due to gravity times the distance the mass moved. Since power is kinetic energy per unit time:

Power output (P_o) = KE/unit time = $P_o = M_2gh/t$ (2)

where M_2 = mass in kg of the mass standard,

g = acceleration due to gravity, 9.8 m/sec^2,

h = height in meters, and

t = time in seconds.

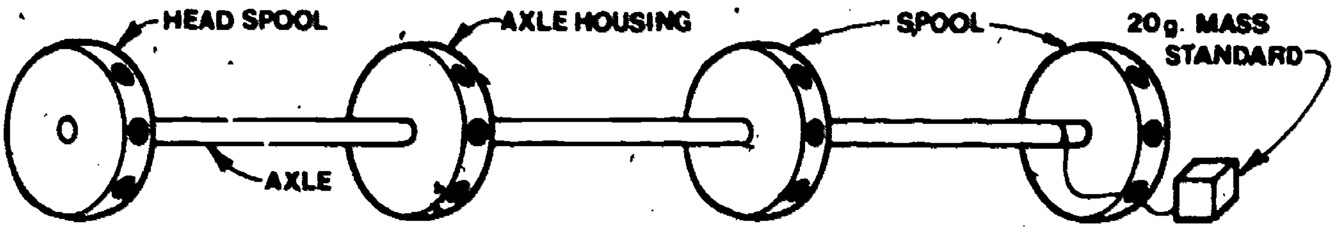
Since efficiency equals power output divided by power input, you will be able to calculate the efficiency from the Equations (1) and (2).

$$\%\ \text{efficiency} = \frac{Po}{Pi} \times 100 = \frac{M_2 gh/t}{\frac{1}{2}\rho AV^3} \times 100$$

PROCEDURE:

1. Your wind machine head consists of the following parts:

Figure 1. Wind Machine Head



Place four spokes with fins attached evenly around the head spool.

2. Test the position best suited to produce constant rotary motion by rotating the "spokes" and fins to different positions. Try placing the fins parallel, perpendicular, and at various angles to the plane of the head spool and check which position produces the fastest spin when placed in front of the fan. Attach the axle housing to a clamp on a ring stand before using the fan to test spin.
3. Attach 30 cm of string to the axle as shown in Fig. 1 after you have found the best fin angle. Attach a 20 g mass standard, shortening the string so that it will rest on the table top or floor when the wind machine head is attached to the ring stand clamp.
4. Check the wind speed using the wind meter.
5. Place the wind machine in position and measure the time it takes for the mass standard to be lifted to the axle.

6. Repeat Step 5.
7. Replace the 20 g mass standard with a 50 g mass standard and repeat Steps 5 and 6.
8. Make two trials with one of the mass standards using a different wind speed.
9. Make two trials with one of the mass standards using larger fins.
10. Record all data in the table below.

DATA TABLE 1

Barometric pressure (mm Hg) ____________________

Temperature (°C) ____________________

Trial No.	V (mph)	V(m/sec)	Mass (g)	Mass (kg)	h (m)	t (sec)

CALCULATIONS: Density varies with the temperature and pressure according to the Ideal Gas Law:

$$v_2 = v_1 \frac{T_2 P_1}{T_1 P_2}$$

where: v_1, T_1 and P_1 are the volume, absolute temperature and pressure (respectivel

STP (Standard conditions of Temperature and air Pressure) and v_2, T_2 and P_2 reflect your local conditions.

Since the density has an inverse relationship with the volume:

$$\rho_2 = \rho_1 \frac{T_1 P_2}{T_2 P_1} \qquad (3)$$

where ρ_1 is STP density and ρ_2 is classroom air density.

(Density of air at 0°C and 760 mm pressure is 1.30 kg/m^3.)

Convert to the density at your location and room temperature.

(Reminder: Temperatures must be expressed in Kelvin degrees to use the Gas Law.)

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}} \times 100 \qquad (4)$$

Conversition units needed:

1 mi = 1.61×10^3 meters

1 hr = 3.6×10^3 sec

1 g = .001 kg

g (acceleration due to gravity) = 9.8 meters/sec^2 on the surface of the earth

CALCULATIONS

Trial No.	V^3	Diameter (m)	Area (m^2)	Power input ($P_i = \frac{1}{2}\rho A V^3$)	Power output $P_o = M_2 gh/t$	Efficiency ($\frac{\text{output}}{\text{input}} \times 100$)

CONCLUSION: Include in your written conclusion: 1) the efficiency values you obtained in terms of the theoretical value, 2) the relationship between the power output and the velocity of the wind, and 3) the relationship between the power output and the area of the aeroturbine.

QUESTIONS:

1. How could friction in a wind machine be reduced?
2. What is the single most important factor which reduces the theoretical efficiency to 59.3%?
3. Why is the actual efficiency less than the theoretical efficiency?
4. What major factor would reduce the amount of power obtained from a full-sized wind machine?
5. List areas of major cost in erecting a wind machine?

EXTENDED ACTIVITIES:

1. Build a model wind machine designed to operate more efficiently.
2. Write a report on wind generators.
3. Write a report on the structure of fins.
4. Write a report on placement of wind machines in terms of local and regional topography.
5. Wind machines opera[illegible] when the winds range from 10 to 20 mph. Study your locality to check whether a wind machine would be practical.
6. Write a report about how the winds are driven by the sun.

TEACHER'S GUIDE

OBJECTIVE: The student will demonstrate the power of the wind, determine the amount of useable power that can be extracted from the wind, and determine the effect of wind velocity and aeroturbine area on power output.

BACKGROUND: The wealth of information about wind power is almost overwhelming. There are records of quantitative studies done as early as 1759. Understanding how wind is produced makes a fascinating study. Tropical air rising to the upper level of the troposhere causes cold polar air to move in to replace the rising warmer air. Coriolis forces, resulting from the rotation of the earth, also play a large part. Localized winds, of course, depend on the topography of an area.

Historically, wind power included using sails which were attached to boats and bicycles. The first windmill was used to grind grain, and those wind machines used to pump water, their most common usage in the U.S. , are actually wind pumps. Wind machines used for generating electricity are called wind generators or wind chargers.

Students may be particularly interested in wind power to generate electricity. Supposedly, home wind generators are capable of generating electricity into a power grid when both systems are hooked together. Home Energy - How To has a very practical description of the advantages and disadvantages of home wind generators, as well as approximate costs of some recent attempts to harness wind for the generation of electricity.

Wind energy as an alternative source of power has several major drawbacks: 1) Wind does not blow steadily. 2) Storage of energy produced from wind has many more problems than storage of energy from the sun. 3) The super-structure required to support a wind generator adds appreciably to the cost. 4) Wind energy at a particular location is hard to quantify. Although many studies have been done on the types of rotors and, in the case of propeller machines, the types of blades which work best, most of these studies are essentially qualitative in nature. A most useful quantitative study is described below.

A. Betz in Germany calculated the theoretical efficiency of wind machines by applying the momentum theory used for ship's propellers. Three velocities exist when wind passes through a wind machine:

V_1 = wind speed before the rotor

V = wind speed through the rotor

V_2 = wind speed beyond the rotor

If M is the mass of air passing through the rotor per unit time, the rate of change of momentum is $M(V_1 - V_2)$ and this is the resulting thrust. Power can be found by multiplying the thrust by V: $M(V_1 - V_2)V$ = Power.

The rate of change of kinetic energy is $1/2\ M(V_1^2 - V_2^2)$ (1) which, when simplified, indicates that the wind speed through the rotor equals the average V_1 and V_2, or

$$V = \frac{V_1 + V_2}{2}$$

The mass of air passing through the rotor per unit time is equal to the air density times the area of the rotor times the wind velocity:

$$M = \rho AV$$

The power, P, is $P = \rho AV(V_1 - V_2) V$

Substituting $V = (V_1 + V_2)/2$,

$$P = \rho A\left[\frac{V_1 + V_2}{2}\right]^2 (V_1 - V_2)$$

Substituting $\rho = V_2/V_1$, power becomes.

$$P = \frac{\rho AV_1^3}{4}(1 + \alpha)(1 - \alpha^2)$$

Multiplying to simplify,

$$P = \frac{\rho AV_1^3}{4}(1 + \alpha - \alpha^2 - \alpha^3)$$

differentiating,

$$\frac{dP}{\alpha d} = \frac{\rho AV_1^3}{4}(1 - 2\alpha - 3\alpha^2)$$

The maximum power occurs when the slope $\frac{dP}{d\alpha} = 0$.
Solving for α, the power is maximum when $\alpha = 1/3$.
Thus, the power is maximum when the final velocity, V_2, is one-third of the upwind velocity, V_1.

Maximum power is obtained when

$P = AV_1^3 \times 8/27$ as compared with $P = \frac{\rho AV_1^3}{2}$ in the wind,

originally, or 16/27 (59.3%) becomes the maximum obtainable power. (Refer to E.W. Golding, The Generation of Electricity by Wind Power.) A similar coefficient has been developed for propeller wind machines, using aerodynamic principles of lift and drag. In that case, the coefficient is slightly higher, about 68.7%.

Both derivations ignore such factors as friction and other losses, resulting in the actual maximum efficiency of 40%.

If students are familiar with rotational calculations, it is possible to approach the problem in terms of torque. Since the wind is acting perpendicular to the face of the wind machine, only that force which is acting parallel to the face of the wind machine on the tipped blades will produce a torque. This torque will, in turn, set up an angular velocity which has kinetic energy or power in terms of energy per unit time. This must be translated into linear energy to lift the mass attached to the shaft.

Listed below are some references. Practical-minded students would also enjoy articles from Popular Science or Mother Earth News which tend to feature unusual uses of alternative energy.

MATERIALS: One set of Tinker Toys, Set 136 (about $4.95) can supply eight sets of wind machine heads, if you use only one axle housing; four, if you use two. If your class is small, a more stable wind machine head can be prepared by using two axle housings attached to two clamps and two ring stands. These axle housings are called 'W' in the set. The orange rods form the spokes, and the order for the rest consists of spool, blue rod, axle housing, spool, second axle housing (if used), yellow rod, string, final spool or a wheel. Each of the 'W' pieces (axle housings) must be secured by the orange washers supplied or lock washers. You may also have to cut extra pieces the same size as the orange rods for spokes. A hand-held wind meter is available for under ten dollars. If you have an anemometer available, it would be more accurate.

A propeller-type, portable fan with variable speed control which is larger than 12 inches in diameter should supply speeds from 10-12 mph. A rheostat (try borrowing one from the drama dept.) would make it possible to use more precise velocities; e.g., 6 mph or 12 mph, 5 mph and 10 mph, which would make the increase in power as a cubic function of the velocity easier to observe. A streamlining grid consisting of inch-wide boards placed in a network of squares (about 2 inches square) will reduce turbulence. A wind tunnel, perhaps made from a large cardboard box, might increase wind speed and reduce turbulence.

TIME REQUIRED: One period for actual operation, with 6 to 8 groups. More time may be needed if you choose to give an introduction to wind energy and its technical potential or if you feel that calculations need to be done with your class.

SUGGESTIONS:

Answers to questions:

1. Use an oiled metal axle holder.
2. The fins--not all the wind power can be captured.
3. Theoretical does not take into account friction losses, etc.
4. Wind is not steady.
5. Support structure.

Students will do well to get 5% efficiency.

Cardboard fins may be made out of heavy cardboard (such as a puzzle box).

ADDITIONAL ACTIVITIES:

1. Determine the maximum lifting mass for the wind machine.
2. Measure the effect of increasing or decreasing the number of fins.
3. Change the shape of the fins. Measure the effect.

4. An advanced class might wish to build a school wind generator.

REFERENCES:

The Mother Earth News Handbook of Homemade Power, Bantam Books, Inc., New York, New York, 1974. Many clever ideas.

Hand, A.J., Home Energy How-To, Book Division, Times Mirror Magazines, Inc., Harper and Row, New York, 1977. Very practical. Also realistic on costs.

Golding, E.W., The Generation of Electricity by Wind Power, Halsted Press Book, John Wiley and Sons, Inc., New York, 1955. A very technical book.

Crowther, Richard L., Sun Earth, A.B. Hirschfield Press, Inc., Denver, Colorado, 1976. Good general information.

Hamilton, Roger and Emory Kristof, "Can We Harness the Wind?", National Geographic, Vol. 148, No. 6, December 1975, pp. 812-829. Good pictures.

Hackleman, Michael A., Wind and Windspinners, Peace Press, Culver City, California, 1974. Interesting.

ANALYTICAL DETERMINATION OF THE SOLAR ANGLE OF INCIDENCE ON A FLAT PLATE COLLECTOR

INTRODUCTION: Consider the rays of the sun as sources of heat and energy. Many calculations for solar energy are applications of basic trigonometry.

PROCEDURES, CALCULATIONS AND RESULTS:

A. Consider a flat plate solar collector as an example (Fig. 1):

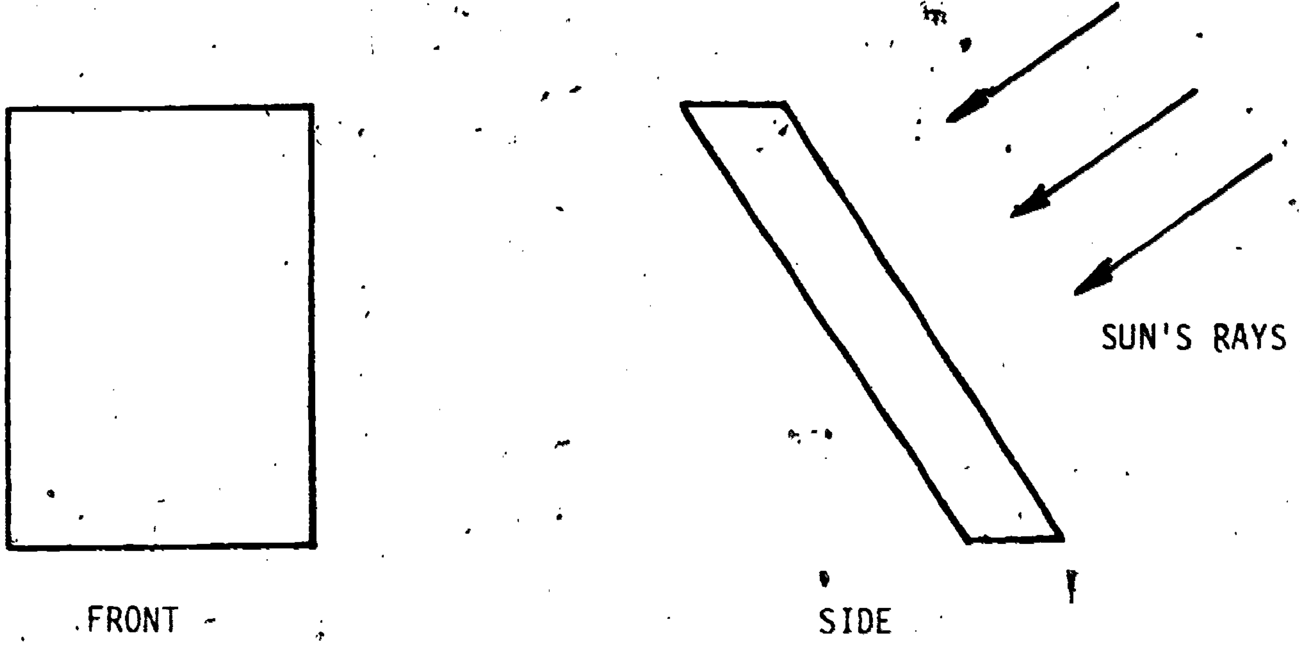


Figure 1. Flat Plate Solar Collector

Note that the sun's rays are considered to be parallel. The placement of the flat plate of the collector relative to the direction of the sun becomes critical. The direct normal component of solar insolation, I_b, is given by the formula

$$I_b = I_{maximum} \cdot \cos \sphericalangle i \qquad (1)$$

where $\measuredangle i$ is the angle of incidence as shown in Fig. 2 and $I_{maximum}$ is the amount of solar insolation on a flat surface.

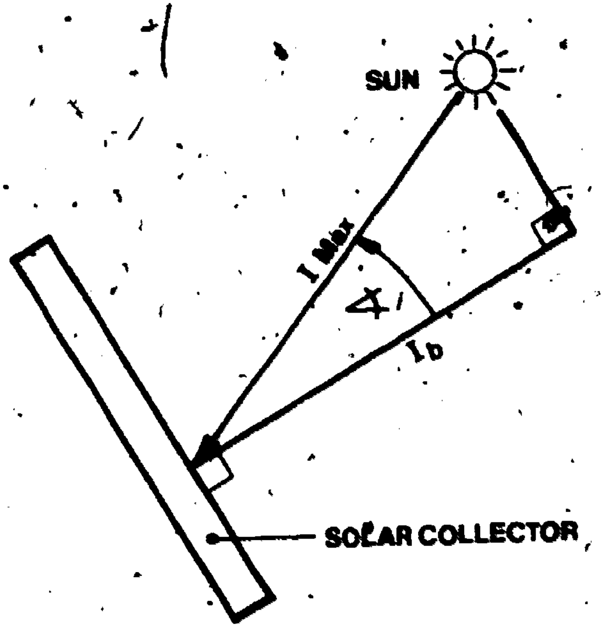


Figure 2. Side View of Collector

Does it seem logical that the maximum insolation will be received when the sun's rays are perpendicular to the collector face? Verify this from the formula $I_b = I_{max} \cos \measuredangle i$ when $\measuredangle i = 0^0$. (Hint: Recall the graph of the cosine shown in Fig. 3.)

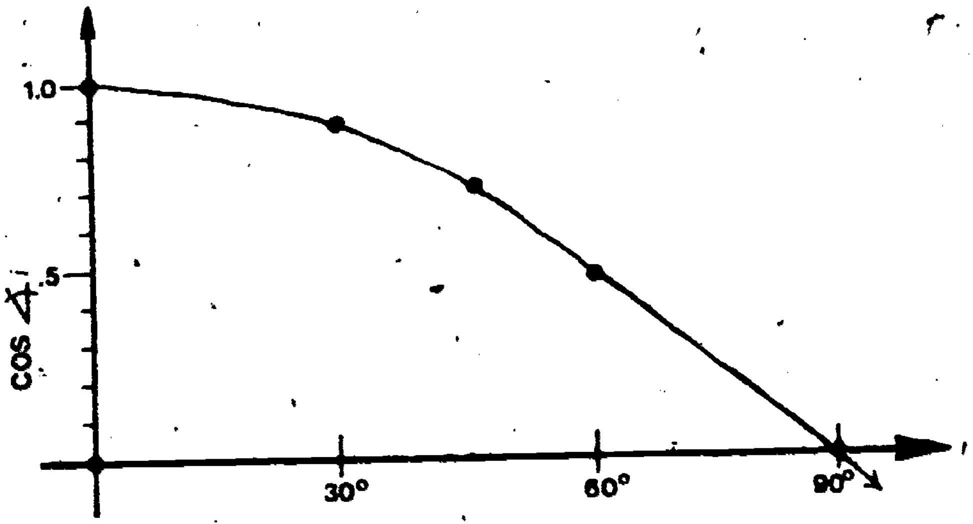


Figure 3. Cosine Curve

(Note that the graph of the cosine is at a maximum when $\angle i = 0$.)

Once the collector plate is in place, the sun will move relative to the collector. Note the apparent motion of the sun.

Exercise: What percentage of the maximum insolation will the solar collector have available as the angle of incidence varies? (Hint: Use equation (1), trig tables or the trig functions on a calculator to work the following excercise.

EXCERCISE:

Angle of Incidence, $\angle i$	% of Maximum Solar Insolation
a) $i = 10^0$	
b) $i = 20^0$	
c) $i = 30^0$	
d) $i = 45^0$	
e) $i = 60^0$	
f) $i = 90^0$	

After 60^0 you might as well zip yourself into a down sleeping bag and forget about solar energy.

B. Determining the Angle of Incidence. Now that you can see the effect of the angle of incidence of the sun's rays on the collector plate, of what is that angle i a function? How does one determine $\angle i$ for a south-facing collector?

Part 1. DETERMINE δ

First, let's consider

δ = the solar declination angle.

This angle varies with the day of the year as the earth rotates around the sun and changes because the earth's axis is "tilted" 23.5° from the vertical. See Figure 4.

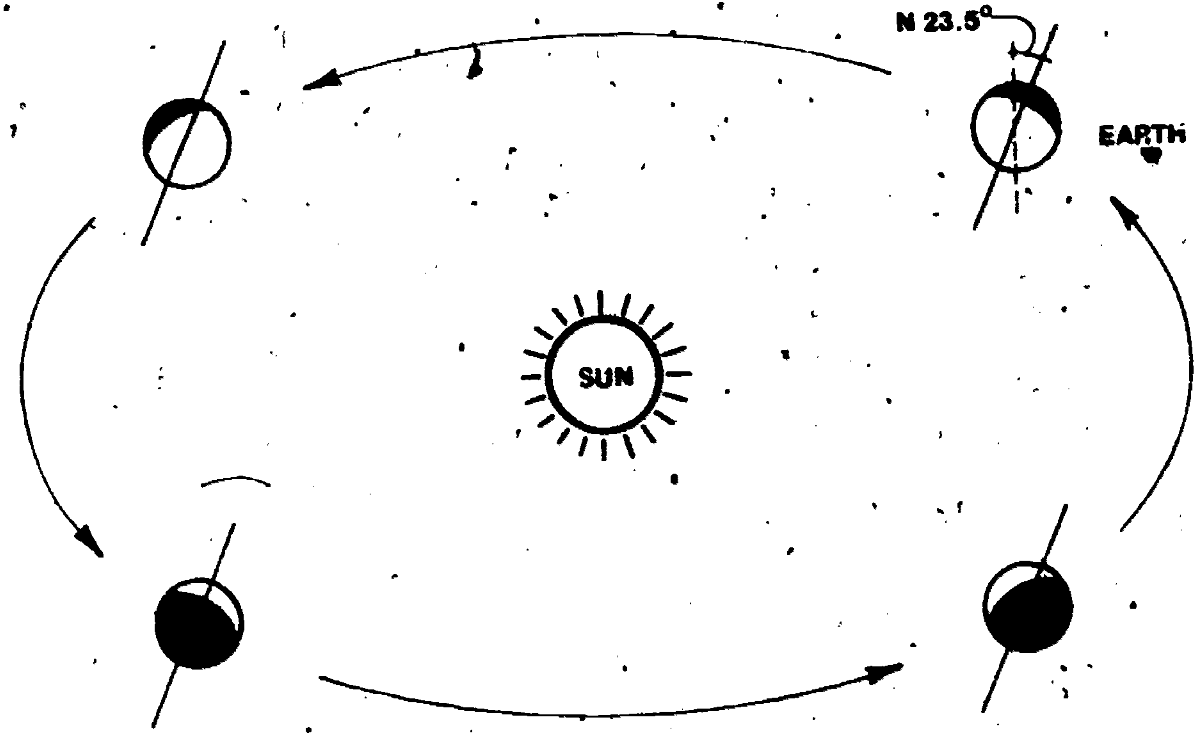


Figure 4. Earth's Revolution Around the Sun

To find the solar declination $\measuredangle\delta$ for any day of the year,

Let Jan 1 = day 1

Jan 2 = day 2

Jan 30 = day 30

Feb 1 = day 32

⋮

Dec 31 = day 365

Then $\measuredangle\delta = 23.5 \sin\left[360\left(\frac{284+\text{day}}{365}\right)\right]$ (2)

Examples:

a) Jan 1, $\sphericalangle\delta = 23.5 \sin\left[360\left(\frac{284+1}{365}\right)\right]$

$= 23.5 \sin 281.10 = -23.06$

b) Mar 21, $\sphericalangle\delta = 23.5 \sin\left[360\left(\frac{284+81}{365}\right)\right]$

$= 23.5 \sin\left[360\ \frac{365}{365}\right]$

$= 23.5 \sin 360^{o}$

$= 23.5\ (0$

$= 0$.

Note that March 21 is the vernal equinox when the day and night are of equal length. How convenient that on that day, sin = 0 and that the angle of declination, δ = 0. (Of course, this is not a coincidence.)

Exercises:

Find $\sphericalangle\delta$ for the following dates using Eq. 2.

a) May 21
(day 141) $\sphericalangle\delta$ ______________

b) September 21
(day 261)

(Hint: September 21 is the autumnal equinox) $\sphericalangle\delta$ ______________

c) Dec. 31
(day 365) $\sphericalangle\delta$ ______________

Part 2. DETERMINE L

Now that you have found δ, the angle of solar declination, consider the latitude L of the site of the flat plate collector. This is easy enough to find on a map, a globe, or an atlas. (Let $L = 40^\circ$N unless otherwise specified). See Fig. 5.

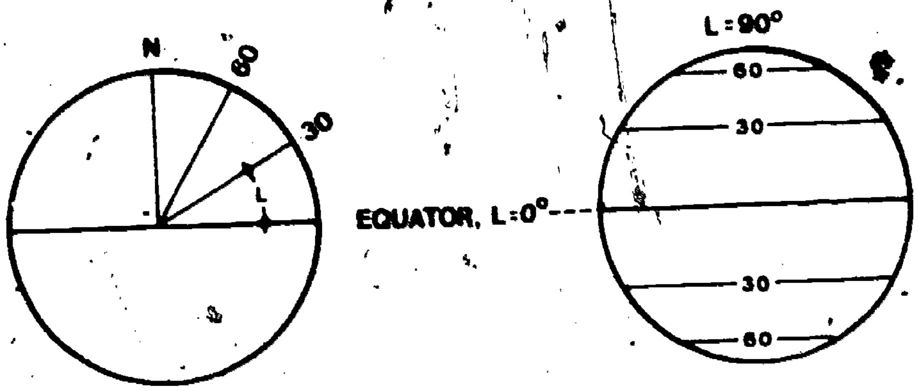


Figure 5. Latitude

3. Determine H

Next, consider H, the hour angle, for you know that the sun's angle varies throughout the day. The hour angle, $\angle H = 15^\circ$ x the number of hours away from solar noon.

A quick <u>approximation</u> may be made by using local <u>standard</u> time.

$$\angle H = (12{:}00 - \text{Standard Time}) \cdot 15^\circ/\text{hr} \qquad (3)$$

<u>Examples:</u>

at 11 a.m. (1 hour before noon), $\angle H = +15^\circ$

at 9 a.m. (3 hours before noon), $\angle H = +45^\circ$

at 7:30 a.m. (4.5 hours before noon), $\angle H = +67.5^\circ$

at 2 p.m. (2 hours after noon), $\angle H = 30^\circ$

Part 4. DETERMINE α

Now we have the information we need to find α, the angle between the sun and the horizon. The solar altitude, α, as seen by an observer on the earth is depicted in Fig. 6.

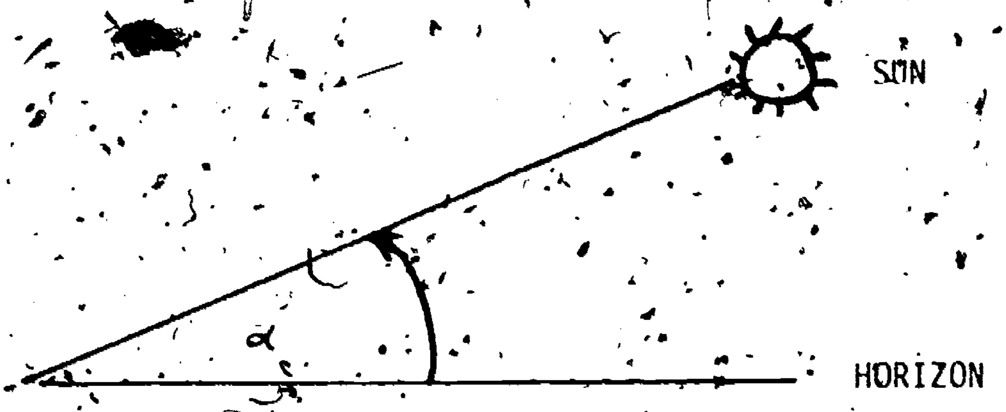


Figure 6. Solar Altitude, α

α is determined by Eq. 4:

$$\sin\alpha = (\sin L \sin\delta) + (\cos L \cos\delta \cdot \cos H) \qquad (4)$$

where you will recall.

L = latitude

δ = angle of declination

H = hour angle

Example; Find α at $L = 45^0$ north, at 10 a.m. standard time on March 21, where $\delta = 0^0$.

$H = (12{:}00 - 10{:}00) \times 15^0 = 30^0$ (from Eq. 3)

Then from Eq. 4:

$$\sin\alpha = (\sin 45^0 \sin 0^0) + (\cos 45^0 \cdot \cos 0^0 \cdot \cos 30^0)$$

$$\sin\alpha = (.707 \cdot 0) + (.707 \cdot 1 \cdot .866)$$

$$\sin\alpha = .612$$

$$\alpha = 37.76^0$$

Exercise: Use some of the data you have found from previous exercises. Find α for $L = 40^0$ north, H = 10 a.m. standard time on May 21 (Day 14):

$\measuredangle\,\delta$ = ________________ (Hint: Use Eq. 2.)

$\angle H$ = ____________________ (Hint: Use Eq. 3)

α = ____________________ (Hint: Use Eq. 4)

Part 5. DETERMINE γ

There is one more necessary preliminary angle to find.

γ = the solar azimuth, the angle in the horizontal plane between due south and the projection of the sun's rays. See Fig. 7.

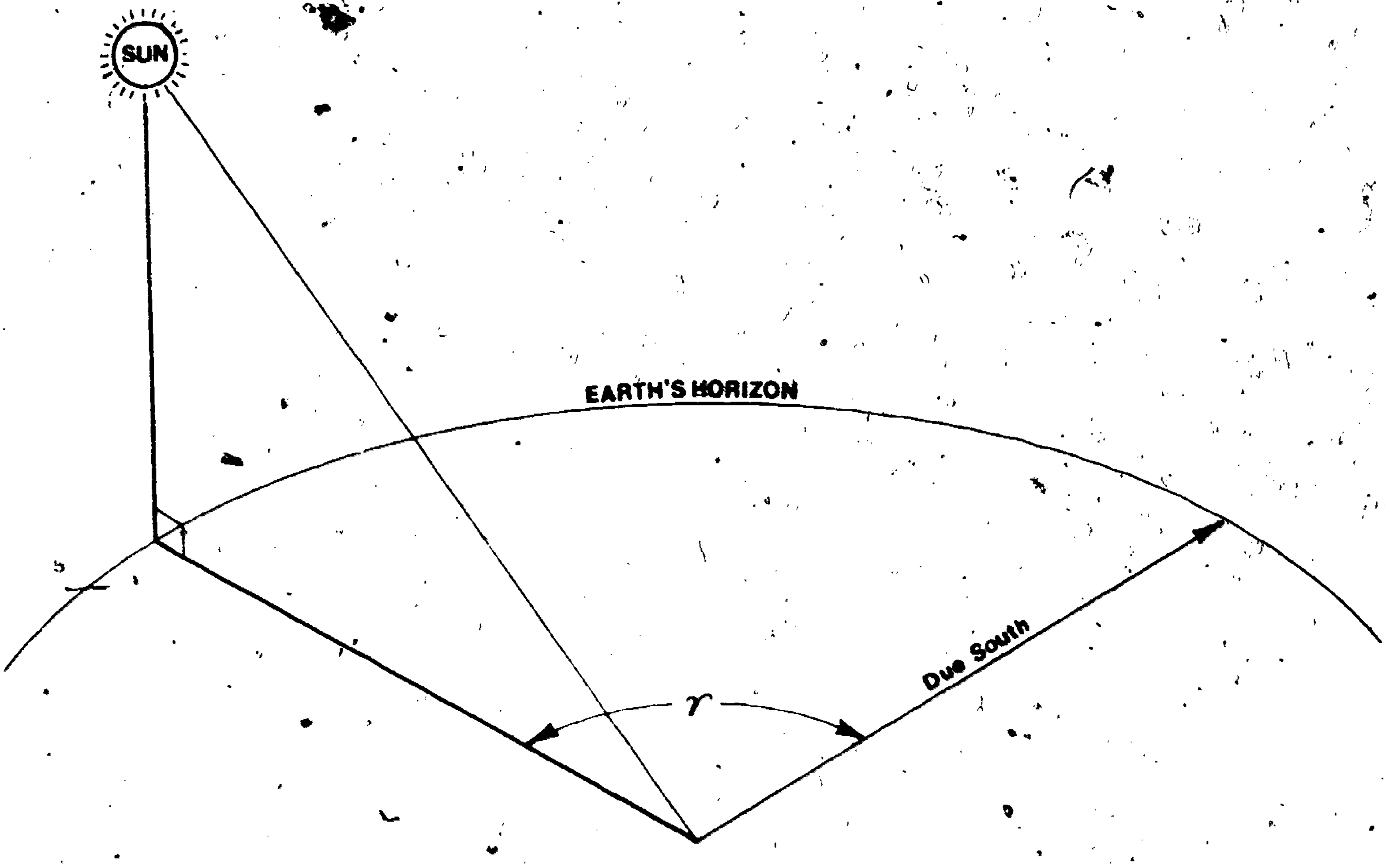


Figure 7. Solar Azimuth

The solar azimuth angle, γ, is given by

$$\sin \gamma = \frac{\cos\delta \sin H}{\cos \alpha} \qquad (5)$$

Example: Find γ for the example in the previous section where

$L = 45^oN$

and H = 10 a.m. standard time ($H = 30^0$) on March 21

where $\delta = 0^0$ and $\alpha = 37.76^0$

$$\text{Then, } \sin\gamma = \frac{\cos 0^0 \sin(+30^0)}{\cos 37.76^0} = \frac{(1.0)\ (.5)}{.7905} = .632$$

$$\gamma \doteq 39.23^0$$

Exercise: Find γ for the exercise in Part 4

$\gamma \doteq$

Part 6. DETERMINE i

Finally, we have enough information to find $\measuredangle i$, given by

$$\cos \measuredangle i = (\cos\alpha \ \cos\gamma \ \sin\theta \ ) + (\sin\alpha \ \cos\theta \ )$$

where, θ = the "tilt" angle of the solar collector (i.e., the angle between the collector and the horizontal). See Fig. 8.

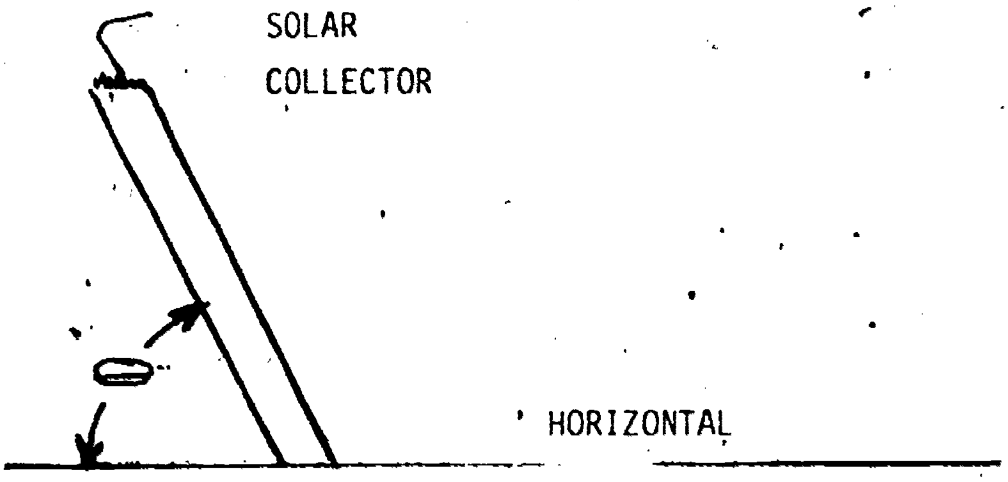


Figure 8. Tilt Angle, θ

Example: Determine the angle of incidence between the sun's rays and a flat plate collector surface tilted at an angle $\theta = 50^0$ on July 21st at 11:00 a.m. The collector is located at 40° north latitude.

a. $\delta = 23.5 \sin \left[360 \quad \left(\frac{284 + 202}{365}\right) \right] = 20.55^{\circ}$

b. $\sin \alpha = (\sin L \sin \delta\ ) + (\cos L \cos \delta \cos H)$

$= \sin 40^{\circ} \sin 20.44^{\circ}) + (\cos 40^{\circ} \cos 20.44^{\circ} \cos 15^{\circ})$

$= .9179$

$\alpha = 66.3^{\circ}$

c. $\sin \gamma = \frac{\cos \delta \sin H}{\cos \alpha} = \frac{\cos 20.55^{\circ} \sin 15^{\circ}}{\cos 66.63^{\circ}}$

$\sin \gamma = .6108$

$\gamma = 37.65^{\circ}$

d. $\cos i = (\cos \alpha \cos \gamma \sin \theta\ ) + (\sin \alpha \cos \theta\ ) \qquad (6)$

$= (\cos 66.3^{\circ} \cos 37.5^{\circ} \sin 50^{\circ}) + (\sin 66.63^{\circ} \cos 50^{\circ})$

$= .8307$

$i = 33.83^{\circ}$

Finally, we have found that $i = 33.83^{\circ}$ and $\cos i = .8307$. Therefore, by Eq. 1, one could collect 83.07% of the maximum insolation.

Part 7. SUMMARY. In order to do the calculations required to find the percent of the available energy a flat plate solar collector could absorb, one must give his trigonometry a real workout by finding:

1) δ - the solar declination for a given day of the year.

2) L - the latitude of the site.

3) H - the hour angle for the time of day.

4) α - the solar altitude

5) γ - the solar azimuth

6) θ - the angle of "tilt" of the collector.

7) i - the angle of incidence.

CONCLUSION

Return to (Eq. 1),

$$I_b = I_{max} \cos i$$

where I_{max} is the maximum amount of solar insolation that falls on a flat surface. Assume idealized conditions, i.e., no reflection off the collector surface, no diffuse beam, clean plates, no loss to smog, fog, shade, etc. Then, I_{max} = 1000 watts/meter^2 (this is a good round number estimate). Then, as an example, using the sample problem from the last section, where $i = 33.83^0$.

$$I_b = 1000 \cdot \cos 33.83^0$$
$$= 1000 \cdot .8307 = 830.7 \text{ watts/meter}^2$$

FURTHER INVESTIGATIONS.

Instead of using a fixed plate, can you see the advantage of devising a method for your collector to "track" the sun, or follow it across the sky? Or, instead of using a flat plate collector, think about the characteristics of a parabola, one of the conic sections.

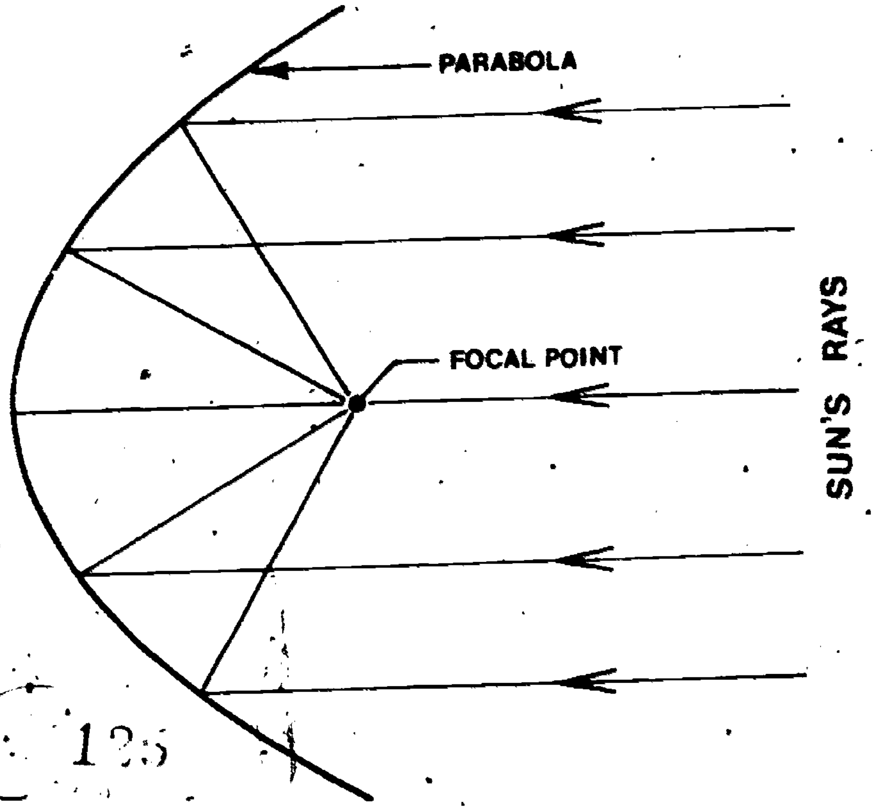


Figure 9. Parabolic Collection

The parallel rays from the sun will focus at a given point, the "focal point" of the parabola. Tracking devices and focusing collectors are now available. New worlds are open to you.

In conclusion, by using basic trigonometry, you can work your way through a typical engineering problem in solar heating. Now you can make up your own data and use the format below to solve your own problems.

Format for Solving Problems

Given: A site where latitude L = ________

Time of day (standard time): ________

Day of the year: ________

the tilt angle θ = ________

Find: 1) δ = ____________ (Eq. 2)

2) L = ____________ (given)

3) H = ____________ (Eq. 3)

4) α = ____________ (Eq. 4)

5) γ = ____________ (Eq. 5)

6) i = ____________ (Eq. 6)

7) I_b = ____________ (Eq. 1)

GLOSSARY OF TERMS AND SYMBOLS

Insolation - the rate of solar radiation received by a unit surface in a unit time (units of watts/meter^2 used here).

Angles - all in degrees:

Solar Declination (δ) - the angle between the equatorial plane of the earth and the sun's direct rays.

Solar Altitude (α) - the angle between the horizon and the sun's direct rays. Solar noon occurs when α is a maximum.

Solar Azimuth (γ) - the angle in the horizontal plane between due south and the vertical projection of the sun's rays.

Latitude (L) - angle between the equatorial plane and the observer.

Angle of Incidence (i) - the angle between the sun's direct rays and the perpendicular to a surface.

Tilt Angle (θ)- the angle between the collector surface and the horizontal

Hour Angle (H) - $\frac{360^0}{24\text{ hr}}$ = 15^0/hr from solar noon

Conversion Units:

1000 watts = 1 kilowatt = 3413 Btu/hr

1 langley = $\frac{1\text{ calorie}}{\text{cm}^2}$ = 369 Btu/ft^2

TEACHER'S GUIDE

OBJECTIVE: Enrichment in trigonometry, grades 11-12. At the end of the course in Basic Trigonometry, some students ask, "What is it good for?" As enrichment for such a student, this unit could be used to illustrate a timely application.

BACKGROUND REQUIRED: An understanding of trigonometry.

TIME REQUIRED: 4-6 hours of individual student's time.

SUGGESTED FOLLOW-UP:

a) Determine the solar insolation constant.

b) Design and build a flat plate.

c) Design and/or build a parabolic collector.

d) Reading - There is a glut of material on solar heating. Many journals, books, texts, etc. are flooding the market; write to SERI in Golden, Colorado for up-to-date bibliographies.

Answers to Exercises:

Section A.
a) 98%
b) 94%
c) 87%
d) 71%
e) 50%
f) 0%

Section B. Part 1)
a) 20.25^{0}
b) 0^{0}
c) -22.94^{0}

Part 4) $\delta = 20.14^{0}$, $H = 30$
$\alpha = 57.58^{0}$

Part 5) $\gamma = 61.12^{0}$

#12. LET THE SUN DO IT

PURPOSE: To determine the most efficient way to utilize the sun's energy for heating by experimenting with home design, insulation, and color.

INTRODUCTION: One purpose of a shelter is to moderate extremes of temperature. The combination of a fossil fuel shortage and the high cost of living enhances the need for solar heating. Proper planning and construction of a building to make use of the sun can result in energy savings. A technique which employs the conventional parts of a building to collect, store and distribute solar heat without energy-using mechanisms is called "passive" solar heating.

Collecting the sun's energy involves three basic requirements:

1. The house itself must be a solar collector, which means the sunlight should be let in when needed.
2. The building should be a storehouse for heating. Heavy materials such as stone or concrete accomplish this.
3. The house must be a heat trap. Insulation, weatherstripping, shutters, and storm windows help fulfill this requirement.

The optimum shape is an elongated building with an east-west axis. This design should permit the greatest number of windows facing the south and the least facing the north.

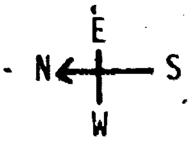
MATERIALS: Cardboard, Saran wrap, masking tape, insulation of some type, material for carpet, meterstick, thermometer.

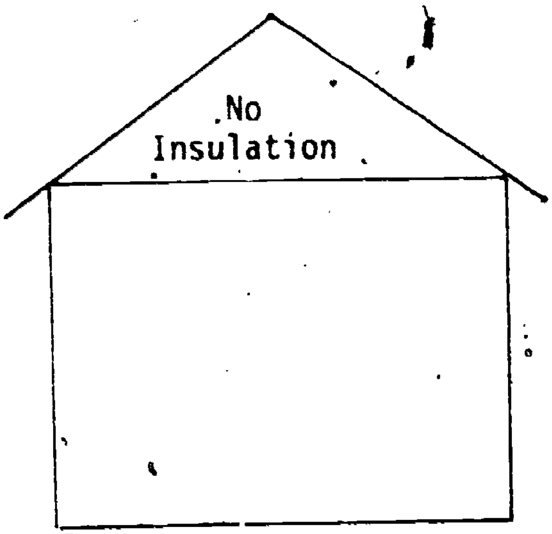
PROCEDURE:

1. Choose one model design from the model page below and construct your model home of cardboard with a $.45\ m^2 \le \text{base} \le .50\ m^2$. Windows should cover

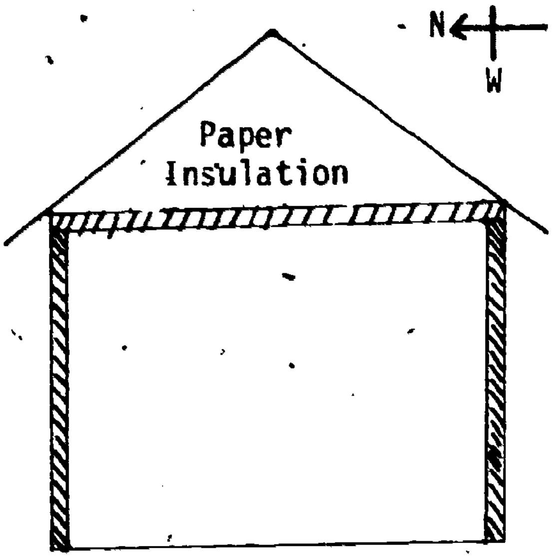
MODELS

These are side views of the model homes. Each "home" should be oriented outside with an east-west axis. To insert insulation, walls and ceiling should be made of two pieces of cardboard 1 cm apart. Fill in the space with designated insulation.





1.



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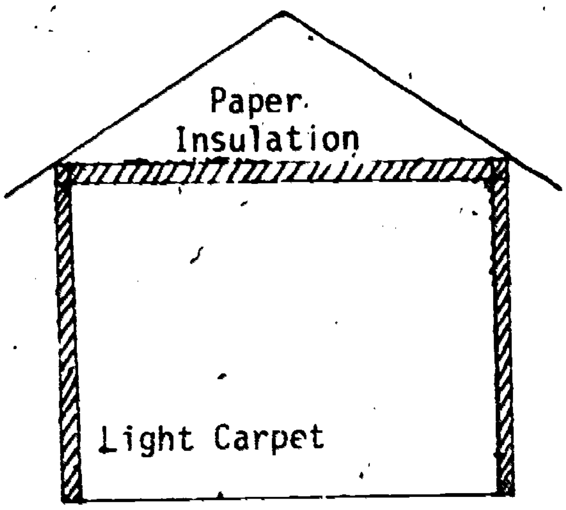

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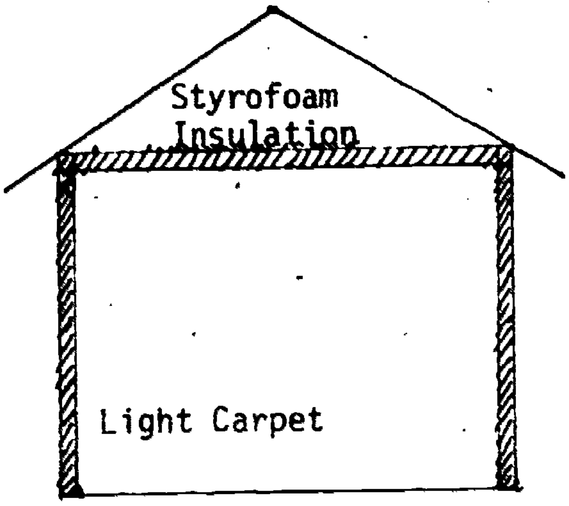

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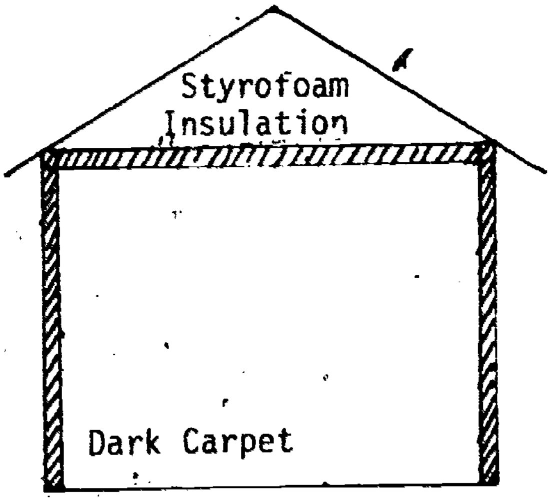

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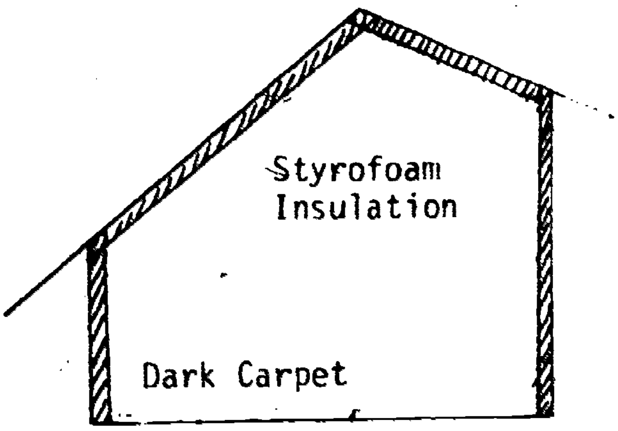


6.

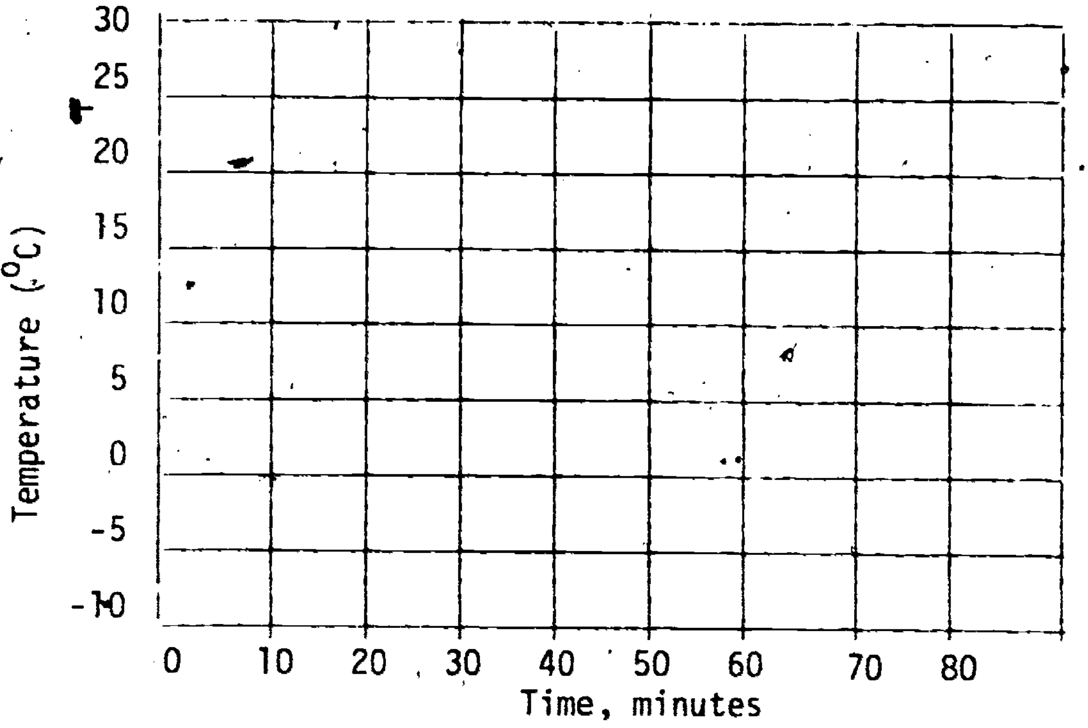
600 cm^2: 450 cm^2 on the south, 150 cm^2 on the east and west sides. Use Saran wrap for windows. To construct walls use two pieces of cardboard spaced 1 cm apart. Fill in with specified insulation. All inside walls will be a light color. Carpet colors will be specified.

2. Compute the volume of the home in m^3. (The volume of any regular prism is Ah where A is the area of the base and h is the height.)

3. On a cold, clear day place your model home outside for approximately one hour, oriented with an east-west axis.

4. With a thermometer, check the temperature outside and record. Then check the temperature inside at 10 minute intervals until no further temperature increase is observed.

5. Plot a graph of temperature as a function of time. Complete the data section below.



DATA: Volume of building________________ m^3

Outside temperature________________ ^oC

Final inside temperature________________ ^oC

Specific heat of air = .248 kilocalories/kg ^oC

Mass of $1m^3$ of air = 1.29 kg.

QUESTIONS, PROBLEMS, AND CONCLUSIONS:

1. Define: calorie, kilocalorie, Btu.
2. Using the formula, $Q = mc\ (T_{Inside} - T_{Outside})$, where Q is heat in kilocalories, m is the mass of air contained in the model in kilograms, c is the specific heat of air in kcals per kilogram per degree and T is temperature in degrees Celsius, find the amount of heat stored in your passive solar home in kilocalories.
3. One Btu = .252 kcal. Express your answer to #2 in Btu's.
4. Compare the amount of heat stored in your model solar home with the models made by your classmates.
5. What conclusions can you make regarding the passive heating capabilities of the various models tested?

TEACHER'S GUIDE

OBJECTIVES: At the completion of this experiment the students should be able to:

1. Calculate the amount of heat stored in a given volume of air.
2. Understand the meaning of passive solar energy.
3. Utilize the reflective and absorptive characteristics of interior colors.

BACKGROUND:

> "Now in houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in summer the path of the sun is right over our heads and above the roof, so that there is shade. If then, this is the best arrangement, we should build the south side loftier to get the winter sun and the north side lower to keep out the cold winds." Socrates (469-399 B.C.) as quoted by Xenophon in Memorabilia.

Passive solar heating is defined as the technique which uses the conventional parts of a building to collect, store, and distribute solar heat without energy-using pumps or fans. Generally, it relies on the south wall to collect and store heat. Other innovators have used 55-gallon steel drums filled with water to construct the south wall. The water heats by day and radiates inside the home at night. A home with proper design and construction can result in energy savings.

As can be learned from the quotation, solar heating is not a twentieth century invention. According to Roman regulations the axis of a military camp had to be within 30° of true south. Teotihuacan, a Meso-American city, was laid out on a grid 15° west of south. Pueblo Bonito was built by the Indians in Chaco Canyon, New Mexico, between 919 to 1180 A.D. The semicircular structure with a 520 ft. diameter and four stories high housed 1200 inhabitants. The plan of the structure was based on the position of the sun in the summer and winter solstices. Surfaces were exposed to more radiation in the winter than in the summer. Wall and roof construction was varied in thickness and composition to store the sun's heat and to permit the proper time lag of the day's heating effect to radiate into the interior at night. The Acoma Pueblo near Albuquerque was built on a similar plan. Early New England houses had masonry-filled walls and compact layouts to minimize heat losses during frigid winter months. Many colonial American homes had high walls and windows on the south while a low sloping roof faced the north.

Since an abundant supply of cheap fossil fuels became available during the present century, the sun was ignored in designing buildings. Now high costs and the shortage of fossil fuels have reversed the situation.

TIME REQUIRED: 5-10 days

MATERIALS: Each group will need a sufficient amount of cardboard (packing boxes will suffice for a source), masking tape, Saran wrap, material for walls and floors, thermometer, meterstick.

SUGGESTIONS: This experiment can be a group project with groups of three or more as the instructor deems advisable. One model can be built with a standard inverted v-shaped roof and no insulation to serve as a basis for comparison. The other homes can be varied according to types of insulation in wall and ceiling, color of carpets and chosen design. Model designs have been developed so that subtraction of results from two models will yield a difference attributable to one variable.

SAMPLE PROBLEM: Assume a model has a volume of $.2\text{m}^3$. Find Q (amount of heat).

c = Specific heat of air = .248 kcal/kg $\cdot$ °C

T_{Inside} = final inside temperature = 20 °C

$T_{Outside}$ = ambient air temperature = 0 °C

Mass of 1 m^3 air = 1.20 kg

Mass of air in kg contained by model = $.2 m^3 \times \frac{1.29\ kg}{m^3} = .258$ kg

Then $Q = mc\,(T_{Inside} - T_{Outside}) = .258\ kg \times \frac{.248\ kcal}{kg \cdot {}^{o}C} \times 20^{o}C = 1.28$ kcal

SUGGESTED FOLLOW-UP ACTIVITIES:

1. Let any of the models heat up to its maximum capacity. Open and close a door at minute intervals for twenty minutes. Graph the temperature as a function of time. Conclusions?
2. Add a "fireplace" (do not ignite) to one of the homes. Observe the temperature inside the model as the "flue" is opened and closed. Conclusions?
3. Vary orientation of the same houses.
4. Calculate mass of air at local conditions using gas laws.

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Direct Use of the Sun's Energy, by Farrington Daniels, New Haven, Yale University Press, 1974.

#13. CONSTRUCTING A MODEL GREENHOUSE

PURPOSE: The purpose of this activity is to provide students with and experience of constructing a model solar greenhouse from the materials provided and to determine quantitatively the total heat gain, in Btu's, for the solar greenhouse.

INTRODUCTION: This activity is designed especially for the student who likes to eat. Realizing that our present energy resources are being depleted rapidly, we must seek other useful forms of energy for long term use and storage. This is applicable to food production.

What is a solar greenhouse? The term solar greenhouse generally refers to greenhouses whose heating and light requirements are largely provided by the sun. All greenhouses receive most of their light from the sun and recently some have been designed to use the sun for heating as well. Solar greenhouses collect and store solar energy for heating and are well insulated so that the heat may be used at night and during cloudy periods.

MATERIALS (per group):

Cardboard box 33" x 20" x 20". Box size may vary
Styrofoam - enough to line all interior surfaces of greenhouse
Aluminum cans, 16 - standard pop cans
High temperature, non-toxic, flat black paint - 1 large spray can
Saran wrap
One-hole rubber stopper
Thermometer - 300°F maximum (oven thermometer)

Glue

Masking tape

Knife or razor blade

Ruler

Pencil

Data sheet

Graph paper

PROCEDURE:

Day 1. Activity 1

1. Construct your solar greenhouse using the cardboard box. (Refer to Fig. 1 for plan.)
2. Insert thermometer into one hole rubber stopper and then insert stopper centered into side of greenhouse.
3. Cover the opening with one sheet of Saran wrap.

Day 2. Activity 2

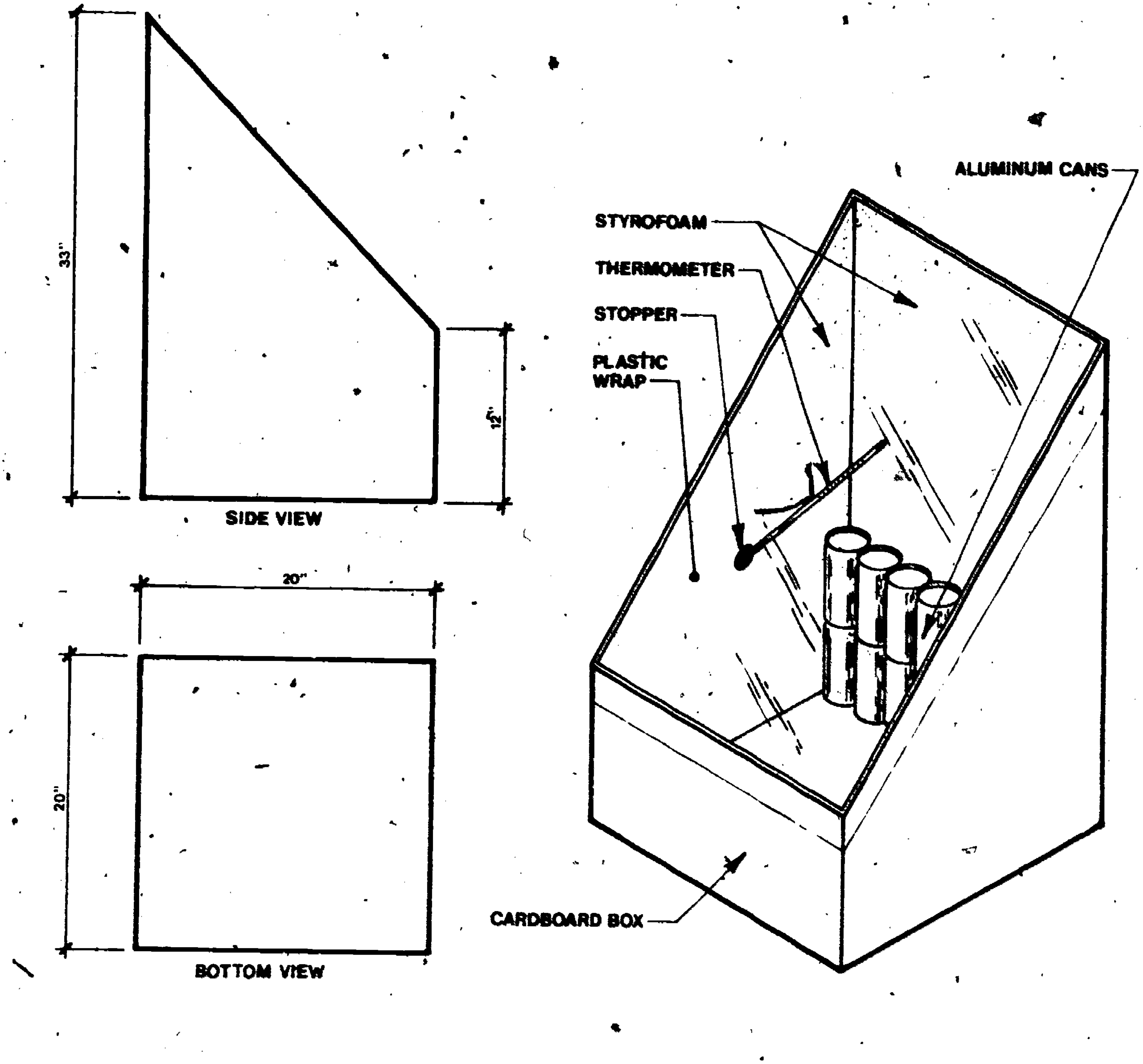
Place your greenhouse on the south side of the school building with the Saran wrap surface facing south.

1. Record the ambient air temperature on a data sheet and record the "greenhouse" temperature every two minutes on your data sheet.
2. Note changes of cloud cover on data sheet.
3. Graph the temperature as a function of time for outside and inside.

Review Questions for Activity 2.

1. How fast did the greenhouse heat up to its maximum temperature?
2. What maximum temperature was reached?

Fig. 1. Diagram of a Model Solar Greenhouse



3. What effects do weather conditions have on a solar greenhouse?

Day 3. Activity 3

1. Remove Saran wrap and thermometer.
2. Using ruler, knife and glue, insulate the interior walls of the greenhouse with styrofoam.
3. Paint the interior of the greenhouse with flat black, non-toxic paint.
4. Paint all sixteen aluminum cans with flat black.

Allow everything to dry until next day.

Day 4. Activity 4

1. Fill aluminum cans with water and cover holes with masking tape, Record weight of water. Fill each can with same amount.
2. With masking tape connect aluminum cans side-by-side in four groups of four.
3. Tape each set of cans on top of one another, and attach with tape or staples to the back of the greenhouse.
4. Touch-up inside of greenhouse with flat black paint.
5. Insert thermometer into side wall by pushing through styrofoam.
6. Stretch one layer of Saran wrap over opening.
7. Place greenhouse on south side of school building exposed to the sun. Record ambient air temperature on data sheet, and record inside temperatures at two minute intervals for fifteen minutes.
8. Graph temperature as a function of time for the next class meeting.

Day 5. Activity 5

1. Place greenhouse outside and record temperature for fifteen minutes. Remember to record ambient air temperature first.
2. Take greenhouse inside and record the temperature for fifteen minutes. Continue to observe temperature change if change occurs slowly.
3. Construct a graph of temperature as a function of time for your model from data sheets. Compare graph with uninsulated greenhouse.

Day 6. Activity 6

1. Using data provided by your teacher, calculate the heat gain for Activities 2, 4 and 5 in btu's/hr on the "collector" surface.
2. What effect did the insulation, black paint and cans of water have on temperature change?
3. What changes can be made in construction of your model to allow it to collect more heat?
4. How might a simple solar greenhouse be constructed to provide heat for a home.

TEACHER'S GUIDE

OBJECTIVE: The student will construct a model solar greenhouse, determine quantitatively the number of Btu's "collected" by the solar collector surface and the total heat gain, in Btu's. Optional activities are included.

BACKGROUND: The Btu, or British Thermal Unit, is a commonly used unit of heat. It is defined as the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit; specifically, from 59°F to 60°F. Heat losses and furnace capacities are described in Btu's per hour. For example, one gallon of oil burned at 70% efficiency will deliver about 100,000 Btu's (one kilowatt-hour is the equivalent of 3,412 Btu's). In comparison, the maximum intensity of sunlight at 40°N latitude is 306 Btu's per square foot per hour.

The student will determine the principles upon which a solar greenhouse functions. Model construction, accurate calculations and measurements and recording of data, as well as visual observations, are stressed.

The term solar greenhouse generally refers to greenhouses whose heating and light requirements are provided by the sun. Most solar greenhouses collect and store solar energy for heating and are insulated so that the heat collected can be used at night and during cloudy days. Solar greenhouses can be used to collect and store solar energy in many ways. The design of solar collectors and storage systems depends upon such factors as climate, economics and local weather conditions.

The two main types of solar systems are active and passive. An active system collects heat energy at one point, transports it, stores it at another, and delivers it for use somewhere else. Conventional energy sources are needed to move the collected solar energy.

In a passive system water containers, water pools, rock walls and other materials with high thermal mass collect, store and deliver the heat without circulating fans and pumps. If at any point in the system, additional energy must be used for storage or delivery, then that portion of the system has become active.

Solar greenhouses can be built independently or attached to an existing structure. A well-designed solar greenhouse can deliver more heat to a house during the day than the house loses at night.

Another advantage of a solar greenhouse is the extended, year-round growing season at a much lower operating cost than the conventional units. They are relatively inexpensive and easy to build.

On the average, there is enough solar energy to heat a greenhouse in the winter in most of the United States and Canada. During the coldest time of the year, late January on a clear day, the intensity of direct solar radiation is about 290 Btu's per square foot per hour at noon at 40°N latitude. This energy could heat the air from 40° to 70°F in one hour in a properly oriented 12' x 16' greenhouse.

Solar energy enters the greenhouse as shortwave radiation. When it's absorbed by inside surfaces, infra-red waves (heat) are radiated. These longer wavelengths cannot escape back into the atmosphere (the "Greenhouse Effect").

The light requirements must be balanced with heat requirements in a solar greenhouse. If the greenhouse is to function properly, it will require some type of heat and storage capability. The activities are designed to illustrate these basic solar greenhouse principles.

TIME REQUIRED: Six class hours.

SUGGESTIONS: Some students may wish to gather data on days when there is partial cloud cover. This would provide comparative data.

Day 1. Activity 1:

1. Students will construct their model solar greenhouses.
2. Time remaining in class period may be used to discuss various types of greenhouse construction and cost.

Day 2. Activity 2:

1. Complete Activity 1. Remind students to save their data sheets.
2. Students complete their graphs as homework, using their data.
3. Students should answer review questions at end of Activity 2.

Day 3. Activity 3:

1. Students will make basic changes in greenhouse construction: insulating and painting interior and aluminum cans with non-toxic, flat black paint.
2. If time permits, discuss and compare student graphs from previous day (Activity 2).

Day 4. Activity 4:

1. Complete modifications of model.
2. Set-up model and record temperature on data sheet for fifteen minutes.

Day 5. Activity 5:

1. Discuss graphs from Activity 4.
2. Students may collect more data for comparison.
3. Data should be graphed for following class meeting.

Day 6. Activity 6:

1. Explain to students the method used to calculate total insolation on a surface in Btu/hr. Refer to Sample Problem (A) below.
2. Discuss implications of solar energy based on experiences with the model solar greenhouses.

OPTIONAL ACTIVITIES:

1. Students who have mastered trigonometry may wish to calculate total clear-sky insolation with reference to angle of collector surface. Refer to Sample Problem (B) below. (Reflective radiation need not be considered.)
2. Determine total number of Btu's collected in the solar greenhouse. Refer to Sample Problem (C) below.
3. Thermocouple may be substituted for thermometer. Insert it in one aluminum can and attach to voltmeter. (Refer to "Calibrating A Thermocouple" in this manual for set-up instructions.

GENERAL INFORMATION AND EXPLANATION OF PROBLEMS:

Sample Problem (A)

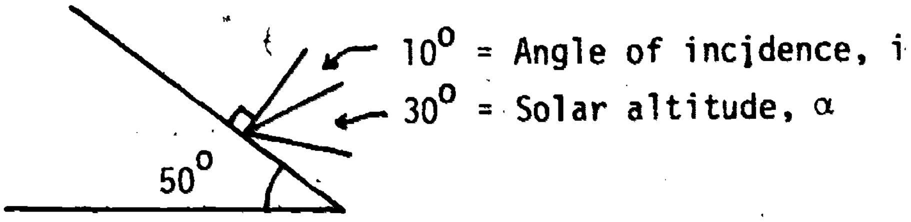
How many Btu's of solar heat impinge on the surface (2.5 ft^2) of a south-facing collector tilted 40^o from the horizontal at 10:00 a.m. on January 21 (latitude, 40^o N)?

From Table 2, the solar radiation is 237 Btu's/ft^2. Therefore, the radiation striking 2.5 ft^2 is:

$$2.5\ \text{ft}^2 \times 237\ \frac{\text{Btu's}}{\text{ft}^2} = 592.5\ \text{Btu's}$$

Sample Problem (B)

Determine the total clear-sky solar radiation falling on a flat-plate collector tilted 50° to the horizontal on Jan. 21 in Boulder, Colorado at noon. See drawing.



The solar radiation that strikes the earth is made up of two components, beam (or direct) radiation and diffuse (or scattered) radiation. Beam radiation is that solar radiation received directly from the sun without change in direction. Diffuse radiation is solar radiation received after its direction has been changed by reflection and atmospheric scattering.

The amount of beam radiation impinging on a surface on the earth is a function of surface-to-sun geometry. The beam component of solar radiation (I_b) effectively received by a collector is given by

$$I_b = I_{bn} \cdot \cos i \qquad (1)$$

where I_{bn} is the beam radiation falling on a surface perpendicular to the sun's rays, and 'i' is the angle of incidence measured between the sun's rays and the normal to the collector surface. When the angle of incidence 'i' is equal to 0, cos(i) = 1, and the beam radiation available to the collector (I_b) is the maximum value, I_{bn}.

The diffuse radiation component, (I_d), received by the collector is determined by the equation

$$I_d = C \cdot I_{bn} \cdot Fa$$

where C is the dimensionless value given in the last column of Table 1 presented below; and Fa is the angle factor from the surface to the sky:

$$Fa = (1 + \cos(\theta)/2)$$

where θ is the collector tilt angle measured from the horizontal.

Table 1 Extraterrestrial Solar Radiation Intensity (Btuh/ft^2) and Related Data for Twenty-First Day of Each Month, Base Year 1964

	I_o Btuh/ft^2	Equation of Time, min.	Declination deg	A Btuh/ft^2	B (Dimensionless	C Ratios)
Jan	442.7	-11.2	-20.0	390	0.142	0.058
Feb	439.1	-13.9	-10.8	385	0.144	0.060
Mar	432.5	- 7.5	0.0	376	0.156	0.071
Apr	425.3	+ 1.1	+11.6	360	0.180	0.097
May	418.9	+ 3.3	+20.0	350	0.196	0.121
June	415.5	- 1.4	+23.45	345	0.205	0.134
July	415.9	- 6.2	+20.6	344	0.207	0.136
Aug	420.0	- 2.4	+12.3	351	0.201	0.122
Sep	426.5	+ 7.5	0.0	365	0.177	0.092
Oct	433.6	+15.4	-10.5	378	0.160	0.073
Nov	440.2	+13.8	-19.8	387	0.149	0.063
Dec	443.6	+ 1.6	-23.45	391	0.142	0.057

To convert Btuh/ft^2 to W/m^2, multiply by 3.1525; example: 442.7 Btuh/ft^2 x 3.1525=1395.6 W/m^2. (The Btu units in this chapter are thermochemical.) To convert deg to rad (SI unit), multiply deg by 0.01745.

In addition to the beam and diffuse radiation components, there may exist a further gain in radiated energy due to reflection from the immediate surroundings. In the Boulder, Colorado area about 70% to 90% of the total radiation collected is generally in the form of beam radiation. However, in northern climates where snow covers the ground for most of the winter, the diffuse and reflected radiation can account for half of the total energy collected.

$$I_t = I_b + I_d + I_r \qquad (2)$$

where I_t = total solar radiation

I_b = direct beam radiation

I_d = diffuse radiation

I_r = reflective radiation

To calculate the beam radiation, refer to Table 2 "Normal" column.

Now refer to Table 2, "Normal" column. (No angle adjustment has been made). Note that Btuh = Btu's per hour. I_{bn} at normal at 12 noon = 294. Source of i is shown in figure below.

$$I_b = I_{bn} \cdot \cos i$$
$$= \frac{(294 \text{ Btu})}{\text{ft}^2}(\cos 10^0)$$
$$= (294)\ (.984)$$
$$I_b = 289.5 \text{ Btuh/ft}^2$$

Table 2.*

Date	Solar Time		Solar Position		Btu/ Sq. Ft. Total Insolation on Surfaces						
							So.Facing Surface Angle with Hor				
	AM	PM	Alt.	Azm.	Normal	Horiz.	30	40	50	60	90
Jan 21	8	4	8.1	55.3	142	28	65	74	81	85	84
	9	3	16.8	44.0	239	83	155	171	182	187	171
	10	2	23.8	30.9	274	127	218	237	249	254	223
	11	1	28.4	16.0	289	154	257	277	290	293	253
	12		30.0	0.0	294	164	270	291	303	306	263
			Surface Daily Tot.		2812	948	1660	1810	1906	1944	[illegible]26

* See Appendix B-5

Calculate diffuse radiation:

$$I_d = CI_{bn} \cdot Fa$$

$$Fa = \frac{1 + \cos 50}{2}$$

$$Fa = .821$$

$$C = .058$$

$$I_d = (.058)(294)(.821)$$

Idv= 13.99 Btuh

Calculate total solar radiation:

$$I_t = I_b + I_d$$

$$I_t = 289.5 + 14$$

$$I_t = 303.5 \text{ Btu}$$

Note that this figure is found under 50° surface angle at noon as total insolatio

Sample Problem (C)

Equation (3) is used to determine total heat, H.

$$H = \text{Btu of } H_2O + \text{Btu of air} \qquad (3)$$

$$H = (\text{mass})(\text{specific heat})(\Delta \text{ temp}) + (\text{volume})(\text{density})(\text{specific heat})(\Delta \text{ temp})$$

or $$H = (\text{lbs})(\text{Btu/lb}^\circ\text{F})(^\circ\text{F}) + (\text{ft}^3)(\text{lb/ft}^3)(\text{Btu/lb}^\circ\text{F})(^\circ\text{F})$$

Follow-Up Activities:

1. Various paint treatments may be used on the inside of the greenhouse to determine heat gain as a function of color.

2. Some students may wish to design a solar greenhouse on a larger scale and delve into other investigations; e.g., construction types, design, orientation, climatic effects, solar geometry.
3. The model greenhouse may be used to heat water. Pertinent data can be collected to illustrate the principle of a solar water heater.
4. A large scale solar greenhouse might be constructed from 3/8" plywood as an industrial education project.
5. The basic model design could be modified to make a solar oven.
6. The basic model design could be modified to include solar distillation.
7. Determine R-factors and U-factors for insulation used in the model. Refer to Homeowner's Energy Guide (in bibliography); also ASHRAE, American Society of Heating, Refrigerating and Air Conditioning. 1977 Fundamentals Handbook, Chapter 26, Table I.

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#14. SOLAR HEAT STORAGE AND HEAT OF PHASE CHANGE

PURPOSE: You will learn how to calculate the heat of fusion (heat of solidification) of a pure substance. With this information and class data, you will be able to choose which substance would be best suited for use in a solar heat storage unit.

INTRODUCTION: Imagine no available energy resources to heat your home! Solar energy technology may very well be one of the best solutions to the future energy crunch. As you know, heat storage from a solar collector must be considered if one intends to stay warm at night or when the sun is obscured by clouds.

Heat storage has been effectively accomplished with large rock bins and water tanks. But one problem is the space they must occupy. Finding materials that release more heat per unit of storage volume becomes a very important consideration.

It has been found that as materials change phase they absorb or emit much more heat per gram than just one phase absorbs or emits as it is heated or cooled. The heat absorbed by a melting substance at its melting point is called the heat of fusion; the heat released when a substance solidifies at its freezing point is called the heat of solidification. Can this "latent heat" be used to design a compact solar heat storage unit? You'll compare the heats of fusion of some pure substances and choose which might be best for your storage bin.

MATERIALS:

1 thermometer ($0^{o}C$ to $110^{o}C$)

1 small burner

1 styrofoam cup, 1 pt

Test tubes (18 x 150 mm)

Test tube holder

Ice

Paradichlorobenzene ($C_6H_4Cl_2$); melting point 53°C.

Ring stand, clamps for holding thermometer and test tube.

Plastic caps

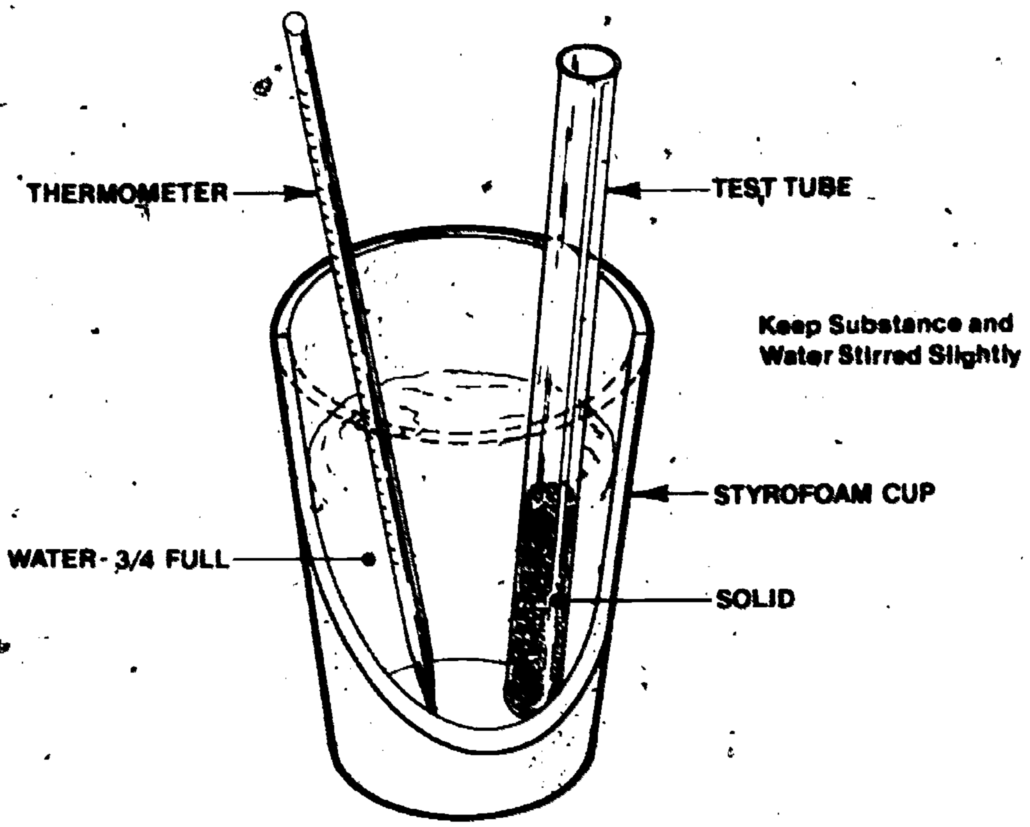

Fig. 1. Apparatus

PROCEDURE: Part I - Heat of Fusion

At the conclusion of this part of the experiment, Data Chart I should be completed.

Data Chart I

1. Mass of test tube ________ g

2. Mass of test tube + substance ________ g

3. Mass of substance ________ g

4. Volume of water used ______________ ml
5. Initial temperature of water bath ______________ ^{o}C
6. Final temperature of the water bath ______________ ^{o}C
7. $\Delta T(^{o}C)$ ______________ ^{o}C
8. Heat in calories lost by the water to the substance ______________ cal
9. Heat of fusion in calories per gram of substance ______________ cal/g
10. Heat of fusion in kcal per mole ______________ kcal/mole

---

1. Find the mass of a clean, dry test tube to the nearest .01 g. Fill it approximately half-full with one of the substances provided by your instructor, and mass it again (be sure to write down the name of your substance).

2. Heat enough water to fill your styrofoam cup calorimeter three-quarters full (know the volume exactly). The water temperature should be 25°C to 30°C above the melting point of the substance. Prepare calorimeter by placing one styrofoam cup in another cup. Cut holes for thermometer and test tube in cap.

3. Place the test tube and your thermometer into the calorimeter. See Fig. 1. Record the temperature of the water every 30 seconds. Note when the substance first appears to be melting and when it has <u>all</u> been melted. After all of the substance has melted and the temperature remains fairly constant, stop recording.

<u>CALCULATIONS</u>: As you have noted, the temperature of the water bath dropped. We must make the assumption that the heat energy associated with the temperature change (ΔT) was gained by the substance in the test tube and not lost to the surroundings; i.e., the heat gained by substance equals the heat lost by the water bath.

To calculate the heat lost by the water bath you must know the mass of water, ΔT (^{o}C), and the specific heat of water (1 calorie per gram per ^{o}C). The equation looks like this:

$$\text{Heat lost by water} = \text{Heat of fusion} = (\text{mass g})\ (\Delta T,\ ^{o}C)\ (\text{specific heat},\ 1\ \frac{\text{cal}}{g\,^{o}C})\quad (1)$$

By Eq. (1) you can see that the heat will be expressed in calories.

1. Calculate the number of calories required to melt the substance.
2. Calculate the number of calories required to melt one gram of the substance (divide the total number of calories by the number of grams of substance).
3. Calculate the number of kcal required to melt one mole of your substance. Hint:

$$\text{cal/g} \times \frac{1\ \text{kcal}}{1000\ \text{cal}} \times \text{g/mole} = \text{kcal/mole}$$

where g/mole = the molecular weight

PROCEDURE: Part 2. Heat of Solidification

At the conclusion of this part of the experiment, Data Chart II should be completed.

Data Chart II.

---

1. Mass of test tube ____________ g
2. Mass of test tube and substance ____________ g
3. Mass of substance ____________ g
4. Volume of water used ____________ ml
5. Initial temperature of water bath ____________ ^{o}C
6. Final temperature of water bath ____________ ^{o}C
7. ΔT (^{o}C) ____________ ^{o}C

8. Heat in calories gained by the water bath from the substance _______ cal

9. Heat of solidification in calories per gram of substance _______ cal/g

10. Heat of solidification in kcal per mole _______ kcal/mole

---

1. Mass a clean, dry test tube to the nearest .01 g. Then fill it one-half full with one of the substances provided by your instructor, and mass it again.

2. Obtain a known volume of water at a temperature which is approximately 20^{0} to 30^{0}C below the melting temperature of your substance and fill your styrofoam cup calorimeter.

3. Heat the solid until it is entirely melted. (Do not overheat). As soon as the crystal formation is evident, place the test tube in the calorimeter and record the temperature of the water bath every 30 seconds. When all of the substance has solidified and there is no further temperature change, stop recording.

CALCULATIONS: As the substance solidifies, it gives off heat to the water bath, causing its temperature to rise. Assuming no heat loss to the surroundings, the heat absorbed by water equals the heat released by the substance. Again the calculation uses the mass of substance, ΔT ^{0}C and the specific heat.

Heat gained by water = Heat of solidification = (mass, g)(ΔT, ^{0}C) (specific heat, $\left(\frac{1\ \text{cal}}{\text{g}\ \text{C}^{0}}\right)$.

1. Calculate the number of calories released by the substance as it solidifies.

2. Calculate the number of calories released by one gram of your substance

as it solidified.

3. Calculate the number of kcal released by 1 mole of your substance.

$$\text{cal/g} \times \frac{1\ \text{kcal}}{1000\ \text{cal}} \times \text{g/mole} = \text{kcal/mole}$$

DISCUSSION QUESTIONS:

1. How do your two values (heat of fusion, heat of solidification) compare?
2. Is there any heat gained while the substance is only in one phase? (Hint: Think of specific heat capacity.)
3. What would be the effect on your results if the calorimeter were better insulated? How could you find out?
4. Find the specific heat of fusion of other substances which would be suitable for use in solar storage. Discuss the possibilities of using these substances.
5. Sketch a very simple diagram of the flow of air from solar collectors on a roof through a heat storage unit and then to a home's living space. Could one use this system to cool a house in the summer?

TEACHER'S GUIDE

OBJECTIVES: Students will understand: 1) that there is a definite heat effect associated with the melting and freezing processes; 2) the terms: heat, temperature, calorimetry, heat of fusion and heat of solidification; 3) various aspects of solar energy storage technology.

BACKGROUND: Energy storage can be accomplished in several ways. Passive thermal storage is the storing of the sun's heat in a structure (e.g., a wall of your house). Later, the wall will radiate heat into the house. Chemical storage utilizes a substance like hydrogen in a fuel cell. Fly wheels also store energy. Chemical batteries are a common means of electrical storage, but they are expensive.

Finally, eutectics can be effective materials in which to store energy. The latent heat of a eutectic is energy stored or released in a phase change. Most common substances used for storage have specific heats of one or less. A given eutectic with a high heat of fusion requires less mass for the same amount of heat storage capability.

A problem is finding materials that change phase in the temperature range of solar collector operation (100-300^{0}F). One substance that has been studied is Glauber's Salt ($Na_2SO_4 \cdot 10H_2O$). Its disadvantage is that it often deteriorates after several cycles.

TIME REQUIRED: 3-4 class periods.

SUGGESTIONS:

1. This activity is designed for an 11th grade chemistry class to develop the

topics of calorimetry, heat of fusion, and initiate interest in solar storage technology. It is hoped that post-lab discussion will include the need for alternate energy technologies.

2. To be conversant with engineers, one must use Btu's (British Thermal Units). One Btu is the amount of energy required to heat one pound of water one degree Fahrenheit. The appropriate conversion factor is:

$$\frac{1\text{ Btu}}{252\text{ calories}}$$

3. Other substances to use:

Substance	Melting point, °C	Molecular weight	Heat of fusion, cal/g
1,4-Butanediol	15-19	90	------
n-Octadecane	27-29	255	------
Paraffin	50-58	500	35.1
Paradichlorobenzene	53	147	29.07
Diphenylamine	53	163	≈ 30.4
Naphthalene	79-80	128	35.06
Naphthol	94	144	38.94

4. Be certain that students know the difference between temperature and heat. Temperature is merely an arbitrary scale of the flow of heat from hot to cold, whereas heat is the amount of energy the system may contain measured in units like calories. Students should realize that a substance may release or absorb heat energy at its freezing point without a change in temperature.

SUGGESTED FOLLOW-UP ACTIVITY: Determine the dollar savings that a eutectic heat storage unit could save. Contact your local utility company about prices of heating. Discuss criteria for selecting practical storage media.

ANSWERS TO QUESTIONS:

1. Nearly the same.
2. Yes

   $H = (\Delta T)\,(\text{mass})\,(\text{specific heat of eutectic}) = \text{calories}$

3. Insulating the calorimeter would reduce the heat lost to the surroundings. This would increase values obtained for the heat of fusion.

5. a. See Fig. 2.

   b. Yes

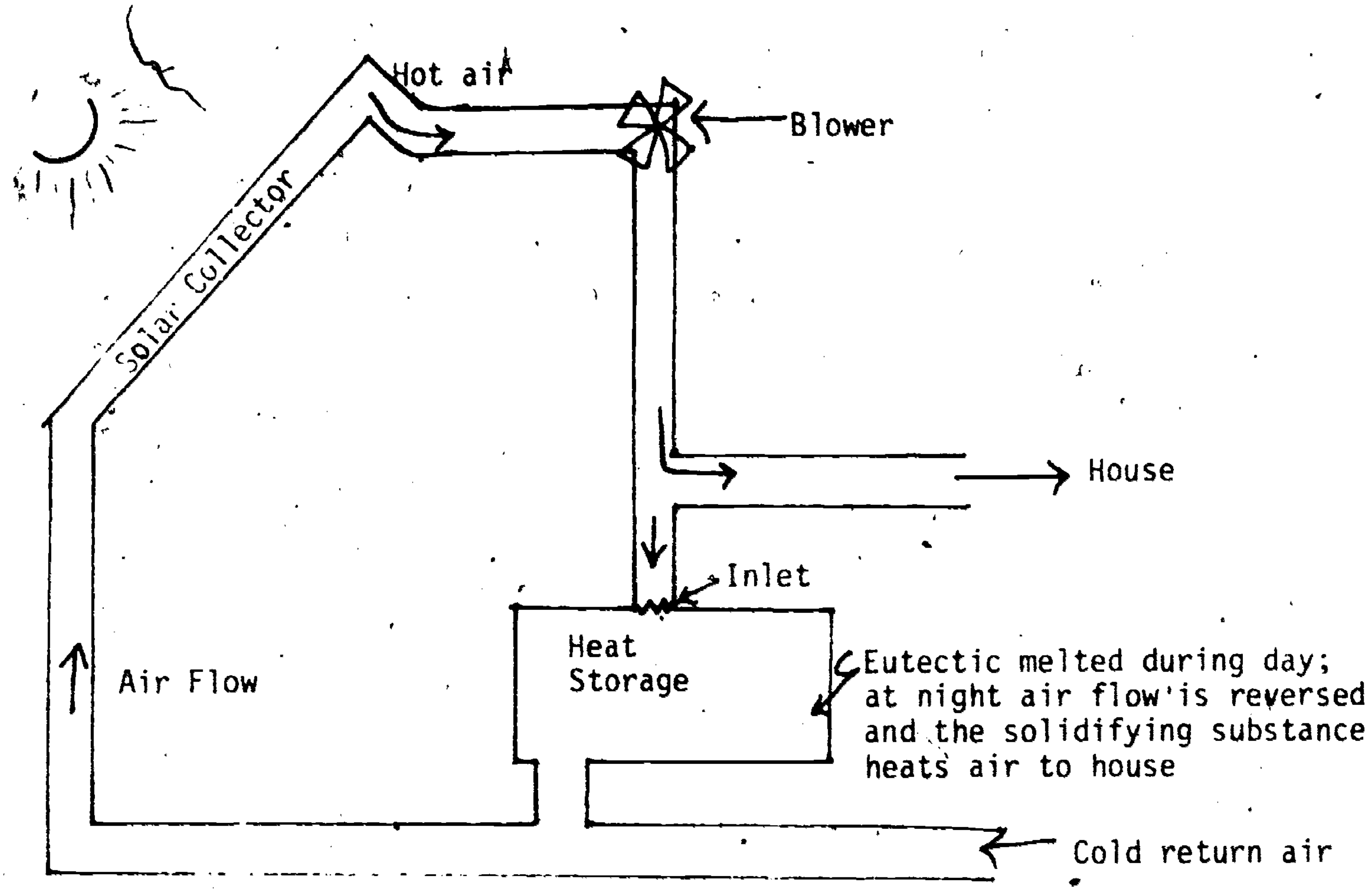

Fig. 2.

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#15. SOLAR ENERGY STORAGE IN GRAVEL

PURPOSE: You will measure the heat storage capacity and the efficiency of a gravel bed system.

INTRODUCTION: Solar energy heats our homes passively now through south-facing windows. We can augment our home heating with a solar collector, storing excess heat for nights and cloudy weather. Solar heat can be stored in water for later transfer to room air, or it can be stored in gravel or broken brick.

In this experiment a hair dryer will be used to simulate an air-heating collector and a gravel storage bed will be used, but the principles can be applied to any collector/storage system. The size chosen for the gravel bed, the collector size, and the heat loss of your component, will help determine the highest bed temperature for a given amount of solar radiation. Remember, in transferring the heat from source to storage to house, use as few steps as possible, keeping the path of heat flow short, and insulate heavily to reduce heat losses.

MATERIALS:

Three thermometers

Plywood or sheeting material

Hair dryer, 1000-watts

Gravel (1.5 inches)

10 x 10 graph paper

Small electric fan

Glue

Nails

Duct tape

2-inch duct

Screen

PROCEDURE:

1. Construct a container of the appropriate volume (1 ft^3) to hold the rocks, using sheeting material or plywood. Seal all edges with 2" duct tape. The top should fit tightly to limit heat losses.

2. Make an inlet at the top and an outlet on the opposite side near the bottom, so that the air flow contacts the maximum amount of rock.

3. Determine the mass of rock you are using. Weighing can be avoided by remembering that the density of rock is about 126 lbs/ft^3.

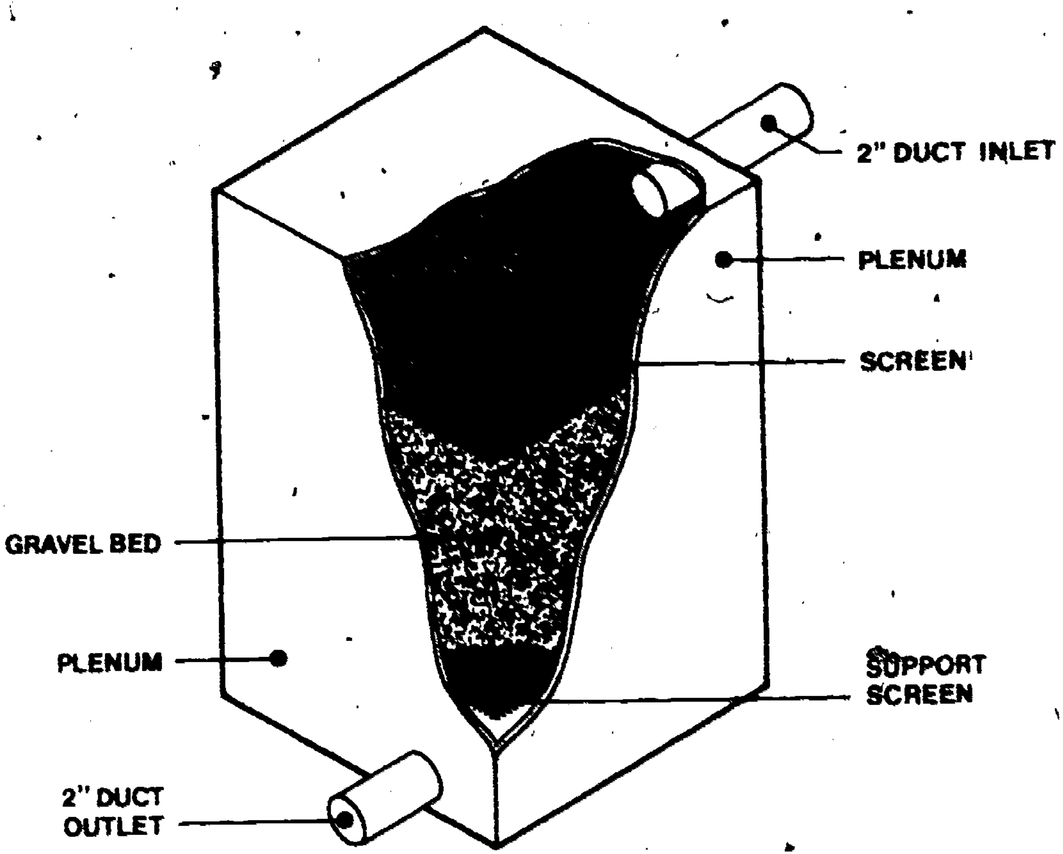

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Figure 1.

4. Mount the hair dryer in the inlet.
5. Insert a thermometer in the inlet and a thermometer in the outlet ducts of your storage bin.
6. Insulate the storage bin to simulate a basement location.
7. Fill the storage component with gravel and seal top. Turn on hair dryer.
8. Measure and record temperatures of the air in the inlet and outlet ducts at 5 minute intervals for thirty minutes.
9. Shut off hair dryer.
10. If possible, temperature measurements should continue to determine how long it takes for the stored heat in the rock to be released.
11. Plot the temperature as a function of the time on 10 x 10 graph paper.
12. Compute the total amount of heat stored in the storage component using

    $$\Delta H = m \times s \times \Delta T$$

    where m is the mass of rock, s is the specific heat, $0.205\ \mathrm{cal/g{\cdot}C^{o}}$ ($0.205\ \mathrm{Btu/lb{\cdot}F^{o}}$), and ΔT is the difference between the initial temperature and the maximum temperature of the rock storage bin.
13. Determine the volume of your storage bin ($V = \ell \times w \times h$), and the rock density ($D = m/v$).
14. Determine the air flow rate, R = volume of air/time

<u>QUESTIONS:</u>

1. How could we use this stored energy? What was the cost?
2. What size solar system would you need to heat your home? Your classroom?
3. What other storage material could be used?

TEACHER'S GUIDE

OBJECTIVE: The student will be able to measure the heat storage capacity and efficiency of a gravel bed.

TIME REQUIRED: Five or six 45-minute class periods. This experiment may be done individually or in small groups.

MATERIALS: Three thermometers, plywood or sheeting material, insulating material, gravel (1/2 - 1"), 10 x 10 graph paper, glue, nails, duct tape, "2" metal duct; 1000-watt hand-held hair dryer.

SUGGESTED FOLLOW-UP ACTIVITIES:

1. Visit a solar home, measure and record Btu's produced, Btu's stored, and Btu's used.
2. Compare two or more solar storage units and their cost effectiveness.
3. Design and build an air-loop, rock storage, convective solar heater.

SUGGESTED CAREER/EDUCATION ACTIVITIES: Given the opportunity to identify three occupations of interest, the student will list the names, addresses and phone numbers of local persons and/or groups with whom the student could discuss:

employment opportunities
training or skills required
hiring procedures

Given the opportunity to work in small groups, the student will identify the business opportunities in the solar industry.

REFERENCES:

The Solar Home Book, Bruce Anderson, M. Riordan, Cheshire Books, 1976.

Build-It Book of Solar Heating Projects, W.F. Foster, Tab Books, 1976.

Homeowner's Guide to Solar Heating and Cooling, W.M. Foster, Tab Books, 1976.

Sun Earth, R.L. Crowther, A.B. Wirchfeld Press, Inc., 1976.

APPENDIX A

Appendix A-1

Selected Constants

CONSTANTS		
Acceleration of gravity	g	980.7 m/sec^2
		32.17 ft/sec^2
Atomic mass unit	amu	1.660531×10^{-27} kg
Electron rest mass	M_e	9.109558×10^{-31} kg
Proton rest mass	M_p	1.672614×10^{-27} kg
Neutron rest mass	M_n	1.674920×10^{-27} kg
Avogadro's number	N_A	6.022×10^{23} /gram-mole
Boltzmann's constant	k	1.38×10^{-23} joule/$^{\circ}$K
Gas constant	R	1.987 cal/gram-mole $^{\circ}$K
		1.987 Btu/lb mole $^{\circ}$R
Planck's constant	h	6.62×10^{-34} joule-sec
Stefan-Boltzmann constant (black body)	σ	5.67×10^{-8} W/m^{2}K^4
Velocity of light	c	2.9979×10^8 m/sec 186,282 mi/sec

PREFIXES

micro (μ) = one millionth
milli (m) = one thousandth
centi (c) = one hundredth
deci (d) = one tenth
deka (D) = ten times

hecta (h) = one hundred times
kilo (k) = one thousand times
mega (M) = one million times
giga (G) = 10^9 times
tera (T) = 10^{12} times

Appendix A-2

Conversion of Units

From	To	Multiply by	From	To	Multiply by
acre-ft	gal	3.26×10^5	cal/g	Btu/lb	1.80000
"	liters	1.233×10^6	"	Wh_t/kg	1.1622
"	m^3	1233.5	cal/sec	Btu/h	14.286
acre	ha	0.4047	"	W	4.184
Angstrom (Å)	μm	$1.--- \times 10^{-4}$	"	J/sec	4.184
atm	kg/m^2	1.0332×10^4	"	Btu/sec	3.9684×10^{-3}
"	kg/cm^2	1.0332	"	ft-lb/sec	3.0860
"	g/cm^2	1.0332×10^3	"	g-cm/sec	4.2665×10^4
"	lb/in^2	14.70	cal/cm^2sec	Btu/ft^2h	1.3272×10^4
"	$tons/ft^2$	1.058	"	W/cm^2	4.184
bar	atm	0.9869	"	W/m^2	4.184×10^4
"	$dyne/cm^2$	10^6	"	J/m^2sec	4.184×10^4
"	kg/m^2	1.020×10^4	"	kW/m^2	41.84
"	lb/in^2	14.5038		MJ/m^2h	150.62
Btu	J	1.0548×10^3	cal/cm^2	L (langley)	1.0000
"	kJ	1.0548	"	Wsec	4.184
"	cal	251.996	cal/cm^2h	kW/m^2	1.1622×10^{-2}
"	kWh_t	2.928×10^{-4}	"	W/cm^2	1.1622×10^{-3}
"	ft-lb	778.3	cal/cm^2min	kW/m^2	6.9732×10^{-1}
Btu/h	ft-lb/sec	0.2162	"	L/min	1.0000
"	cal/sec	0.0700	$cal/cm^2C^osec/cm$	$Btu/ft^2F^oh/ft$	0.067197
"	W_t	0.2931	"	$Btu/ft^2F^oh/in$	0.80636
Btu/min	kW_t	0.01757	"	$J/cm^2C^osec/cm$	4.184
"	W_t	17.57	"	$W/cm^2C^o/cm$	4.184
Btu/lb	J/kg	2.326×10^{-3}	"	$W/m^2C^o/cm$	4.184×10^4
"	cal/g	0.55555	cm	in	0.39370
Btu/ft^2min	W/m^2	18.914	"	ft	0.03281
"	cal/cm^2sec	4.521×10^{-3}	cm^2	in^2	0.15500
Btu/ft^2h	cal/cm^2sec	7.5344×10^{-5}	"	ft^2	1.0764×10^{-3}
"	J/cm^2sec	3.1524×10^{-4}	cm^3	in^3	6.1023×10^{-2}
"	W/m^2	3.1524	"	ft^3	3.5315×10^{-5}
"	kJ/m^2h	11.348	cfm	liters/sec	0.4720
"	cal/cm^2h	0.27125	day	sec	86,500.0
"	cal/cm^2min	4.5208×10^{-3}	dyne	J/sec	10^{-7}
"	L/min	4.5208×10^{-3}	$dyne\text{-}cm^2$	bar	10^{-6}
Btu/ft^2F^oh	cal/m^2C^osec	1.3573	erg	Btu	9.4845×10^{-11}
"	W/m^2C^o	5.6783	"	cal	2.3901×10^{-8}
$Btu/ft^2F^oh/ft$	$cal/cm^2C^oh/cm$	14.881	"	g-cm	1.0197×10^{-3}
"	$J/m^2C^osec/m$	1.73073	"	kWh_t	2.7778×10^{-14}
"	$cal/m^2C^osec/cm$	41.13548	ft	cm	30.480
"	$W/m^2C^o/cm$	17.294	"	m	0.30480
$Btu/ft^2F^oh/in$	$cal/cm^2C^oh/cm$	1.2401	ft(water)	atm	0.0295
"	$kJ/m^2C^oh/cm$	100.45	"	lb/in^2	0.4335
"	$cal/m^2C^osec/cm$	3.4447	"	kg/m^2	304.8
"	$cal/cm^2C^osec/cm$	3.4447×10^{-4}	ft^2	cm^2	929.03
"	$W/m^2C^o/cm$	14.412	"	m^2	0.092903
"	$W/m^2C^o/m$	0.14412	ft^3	cm^3	2.8317×10^4
cal	g-cm	42664.9	"	m^3	2.8317×10^{-2}
"	J	4.184	"	gal(U.S.)	7.48052
"	Btu	3.9683×10^{-3}	"	liters	28.3106
"	kWh_t	1.1622×10^{-6}	ft/sec	cm/sec	30.48
"	kJ	4.184×10^{-3}	"	km/h	1.09728
"	Wh_t	1.1622×10^{-3}	"	mi/h	0.68182

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From	To	Multiply by	From	To	Multiply by
ft-lb	Btu	1.2841x10^{-3}	km	mi	0.62137
"	cal	0.32405	"	ft	3280.84
"	J	1.35582	kcal	J	4.1840x10^{3}
gal(U.S.)	cm^3	3785.41	km^2	acres	247.105
"	lb(water)	8.34517	"	mi^2	0.38610
"	kg(water)	3.7852	km/h	ft/sec	0.9113
"	ft^3	0.13368	"	mi/h	0.62137
"	acre-ft	3.0689x10^{-6}	knots	cm/sec	51.444
"	liters	3.7852	"	ft/sec	1.6878
g	lb	2.2046x10^{-3}	"	mi/h	1.1508
g/cm^2	lb/in^2	1.4223x10^{-2}	"	km/h	1.852
"	atm	9.6784x10^{-4}	kW	Btu/min	56.8253
g/cm^3	kg/m^3	10^{3}	"	Btu/h	3414.43
"	lb/in^3	3.6126x10^{-2}	"	hp	1.3410
"	lb/ft^3	62.4280	"	cal/min	1.43197x10^{4}
g-cm	Btu	9.3011x10^{-8}	"	cal/sec	238.662
"	J	9.8066x10^{-5}	"	J/sec	10^{3}
g-cm/sec	cal/sec	2.3438x10^{-5}	"	kJ/h	3600
hp	Btu/min	42.4356	kWh	Btu	3410.08
"	kW	0.74570	"	cal	8.59326x10^{5}
"	kJ-sec	0.74570	"	kcal	8.59326x10^{2}
"	cal/min	1.06936x10^{4}	"	kJ	3600
in	cm	2.54000	"	lb(H_2O evap.)	3.53
in(water)	lb/in^2	3.6126x10^{-2}	kW/m^2	Btu/ft^{2}h	317.21
"	kg/m^2	25.3993	"	W/cm^2	0.10000
"	atm	2.458 x10^{-3}	"	cal/cm^{2}sec	0.23901
in^2	cm^2	6.4516	"	kJ/m^{2}h	3600
"	ft^2	6.9444x10^{-3}	L (langley)	cal/cm^2	1.00000
in^3	cm^3	16.3871	"	J/cm^2	4.184
"	m^3	1.6387x10^{-5}	"	kJ/m^2	41.84
"	ft^3	5.7870x10^{-4}	"	Btu/ft^2	3.6866
in(Hg)	atm	3.3421x10^{-2}	L/min	cal/cm^{2}min	1.0000
"	ft(water)	1.1330	"	cal/cm^{2}sec	1.6667x10^{-2}
J	Btu	9.48451x10^{-4}	"	Btu/ft^{2}h	1.3272x10^{4}
"	kWh	2.7778x10^{-7}	liter	in^3	61.0254
"	cal	0.239006	"	gal	0.26418
"	erg	10^{7}	"	ft^3	3.53157x10^{-2}
"	ft-lb	0.737562	"	cm^3	1000
"	Wh	2.7778x10^{-4}	lb/in^2	g/cm^2	70.3070
J/cm^2	cal/cm^2	0.239006	"	kg/m^2	703.070
J/sec	W	1	lb/in^3	g/cm^3	27.6799
"	Btu/min	5.6907x10^{-2}	"	kg/m^3	2.76799x10^{4}
"	cal/min	14.3404	lumen	W	1.4706
"	hp	1.34109x10^{-3}	m	mi	6.2137x10^{-4}
kJ	kWh	2.7778x10^{-4}	"	ft	3.2808
kJ/m^2	Btu/ft^2	8.8111x10^{-2}	"	in	39.3701
"	cal/m^2	239.006	m^2	ft^2	10.7639
"	cal/cm^2	0.02390	"	in^2	1550.00
"	kcal/m^2	0.23901	"	ha	10^{-4}
kcal/m^{2}day	kJ/m^{2}day	4184.0	"	acres	2.47105x10^{-4}
"	kJ/m^{2}day	4.1840	m^3	ft^3	35.3147
kg	lb	2.20462	"	acre-ft	8.1071x10^{-4}
kg/cm^2	atm	0.96784	"	in^3	6.10237x10^{4}
"	ft(water)	32.8093	"	gal (U.S.)	264.172
"	lb/ft^2	14.2233			

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From	To	Multiply by	From	To	Multiply by
MBtu	kJ	1.0548×10^6	therm	kWh	29.28
"	MkJ	1.0548	"	MJ	1.0548×10^2
"	kWh	292.875	"	kcal	2.5200×10^4
MkJ/m^2	kBtu/ft^2	88.11	W	Btu/h	3.41443
mi	yds	1760	"	cal/sec	0.239045
"	m	1609.34	"	hp	1.34102×10^{-3}
"	km	1.60934	"	J/sec	1.00000
mi^2	km^2	2.58999	W/cm^2	cal/cm^{2}sec	0.239045
"	acres	640.000	"	Btu/ft^{2}h	31.721
"	ha	258.9988	"	kW/m^2	10.0000
N (newton)	dynes	10^5	"	cal/cm^{2}min	14.3310
poundal	lb	0.03108	"	L/min	14.3310
"	g	14.0981	"	kJ/m^{2}h	3.60000×10^4
lb	g	453.5924	Wh	cal	859.184
"	kg	0.453592	"	ft-lb	2655.22
therm	Btu	10^5	"	kg-m	367.098
"	MBtu	0.10000	"	kJ/m^2	3.6000×10^4

Appendix A-3

Conversion of Celsius to Fahrenheit

Temp °C	0	1	2	3	4	5	6	7	8	9
-50	-58.0	-59.8	-61.6	-63.4	-65.2	-67.0	-68.8	-70.6	-72.4	-74.2
-40	-40.0	-41.8	-43.6	-45.4	-47.2	-49.0	-50.8	-52.6	-54.4	-56.2
-30	-22.0	-23.8	-25.6	-27.4	-29.2	-31.0	-32.8	-34.6	-36.4	-38.2
-20	- 4.0	- 5.8	- 7.6	- 9.4	-11.2	-13.0	-14.8	-16.6	-18.4	-20.2
-10	+14.0	+12.2	+10.4	+ 8.6	+ 6.8	+ 5.0	+ 3.2	+ 1.4	- 0.4	- 2.2
- 0	32.0	30.2	28.4	26.6	24.8	23.0	21.2	19.4	+17.6	+15.8
+ 0	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
+10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2
60	140.0	141.8	143.6	145.4	147.2	149.0	150.8	152.6	154.4	156.2
70	158.0	159.8	161.6	163.4	165.2	167.0	168.8	170.6	172.4	174.2
80	176.0	177.8	179.6	181.4	183.2	185.0	186.8	188.6	190.4	192.2
90	194.0	195.8	197.6	199.4	201.2	203.0	204.8	206.6	208.4	210.2
100	212.0	213.8	215.6	217.4	219.2	221.0	222.8	224.6	226.4	228.2
110	230.0	231.8	233.6	235.4	237.2	239.0	240.8	242.6	244.4	246.2
120	248.0	249.8	251.6	253.4	255.2	257.0	258.8	260.6	262.4	264.2
130	266.0	267.8	269.6	271.4	273.2	275.0	276.8	278.6	280.4	282.2
140	284.0	285.8	287.6	289.4	291.2	293.0	294.8	296.6	298.4	300.2
150	302.0	303.8	305.6	307.4	309.2	311.0	312.8	314.6	316.4	318.2
160	320.0	321.8	323.6	325.4	327.2	329.0	330.8	332.6	334.4	336.2
170	338.0	339.8	341.6	343.4	345.2	347.0	348.8	350.6	352.4	354.2
180	356.0	357.8	359.6	361.4	363.2	365.0	366.8	368.6	370.4	372.2
190	374.0	375.8	377.6	379.4	381.2	383.0	384.8	386.6	388.4	390.2
200	392.0	393.8	395.6	397.4	399.2	401.0	402.8	404.6	406.4	408.2
210	410.0	411.8	413.6	415.4	417.2	419.0	420.8	422.6	424.4	426.2
220	428.0	429.8	431.6	433.4	435.2	437.0	438.8	440.6	442.4	444.2
230	446.0	447.8	449.6	451.4	453.2	455.0	456.8	458.6	460.4	462.2
240	464.0	465.8	467.6	469.4	471.2	473.0	474.8	476.6	478.4	480.2
250	482.0	483.8	485.6	487.4	489.2	491.0	492.8	494.6	496.4	498.2
260	500.0	501.8	503.6	505.4	507.2	509.0	510.8	512.6	514.4	516.2
270	518.0	519.8	521.6	523.4	525.2	527.0	528.8	530.6	532.4	534.2
280	536.0	537.8	539.6	541.4	543.2	545.0	546.8	548.6	550.4	552.2
290	554.0	555.8	557.6	559.4	561.2	563.0	564.8	566.6	568.4	570.2
300	572.0	573.8	575.6	577.4	579.2	581.0	582.8	584.6	586.4	588.2
310	590.0	591.8	593.6	595.4	597.2	599.0	600.8	602.6	604.4	606.2
320	608.0	609.8	611.6	613.4	615.2	617.0	618.8	620.6	622.4	624.2
330	626.0	627.8	629.6	631.4	633.2	635.0	636.8	638.6	640.4	642.2
340	644.0	645.8	647.6	649.4	651.2	653.0	654.8	656.6	658.4	660.2
350	662.0	663.8	665.6	667.4	669.2	671.0	672.8	674.6	676.4	678.2
360	680.0	681.8	683.6	685.4	687.2	689.0	690.8	692.6	694.4	696.2
370	698.0	699.8	701.6	703.4	705.2	707.0	708.8	710.6	712.4	714.2
380	716.0	717.8	719.6	721.4	723.2	725.0	726.8	728.6	730.4	732.2
390	734.0	735.8	737.6	739.4	741.2	743.0	744.8	746.6	748.4	750.2
400	752.0	753.8	755.6	757.4	759.2	761.0	762.8	764.6	766.4	768.2
410	770.0	771.8	773.6	775.4	777.2	779.0	780.8	782.6	784.4	786.2
420	788.0	789.8	791.6	793.4	795.2	797.0	798.8	800.6	802.4	804.2
430	806.0	807.8	809.6	811.4	813.2	815.0	816.8	818.6	820.4	822.2
440	824.0	825.8	827.6	829.4	831.2	833.0	834.8	836.6	838.4	840.2
450	842.0	843.8	845.6	847.4	849.2	851.0	852.8	854.6	856.4	858.2
460	860.0	861.8	863.6	865.4	867.2	869.0	870.8	872.6	874.4	876.2
470	878.0	879.8	881.6	883.4	885.2	887.0	888.8	890.6	892.4	894.2
480	896.0	897.8	899.6	901.4	903.2	905.0	906.8	908.6	910.4	912.2
490	914.0	915.8	917.6	919.4	921.2	923.0	924.8	926.6	928.4	930.2
500	932.0	933.8	935.6	937.4	939.2	941.0	942.8	944.6	946.4	948.2
510	950.0	951.8	953.6	955.4	957.2	959.0	960.8	962.6	964.4	966.2
520	968.0	969.8	971.6	973.4	975.2	977.0	978.8	980.6	982.4	984.2
530	986.0	987.8	989.6	991.4	993.2	995.0	996.8	998.6	1000.4	1002.2

Conversion formulae:

$^{o}C = 5/9(^{o}F-32)$

$^{o}F = 9/5\ ^{o}C + 32$

Appendix A-4

Energy Ratings of Fuels

FUEL	Btu	Per Unit
Coal:		
Anthracite	12,700	pound
Bituminous	13,100	pound
Coke	12,400	pound
Hydrogen (dry)	325	ft^3
	62,050	pound
Natural Gas (dry)	1,035	ft^3
	25,047	pound
Natural Gas Liquids (average)	21,325	pound
	4,412,000	barrel
Butane (C_4H_{10})	21,400	pound
	4,506,000	barrel
Propane (C_3H_8)	21,600	pound
	4,402,000	barrel
Petroleum:		
Crude Oil	5,800,000	barrel
	138,100	gallon
	18,100	pound
Gasoline	5,253,000	barrel
	125,000	gallon
	22,200	pound
Kerosene	5,670,000	barrel
	135,000	gallon
	19,700	pound

FUEL AND ENERGY EQUIVALENTS

1 bbl crude oil = 443 lb bituminous coal
= 5,604 ft^3 natural gas
= 1,700 kwh electricity

1 short ton bituminous coal = 4.52 bbl crude oil
= 25,300 ft^3 natural gas
= 7,679 kwh electricity

1000 ft^3 natural gas = 79.01 lb bituminous coal
= 74.95 gallons crude oil
= 303.34 kwh electricity

1000 kwh electricity = 1 Mwh electricity
= 260.5 lb bituminous coal
= 3,397 ft^3 natural gas
= 0.588 bbl crude oil

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Appendix A-5

Specific Heat and Heat Storage

Specific Heat of Materials

Element		*Specific heat, cal/g*	*Compound*		*Specific heat, cal/g*
Hydrogen	H_2	3.41	Water	H_2O	1.00
Helium	He	1.24	Lithium hydride	LiH	0.6
Lithium	Li	0.85	Lithium fluoride	LiF	0.37
Berillium	Be	0.436	Lithium chloride	LiCl	0.28
Sodium	Na	0.293	Sodium fluoride	NaF	0.28
Nitrogen	N_2	0.249	Sodium chloride	NaCl	0.22
Neon	Ne	0.246	Calcium fluoride	CaF_2	0.21
Boron	B	0.245	Potassium fluoride	KF	0.20
Magnesium	Mg	0.243	Sodium hydroxide	NaOH	0.2
Oxygen	O_2	0.219	Potassium hydroxide	KOH	0.2
Aluminum	Al	0.215	Magnesium chloride	$MgCl_2$	0.19
Fluorine	F_2	0.197	Calcium chloride	$CaCl_2$	0.16
Phosphorus	P	0.181	Potassium clhoride	KCl	0.16
Potassium	K	0.180	Iron chloride	$FeCl_3$	0.15
Sulfur	S	0.175	Zinc chloride	$ZnCl_2$	0.14
Silicon	Si	0.168	Copper chloride	$CuCl_2$	0.14

Heat Storage Capacity

	Density	*Specific heat*	*Volume heat capacity*	*Thermal conductivity*	*Thermal diffusivity*
	ρ	c	ρc	k	$k/\rho c$
Material	g/cm^3	$cal/g\,C^\circ$	$cal/cm^3 C^\circ$	$cal\,cm/cm^2 C^\circ sec$	cm^2/sec
Water	1.00	1.00	1.00	0.0014	0.0014
Iron shot	7.86	0.13	1.02	0.160	0.157
Oils	1.00	0.60	0.60	0.00036	0.0006
Rock	2.50	0.20	0.50	0.0060	0.0120
$MgCO_3$	3.0	0.20	0.60	0.0025	0.0042
$MgCO_3 \cdot 6H_2O$	1.7	0.38	0.65	0.0030	0.0046

Appendix A-6

Heat of Fusion of Materials

Heat of Fusion of Materials

Material		*Heat of fusion, cal/g*	*Melting temperature, °C*
Beryllium chloride	$BeCl_2$	310	547
Sodium fluoride	NaF	168	992
Lithium hydride	LiH	139	680
Nickel chloride	$NiCl_2$	139	1030
Sodium metaborate	$NaBO_2$	135	966
Beryllium fluoride	BeF_2	128	800
Sodium chloride	$NaCl$	123	803
Potassium fluoride	KF	117	860
Calcium silicate	$CaSiO_3$	115	1512
Magnesium chloride	$MgCl_2$	109	708
Lithium hydroxide	$LiOH$	103	462
Magnesium fluoride	MgF_2	95	1396
Lithium fluoride	LiF	93	896
Sodium silicate	$NaSiO_3$	84	1087
Iron chloride	$FeCl_2$	82	677
Potassium chloride	KCl	82	776
Lithium silicate	$LiSiO_3$	80	1201
Boric oxide	B_2O_3	76	449
Lithium chloride	$LiCl$	76	613
Manganese chloride	$MnCl_2$	71	708
Chromium chloride	$CrCl_2$	66	814
Aluminum chloride	Al_2Cl_6	63	190
Sodium bromide	$NaBr$	61	742
Potassium bromide	KBr	59	730
Sodium hydroxide	$NaOH$	38	318
Lithium bromide	$LiBr$	34	547
Potassium nitrate	KNO_3	28	337
Copper chloride	$CuCl$	25	430

APPENDIX B

Appendix B-1

Useful Solar Flux Quantities

Quantity	*kW/m²*	*MJ/m²h*	*Btu/ft²h*
Extraterrestrial solar flux (Solar Constant)	1.353	4.871	429.2
Desert sealevel, noon, direct (D)	0.97	3.49	308.
Desert sealevel, noon, direct + scattered (D+S)	1.05	3.78	334.
Standard sealevel, noon, (D)	0.93	3.35	295.
Standard sealevel, noon, (D+S)	1.03	3.71	327.
Urban, typical, noon, (D)	0.61	2.16	193.
Urban, typical, noon, (D+S)	0.81	2.92	257.
24h average, Desert, fully tracking, (D+S)	0.40	1.43	149.
24h average, Desert, fixed λ tilt, (D+S)	0.24	0.87	76.

Ratio, noon/24h average, Desert, fully tracking, (D)	2.66
Ratio, noon/24h average, Desert, fully tracking, (D+S)	2.57
Ratio, noon/24h average, Desert, fixed λ tilt, (D)	4.30
Ratio, noon/24h average, Desert, fixed λ tilt, (D+S)	4.20
Ratio, extraterrestrial/24h average, Desert, FT, (D+S)	3.40
Ratio, extraterrestrial/24h average, Desert, Fλ, (D+S)	5.65

Appendix B-2

Normal Monthly Average Temperature of Selected Cities

(In Fahrenheit degrees. Airport data unless otherwise noted. Based on standard 30-year period, 1931 to 1960.)

	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
AL	Mobile	53.0	55.2	60.3	67.6	75.6	81.5	82.6	82.1	77.9	69.9	58.9	54.1	68.2
AK	Juneau	25.1	26.8	30.4	38.0	45.6	52.3	55.3	54.1	48.9	41.6	34.3	28.4	40.1
AZ	Phoenix	49.7	53.5	59.0	67.2	75.0	83.6	89.8	87.5	82.8	70.7	58.1	51.6	69.0
AR	Little Rock	40.6	44.4	51.8	62.4	70.5	78.9	81.9	81.3	74.3	63.1	49.5	41.9	61.7
CA	Los Angeles	54.4	55.2	57.0	59.4	62.0	64.8	69.1	69.1	68.5	64.9	61.1	56.9	61.9
	Sacramento	45.2	49.2	53.4	58.4	64.0	70.5	75.4	74.1	71.6	63.5	52.9	46.4	60.4
	San Francisco†	50.7	53.0	54.7	55.7	57.4	59.1	58.8	59.4	62.0	61.4	57.4	52.5	56.8
CO	Denver	28.5	31.5	36.4	46.4	56.2	66.5	72.9	71.5	61.0	51.4	37.7	31.6	49.5
CT	Hartford	26.0	27.1	36.0	48.5	59.9	68.7	73.4	71.2	63.1	53.0	41.3	28.9	49.8
DE	Wilmington	33.4	33.8	41.3	52.1	62.7	71.4	76.0	74.3	67.6	56.6	45.4	35.1	54.1
DC	Washington	36.9	37.8	44.8	55.7	65.8	74.2	78.2	76.5	69.7	59.0	47.7	38.1	57.0
FL	Jacksonville	55.9	57.5	62.2	68.7	75.8	80.8	82.6	82.3	79.4	71.0	61.7	56.1	69.5
	Miami	66.9	67.9	70.5	74.2	77.6	80.8	81.8	82.3	81.3	77.8	72.4	68.1	75.1
GA	Atlanta	44.7	46.1	51.4	60.2	69.1	76.6	78.9	78.2	73.1	62.4	51.2	44.8	61.4
HI	Honolulu	72.5	72.4	72.8	74.2	75.9	77.9	78.8	79.4	79.2	78.2	75.9	73.6	75.9
ID	Boise	29.1	34.5	41.7	50.4	58.2	65.8	75.2	72.1	62.7	51.6	38.6	32.2	51.0
IL	Chicago	26.0	27.7	36.3	49.0	60.0	70.5	75.6	74.2	66.1	55.1	39.9	29.1	50.8
	Peoria	25.7	28.4	37.6	50.8	61.5	71.7	76.0	74.3	66.4	55.3	39.7	29.1	51.4
IN	Indianapolis	29.1	31.1	38.9	50.8	61.4	71.1	75.2	73.7	66.5	55.4	40.9	31.1	52.1
IA	Des Moines	19.9	23.4	33.8	48.7	60.6	71.0	76.3	74.1	65.4	54.2	37.1	25.3	49.2
KS	Wichita	32.0	36.3	44.5	56.7	66.0	76.5	80.9	80.8	71.3	59.9	44.4	35.8	57.1
KY	Louisville	35.0	35.8	43.3	54.8	64.4	73.4	77.6	76.2	69.5	57.9	44.7	36.3	55.7
LA	New Orleans	54.6	57.1	61.4	67.9	74.4	80.1	81.6	81.9	78.1	70.4	60.0	55.4	68.6
ME	Portland	21.8	22.8	31.4	42.5	53.0	62.1	68.1	66.8	58.7	48.6	38.1	25.8	45.0
MD	Baltimore	34.8	35.7	43.1	54.2	64.4	72.5	76.8	75.0	68.1	57.0	45.5	35.8	55.2
MA	Boston	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55.0	44.9	33.3	51.4
MI	Detroit	26.9	27.2	34.8	47.6	59.0	69.7	74.4	72.8	65.1	53.8	40.4	29.9	50.1
	Sault Ste. Marie	15.8	15.7	23.8	38.0	49.6	59.0	64.6	64.0	55.8	46.1	33.3	20.9	40.6
MN	Duluth	8.7	10.8	21.3	37.0	49.2	58.8	65.5	63.8	54.2	44.6	27.3	14.0	37.9
	Minneapolis-St Paul	12.4	15.7	27.4	44.3	57.3	66.8	72.3	70.0	60.4	48.9	31.2	18.1	43.7
MS	Jackson	47.9	50.5	56.5	64.9	73.1	79.8	82.1	82.0	76.5	67.0	55.5	49.4	65.5
MO	Kansas City	31.7	35.8	43.1	55.7	65.6	75.9	81.5	79.8	71.3	60.2	44.6	35.8	56.8
	St. Louis	31.9	34.7	42.6	54.9	64.2	74.1	78.1	76.8	69.5	58.4	44.1	34.8	55.3
MT	Great Falls	22.1	23.8	30.7	43.6	53.0	59.9	69.4	66.8	57.4	47.5	34.3	27.3	44.7
NE	Omaha	22.3	26.5	36.9	51.7	63.0	74.1	78.5	76.2	66.9	55.7	38.9	28.2	51.5
NV	Reno	30.4	35.6	41.5	48.0	53.9	60.1	67.7	65.5	58.8	49.2	38.1	31.9	48.4
NH	Concord	21.2	22.7	31.7	43.8	55.5	64.5	69.6	67.4	59.3	48.7	37.6	25.0	45.6
NJ	Atlanta City	44.8	34.7	41.1	51.0	61.3	70.0	75.1	73.7	67.2	57.2	46.7	36.6	54.1
NM	Albuquerque	35.0	39.9	45.8	55.7	65.1	74.9	78.5	76.2	70.0	58.0	43.6	37.0	56.6
NY	Albany	22.7	23.7	33.0	46.2	57.9	67.3	72.1	70.0	61.6	50.8	39.1	26.5	47.6
	Buffalo	24.5	24.1	31.5	43.5	54.8	64.8	69.8	68.4	61.4	50.8	39.1	27.7	46.7
	New York†	32.2	33.4	40.5	51.4	62.4	71.4	76.8	75.1	68.5	58.3	47.0	35.9	54.5
NC	Charlotte	42.7	44.2	50.0	60.3	69.0	77.1	79.2	78.7	72.9	62.5	50.4	42.7	60.8
	Raleigh	41.6	43.0	49.5	59.3	67.6	75.1	77.9	76.9	71.2	60.5	50.0	41.9	59.5
ND	Bismarck	9.9	13.5	26.2	41.5	55.9	64.5	71.7	69.3	58.7	46.7	28.9	17.8	42.2
OH	Cincinnati†	33.7	35.1	42.7	54.2	64.2	73.4	76.9	75.7	69.0	57.9	44.6	35.1	55.2
	Cleveland	28.4	28.5	35.1	47.0	58.0	67.8	71.9	70.4	64.2	53.4	41.3	30.5	49.7
	Columbus	29.9	31.1	38.9	50.8	61.5	70.8	74.8	73.2	65.9	54.2	41.2	31.5	52.0
OK	Oklahoma City	37.0	41.3	48.5	59.9	68.4	78.0	82.5	82.8	73.8	62.9	48.4	40.3	60.3
OR	Portland	38.4	42.0	46.1	51.8	57.4	62.0	67.2	66.6	62.7	54.2	45.1	41.1	52.9
PA	Philadelphia	32.3	33.2	41.0	52.0	62.6	71.0	75.6	73.6	66.7	55.7	44.3	33.9	53.5
	Pittsburgh	28.9	29.2	36.8	49.0	59.8	68.4	72.1	70.8	64.2	53.1	40.8	30.7	50.3
RI	Providence	29.2	29.7	37.0	47.2	57.5	66.2	72.1	70.5	63.2	53.2	43.0	32.0	50.1
SC	Columbia	46.9	48.4	54.4	63.6	72.2	79.7	81.6	80.5	75.3	64.7	53.7	46.4	64.0
SD	Sioux Falls	15.2	19.1	30.1	45.9	58.3	68.1	74.3	71.8	61.8	50.3	32.6	21.1	45.7
TN	Memphis	41.5	44.1	51.1	61.4	70.3	78.5	81.3	80.5	73.9	63.1	50.1	42.5	61.5
	Nashville	39.9	42.0	49.1	59.6	68.6	77.4	80.2	79.2	72.8	61.5	48.5	41.4	60.0
TX	Dallas	45.9	49.5	56.1	65.0	72.9	81.3	84.9	85.0	77.9	67.8	54.9	48.1	65.8
	El Paso	42.9	49.1	54.9	63.4	71.9	81.0	81.9	80.4	74.5	64.4	51.2	44.1	63.3
	Houston	53.6	55.8	61.3	68.5	76.0	81.6	83.0	83.2	79.2	71.4	60.8	55.7	69.2
UT	Salt Lake City	27.2	32.5	40.4	49.9	58.9	67.4	76.9	74.5	64.4	51.7	36.7	30.1	50.9
VT	Burlington	16.2	17.4	26.7	41.2	51.8	64.2	69.0	66.7	58.4	47.6	35.3	21.5	41.2
VA	Norfolk	41.2	41.6	48.0	58.0	[illegible]	75.6	78.8	77.5	[illegible]	62.0	51.4	42.5	59.7
	Richmond	38.7	39.9	47.7	58.1	67.0	75.1	78.1	76.0	70.2	58.7	48.5	39.3	58.1
WA	Seattle Tacoma	38.3	40.8	43.8	49.2	55.5	59.8	64.9	64.1	59.9	52.4	43.9	40.8	51.1
	Spokane	25.5	30.0	38.1	47.3	56.2	61.9	70.5	68.0	60.9	49.1	[illegible]	30.1	47.8
WV	Charleston	36.6	37.5	44.4	55.3	64.8	72.0	74.9	73.8	68.2	57.3	45.3	37.1	55.6
WI	Milwaukee	20.6	22.4	31.0	43.6	53.4	63.3	68.7	67.8	60.3	50.0	35.8	24.6	45.1
WY	Cheyenne	25.4	27.3	32.4	42.6	52.9	63.0	70.0	67.7	58.6	47.5	34.2	29.5	45.9
PR	San Juan	74.4	74.4	75.3	76.6	78.7	80.0	80.4	80.9	80.5	80.0	78.2	76.2	78.0

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*From U.S. Department of Commerce, NOAA, "Local Climatological Data." For more detailed data see U.S. Department of Commerce, NOAA, NCC. "Climatography of the United States," Publ. No. 84

†City office data.

Appendix B-3

Normal Total Heating Degree-Days

	Location	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Ann
AL	Birmingham	0	0	6	93	363	555	592	462	363	108	9	0	2,551
	Huntsville	0	0	12	127	426	663	694	557	434	138	19	0	3,070
	Mobile	0	0	0	22	213	357	415	300	211	42	0	0	1,560
	Montgomery	0	0	0	68	330	527	543	417	316	90	0	0	2,291
AK	Anchorage	245	291	516	930	1,284	1,572	1,631	1,316	1,293	879	592	315	10,864
	Annette	242	208	327	567	738	899	949	837	843	648	490	321	7,069
	Barrow	803	840	1,035	1,500	1,971	2,362	2,517	2,332	2,468	1,944	1,445	957	20,174
	Barter Is.	735	775	987	1,482	1,944	2,337	2,536	2,369	2,477	1,923	1,373	924	19,862
	Bethel	319	394	612	1,042	1,434	1,866	1,903	1,590	1,655	1,173	806	402	13,196
	Cold Bay	474	425	525	772	918	1,122	1,153	1,036	1,122	951	791	591	9,880
	Cordova	366	391	522	781	1,017	1,221	1,299	1,086	1,113	864	660	444	9,764
	Fairbanks	171	332	642	1,203	1,833	2,254	2,359	1,901	1,739	1,068	555	222	14,279
	Juneau	301	338	483	725	921	1,135	1,237	1,070	1,073	810	601	381	9,075
	King Salmon	313	322	513	908	1,290	1,606	1,600	1,333	1,411	966	673	408	11,343
	Kotzebue	381	446	723	1,249	1,728	2,127	2,192	1,932	2,080	1,554	1,057	636	16,105
	McGrath	208	338	633	1,184	1,791	2,232	2,294	1,817	1,758	1,122	648	258	14,283
	Nome	481	496	693	1,094	1,455	1,820	1,879	1,666	1,770	1,314	930	573	14,171
	St. Paul	605	539	612	862	963	1,197	1,228	1,168	1,265	1,098	936	726	11,199
	Shemya	577	475	501	784	876	1,042	1,045	958	1,011	885	837	696	9,687
	Yakutat	338	347	474	716	936	1,144	1,169	1,019	1,042	840	632	435	9,092
AZ	Flagstaff	46	68	201	558	867	1,073	1,169	991	911	651	437	180	7,152
	Phoenix	0	0	0	22	234	415	474	328	217	75	0	0	1,765
	Prescott	0	0	27	245	579	797	865	711	605	360	158	15	4,362
	Tucson	0	0	0	25	231	406	471	344	242	75	6	0	1,800
	Winslow	0	0	6	245	711	1,008	1,054	770	601	291	96	0	4,782
	Yuma	0	0	0	0	148	319	363	228	130	29	0	0	1,217
AR	Ft. Smith	0	0	12	127	450	704	781	596	456	144	22	0	3,292
	Little Rock	0	0	9	127	465	716	756	577	434	126	9	0	3,219
	Texarkana	0	0	0	78	345	561	626	468	350	105	0	0	2,533
CA	Bakersfield	0	0	0	37	282	502	546	364	267	105	19	0	2,122
	Bishop	0	0	42	248	576	797	874	666	519	306	143	36	4,227
	Blue Canyon	34	50	120	347	579	766	865	781	791	582	397	195	5,507
	Burbank	0	0	6	43	177	301	366	277	239	138	81	18	1,646
	Eureka	270	257	258	329	414	499	546	470	505	438	372	285	4,643
	Fresno	0	0	0	78	339	558	586	406	319	150	56	0	2,492
	Long Beach	0	0	12	40	156	288	375	297	267	168	90	18	1,711
	Los Angeles	28	22	42	78	180	291	372	302	288	219	158	81	2,061
	Mt. Shasta	25	34	123	406	696	902	983	784	738	525	347	159	5,722
	Oakland	53	50	45	127	309	481	527	400	353	255	180	90	2,870
	Pt. Arguello	202	186	162	205	291	400	474	392	403	339	298	243	3,595
	Red Bluff	0	0	0	53	318	555	605	428	341	168	47	0	2,515
	Sacramento	0	0	12	81	363	577	614	442	360	216	102	6	2,773
	Sandberg	0	0	30	202	480	691	778	661	620	426	264	57	4,209
	San Diego	6	0	15	37	123	251	313	249	202	123	84	36	1,439
	San Francisco	81	78	60	143	306	462	508	395	363	279	214	126	3,015
	Santa Catalina	16	0	9	50	165	279	353	308	326	249	192	105	2,052
	Santa Maria	99	93	96	146	270	391	459	370	363	282	233	165	2,967
CO	Alamosa	65	99	279	639	1,065	1,420	1,476	1,162	1,020	696	440	168	8,529
	Colorado Springs	9	25	132	456	825	1,032	1,128	938	893	582	319	84	6,423
	Denver	6	9	117	428	819	1,035	1,132	938	887	558	288	66	6,283
	Grand Junction	0	0	30	313	786	1,113	1,209	907	729	387	146	21	5,641
	Pueblo	0	0	54	326	750	986	1,085	871	772	429	174	15	5,462
CT	Bridgeport	0	0	66	307	615	986	1,079	966	853	510	208	27	5,617
	Hartford	0	6	99	372	711	1,119	1,209	1,061	899	495	177	24	6,172
	New Haven	0	12	87	347	648	1,011	1,097	991	871	543	245	45	5,897
DE	Wilmington	0	0	51	270	588	927	980	874	735	387	112	6	4,930
FL	Apalachicola	0	0	0	16	153	319	347	260	180	33	0	0	1,308
	Daytona Beach	0	0	0	0	75	211	248	190	140	15	0	0	879
	Ft. Myers	0	0	0	0	24	109	146	101	62	0	0	0	442
	Jacksonville	0	0	0	12	144	310	332	246	174	21	0	0	1,239
	Key West	0	0	0	0	0	28	40	31	9	0	0	0	108
	Lakeland	0	0	0	0	57	164	195	146	99	0	0	0	661
	Miami Beach	0	0	0	0	0	40	56	36	9	0	0	0	141
	Orlando	0	0	0	0	72	198	220	165	105	6	0	0	766
	Pensacola	0	0	0	19	195	353	400	277	183	36	0	0	1,463
	Tallahassee	0	0	0	28	198	360	375	286	202	36	0	0	1,485
	Tampa	0	0	0	0	60	171	202	148	102	0	0	0	681
	W. Palm Beach	0	0	0	0	6	65	87	64	31	0	0	0	253
GA	Athens	0	0	12	115	405	632	642	529	431	141	22	0	2,929
	Atlanta	0	0	18	127	414	626	619	529	437	168	25	0	2,983
	Augusta	0	0	0	78	333	552	549	445	350	90	0	0	2,397
	Columbus	0	0	0	87	333	543	552	434	338	96	0	0	2,383
	Macon	0	0	0	71	297	502	505	403	295	63	0	0	2,136

"Climatic Atlas of the United States," U.S. Government Printing Office, 1968.

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	Location	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Ann
GA	Rome	0	0	24	161	474	701	710	577	468	177	34	0	3,326
	Savannah	0	0	0	47	246	437	437	353	254	45	0	0	1,819
	Thomasville	0	0	0	25	198	366	394	305	208	33	0	0	1,529
ID	Boise	0	0	132	415	792	1,017	1,113	854	722	438	245	81	5,809
	Idaho Falls 46W	16	34	270	623	1,056	1,370	1,538	1,249	1,085	651	391	192	8,475
	Idaho Falls 42NW	16	40	282	648	1,107	1,432	1,600	1,291	1,107	657	388	192	8,760
	Lewiston	0	0	123	403	756	933	1,063	815	694	426	239	90	5,542
	Pocatello	0	0	172	493	900	1,166	1,324	1,058	905	555	319	141	7,033
IL	Cairo	0	0	36	164	513	791	856	680	539	195	47	0	3,821
	Chicago	0	0	81	326	753	1,113	1,209	1,044	890	480	211	48	6,155
	Moline	0	9	99	335	774	1,181	1,314	1,100	918	450	189	39	6,408
	Peoria	0	8	87	326	759	1,113	1,218	1,025	849	426	183	33	6,025
	Rockford	6	9	114	400	837	1,221	1,333	1,137	961	516	236	60	6,830
	Springfield	0	0	72	291	696	1,023	1,135	935	769	354	136	18	5,429
IN	Evansville	0	0	66	220	606	896	955	767	620	237	68	0	4,435
	Ft Wayne	0	9	105	378	783	1,135	1,178	1,028	890	471	189	39	6,205
	Indianapolis	0	0	90	316	723	1,051	1,113	949	809	432	177	39	5,699
	South Bend	0	6	111	372	777	1,125	1,221	1,070	933	525	239	60	6,439
IA	Burlington	0	0	93	322	768	1,135	1,259	1,042	859	426	177	33	6,114
	Des Moines	0	9	99	363	837	1,231	1,398	1,165	967	489	211	39	6,808
	Dubuque	12	31	156	450	906	1,287	1,420	1,204	1,026	546	260	78	7,376
	Sioux City	0	9	108	369	867	1,240	1,435	1,198	989	483	214	39	6,951
	Waterloo	12	19	138	428	909	1,296	1,460	1,221	1,023	531	229	54	7,320
KS	Concordia	0	0	57	276	705	1,023	1,163	935	781	372	149	18	5,479
	Dodge City	0	0	33	251	666	939	1,051	840	719	354	124	9	4,986
	Goodland	0	6	81	381	810	1,073	1,166	955	884	507	236	42	6,141
	Topeka	0	0	57	270	672	980	1,122	893	722	330	124	12	5,182
	Wichita	0	0	33	229	618	905	1,023	804	645	270	87	6	4,620
KY	Covington	0	0	75	291	669	983	1,035	893	756	390	149	24	5,265
	Lexington	0	0	54	239	609	902	946	818	685	325	105	0	4,683
	Louisville	0	0	54	248	609	890	930	818	682	315	105	9	4,660
LA	Alexandria	0	0	0	56	273	431	471	361	260	69	0	0	1,921
	Baton Rouge	0	0	0	31	216	369	409	294	208	33	0	0	1,560
	Burrwood	0	0	0	0	96	214	298	218	171	27	0	0	1,024
	Lake Charles	0	0	0	19	210	341	381	274	195	39	0	0	1,459
	New Orleans	0	0	0	19	192	322	363	258	192	39	0	0	1,385
	Shreveport	0	0	0	47	297	477	552	426	304	81	0	0	2,184
ME	Caribou	78	115	336	682	1,044	1,535	1,690	1,470	1,308	858	468	183	9,767
	Portland	12	53	195	508	807	1,215	1,339	1,182	1,042	675	372	111	7,511
MD	Baltimore	0	0	48	264	585	905	936	820	679	327	90	0	4,654
	Frederick	0	0	66	307	624	955	995	876	741	384	127	12	5,087
MA	Blue Hill Obsy	0	22	108	381	690	1,085	1,178	1,053	936	579	267	69	6,368
	Boston	0	9	60	316	603	983	1,088	972	846	513	208	36	5,634
	Nantucket	12	22	93	332	573	896	992	941	896	621	384	129	5,891
	Pittsfield	25	59	219	524	831	1,231	1,339	1,196	1,063	660	326	105	7,578
	Worcester	6	34	147	450	774	1,172	1,271	1,123	998	612	304	78	6,969
MI	Alpena	68	105	273	580	912	1,268	1,404	1,299	1,218	777	446	156	8,506
	Detroit (City)	0	0	87	360	738	1,088	1,181	1,058	936	522	220	42	6,232
	Escanaba	59	87	243	539	924	1,293	1,445	1,296	1,203	777	456	159	8,481
	Flint	16	40	159	465	843	1,212	1,330	1,198	1,066	639	319	90	7,377
	Grand Rapids	9	28	135	434	804	1,147	1,259	1,134	1,011	579	279	75	6,894
	Lansing	6	22	138	431	813	1,163	1,262	1,142	1,011	579	273	69	6,909
	Marquette	59	81	240	527	936	1,268	1,411	1,268	1,187	771	468	177	8,393
	Muskegon	12	28	120	400	762	1,088	1,209	1,100	995	594	310	78	6,696
	Sault Ste. Marie	96	105	279	580	951	1,367	1,525	1,380	1,277	810	477	201	9,048
MN	Duluth	71	109	330	632	1,131	1,581	1,745	1,518	1,355	840	490	198	10,000
	International Falls	71	112	363	701	1,236	1,724	1,919	1,621	1,414	828	443	174	10,606
	Minneapolis	22	31	189	505	1,014	1,454	1,631	1,380	1,166	621	288	81	8,382
	Rochester	25	34	186	474	1,005	1,438	1,593	1,366	1,150	630	301	93	8,295
	St. Cloud	28	47	225	549	1,065	1,500	1,702	1,445	1,221	666	326	105	8,879
MS	Jackson	0	0	0	65	315	502	546	414	310	87	0	0	2,239
	Meridian	0	0	0	81	339	518	543	417	310	81	0	0	2,289
	Vicksburg	0	0	0	53	279	462	512	384	282	69	0	0	2,041
MO	Columbia	0	0	54	251	651	967	1,076	874	716	324	121	12	5,046
	Kansas	0	0	39	220	612	905	1,032	818	682	294	109	0	4,711
	St. Joseph	0	6	60	285	708	1,039	1,172	949	769	348	133	15	5,484
	St. Louis	0	0	60	251	627	936	1,026	848	704	312	121	15	4,900
	Springfield	0	0	45	225	600	877	973	781	660	291	105	6	4,561
MT	Billings	6	15	186	487	897	1,135	1,296	1,100	970	570	285	102	7,049
	Glasgow	31	47	270	608	1,104	1,466	1,711	1,439	1,187	648	335	150	8,996
	Great Falls	28	53	258	543	921	1,169	1,349	1,154	1,063	642	384	186	7,750
	Havre	28	53	306	595	1,065	1,367	1,584	1,364	1,181	657	338	162	8,700
	Helena	31	59	294	601	1,002	1,265	1,438	1,170	1,042	651	381	195	8,129
	Kalispell	50	99	321	654	1,020	1,240	1,401	1,134	1,029	639	397	207	8,191
	Miles City	6	6	174	502	972	1,296	1,504	1,252	1,057	579	276	99	7,723
	Missoula	34	74	303	651	1,035	1,287	1,420	1,120	970	621	391	219	8,125

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Location		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Ann
NE	Grand Island	0	6	108	381	834	1,172	1,314	1,089	908	462	211	45	6,530
	Lincoln	0	6	75	301	726	1,066	1,237	1,016	834	402	171	30	5,864
	Norfolk	9	0	111	397	873	1,234	1,414	1,179	983	498	233	48	6,979
	North Platte	0	6	123	440	885	1,166	1,271	1,039	930	519	248	57	6,684
	Omaha	0	12	105	357	828	1,175	1,355	1,126	939	465	208	42	6,612
	Scottsbluff	0	0	138	459	876	1,128	1,231	1,008	921	552	285	75	6,673
	Valentine	9	12	165	493	942	1,237	1,395	1,176	1,045	579	288	84	7,425
NV	Elko	9	14	225	561	924	1,197	1,314	1,016	911	621	409	192	7,433
	Ely	28	43	234	592	939	1,184	1,308	1,075	977	672	456	225	7,733
	Las Vegas	0	0	0	78	387	617	688	487	335	111	6	0	2,709
	Reno	43	87	204	490	801	1,026	1,073	823	729	510	357	189	6,332
	Winnemucca	0	34	210	536	876	1,091	1,172	916	837	573	363	153	6,761
NH	Concord	6	50	177	505	822	1,240	1,358	1,184	1,032	636	298	75	7,383
	Mt. Wash. Obsy.	493	536	720	1,057	1,341	1,742	1,820	1,663	1,652	1,260	930	603	13,817
NJ	Atlantic City	0	0	39	251	549	880	936	848	741	420	133	15	4,812
	Newark	0	0	30	248	573	921	983	876	729	381	118	0	4,859
	Trenton	0	0	57	264	576	924	989	885	753	399	121	12	4,980
NM	Albuquerque	0	0	12	229	642	868	930	703	595	288	81	0	4,348
	Clayton	0	6	66	310	699	899	986	812	747	429	183	21	5,158
	Raton	9	28	126	431	825	1,048	1,116	904	834	543	301	63	6,228
	Roswell	0	0	18	202	573	806	840	641	481	201	31	0	3,793
	Silver City	0	0	6	183	525	729	791	605	518	261	87	0	3,705
NY	Albany	0	19	138	440	777	1,194	1,311	1,156	992	564	239	45	6,875
	Binghamton (AP)	22	65	201	471	810	1,184	1,277	1,154	1,045	645	313	99	7,286
	Binghamton (PO)	0	28	141	406	732	1,107	1,190	1,081	949	543	229	45	6,451
	Buffalo	19	37	141	440	777	1,156	1,256	1,145	1,039	645	329	78	7,062
	Central Park	0	0	30	233	540	902	986	885	760	408	118	9	4,871
	J F Kennedy Intl.	0	0	36	248	564	933	1,029	935	815	480	167	12	5,219
	Laguardia	0	0	27	223	528	887	973	879	750	414	124	6	4,811
	Rochester	9	31	126	415	747	1,125	1,234	1,123	1,014	597	279	48	6,748
	Schenectady	0	22	123	422	756	1,159	1,283	1,111	970	543	211	30	6,650
	Syracuse	6	28	132	415	744	1,153	1,271	1,140	1,004	570	248	45	6,756
NC	Asheville	0	0	48	245	555	775	784	683	592	273	87	0	4,042
	Cape Hatteras	0	0	0	78	273	521	580	518	440	177	25	0	2,612
	Charlotte	0	0	6	124	438	691	691	582	481	156	22	0	3,191
	Greensboro	0	0	33	192	513	778	784	672	552	234	47	0	3,805
	Raleigh	0	0	21	164	450	716	725	616	487	180	34	0	3,393
	Wilmington	0	0	0	74	291	521	546	462	357	96	0	0	2,347
	Winston Salem	0	0	21	171	483	747	753	652	524	207	37	0	3,595
ND	Bismarck	34	28	222	577	1,083	1,463	1,708	1,442	1,203	645	329	117	8,851
	Devils Lake	40	53	273	642	1,191	1,634	1,872	1,579	1,345	753	381	138	9,901
	Fargo	28	37	219	574	1,107	1,569	1,789	1,520	1,262	690	332	99	9,226
	Williston	31	43	261	601	1,122	1,513	1,758	1,473	1,262	681	357	141	9,243
OH	Akron	0	9	96	381	726	1,070	1,138	1,016	871	489	202	39	6,037
	Cincinnati	0	0	54	248	612	921	970	837	701	336	118	9	4,806
	Cleveland	9	25	105	384	738	1,088	1,159	1,047	918	552	260	66	6,351
	Columbus	0	6	84	347	714	1,039	1,088	949	809	426	171	27	5,660
	Dayton	0	6	78	310	696	1,045	1,097	955	809	429	167	30	5,622
	Mansfield	9	22	114	397	768	1,110	1,169	1,042	924	543	245	60	6,403
	Sandusky	0	6	66	313	684	1,032	1,107	991	868	495	198	36	5,796
	Toledo	0	16	117	406	792	1,138	1,200	1,056	924	543	242	60	6,494
	Youngstown	6	19	120	412	771	1,104	1,169	1,047	921	540	248	60	6,417
OK	Oklahoma City	0	0	15	164	498	766	868	664	527	189	34	0	3,725
	Tulsa	0	0	18	158	522	787	893	683	539	213	47	0	3,860
OR	Astoria	146	130	210	375	561	679	753	622	636	480	363	231	5,186
	Burns	12	37	210	515	867	1,113	1,246	988	856	570	366	177	6,957
	Eugene	34	34	129	366	585	719	803	627	589	426	279	135	4,726
	Meacham	84	124	288	580	918	1,091	1,209	1,005	983	726	527	339	7,874
	Medford	0	0	78	372	678	871	918	697	642	432	242	78	5,008
	Pendleton	0	0	111	350	711	884	1,017	773	617	396	205	63	5,127
	Portland	25	28	114	335	597	735	825	644	586	396	245	105	4,635
	Roseburg	22	16	105	329	567	713	766	608	570	405	267	123	4,491
	Salem	37	31	111	338	594	729	822	647	611	417	273	144	4,754
	Sexton Summit	81	81	171	443	666	874	958	809	818	609	465	279	6,254
PA	Allentown	0	0	90	353	693	1,045	1,116	1,002	849	471	167	24	5,810
	Erie	0	25	102	391	714	1,063	1,169	1,081	973	585	288	60	6,451
	Harrisburg	0	0	63	298	648	992	1,045	907	766	396	124	12	5,251
	Philadelphia	0	0	60	291	621	964	1,014	890	744	390	115	12	5,101
	Pittsburgh	0	9	105	375	726	1,063	1,119	1,002	874	480	195	39	5,987
	Reading	0	0	54	257	597	939	1,001	885	735	372	105	0	4,945
	Scranton	0	19	132	434	762	1,104	1,156	1,028	893	498	195	33	6,254
	Williamsport	0	9	111	375	717	1,073	1,122	1,002	856	468	177	24	5,934
RI	Block Is.	0	16	78	307	594	902	1,020	955	877	612	344	99	5,804
	Providence	0	16	96	372	660	1,023	1,110	988	868	534	236	51	5,954
SC	Charleston	0	0	0	59	282	471	487	389	291	54	0	0	2,033
	Columbia	0	0	0	84	345	577	570	470	357	81	0	0	2,484

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	Location	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Ann
SC	Florence	0	0	0	78	315	552	552	459	347	84	0	0	2,387
	Greenville	0	0	0	112	387	636	648	535	434	120	12	0	2,884
	Spartanburg	0	0	15	130	417	667	663	560	453	144	25	0	3,074
SD	Huron	9	12	165	508	1,014	1,432	1,628	1,355	1,125	600	288	87	8,223
	Rapid City	22	12	165	481	897	1,172	1,333	1,145	1,051	615	326	126	7,345
	Sioux Falls	19	25	168	462	972	1,361	1,544	1,285	1,082	573	270	78	7,839
TN	Bristol	0	0	51	236	573	828	828	700	598	261	68	0	4,143
	Chattanooga	0	0	18	143	468	698	722	577	453	150	25	0	3,254
	Knoxville	0	0	30	171	489	725	732	613	493	198	43	0	3,494
	Memphis	0	0	18	130	447	698	729	585	456	147	22	0	3,232
	Nashville	0	0	30	158	495	732	778	644	512	189	40	0	3,578
	Oak Ridge (CO)	0	0	39	192	531	772	778	669	552	228	56	0	3,817
TX	Abilene	0	0	0	99	366	586	642	470	347	114	0	0	2,624
	Amarillo	0	0	18	205	570	797	877	664	546	252	56	0	3,985
	Austin	0	0	0	31	225	388	468	325	223	51	0	0	1,711
	Brownsville	0	0	0	0	66	149	205	106	74	0	0	0	600
	Corpus Christi	0	0	0	0	120	220	291	174	109	0	0	0	914
	Dallas	0	0	0	62	321	524	601	440	319	90	6	0	2,363
	El Paso	0	0	0	84	414	648	685	445	319	105	0	0	2,700
	Ft. Worth	0	0	0	65	324	536	614	448	319	99	0	0	2,405
	Galveston	0	0	0	0	138	270	350	258	189	30	0	0	1,235
	Houston	0	0	0	6	183	307	384	288	192	36	0	0	1,396
	Laredo	0	0	0	0	105	217	267	134	74	0	0	0	797
	Lubbock	0	0	18	174	513	744	800	613	484	201	31	0	3,578
	Midland	0	0	0	87	381	592	651	468	322	90	0	0	2,591
	Port Arthur	0	0	0	22	207	329	384	274	192	39	0	0	1,447
	San Angelo	0	0	0	68	318	536	567	412	288	66	0	0	2,255
	San Antonio	0	0	0	31	207	363	428	286	195	39	0	0	1,549
	Victoria	0	0	0	6	150	270	344	230	152	21	0	0	1,173
TX	Waco	0	0	0	43	270	456	536	389	270	66	0	0	2,030
	Wichita Falls	0	0	0	99	381	632	698	518	378	120	6	0	2,832
UT	Milford	0	0	99	443	867	1,141	1,252	988	822	519	279	87	6,497
	Salt Lake City	0	0	81	419	849	1,082	1,172	910	763	459	233	84	6,052
	Wendover	0	0	48	372	822	1,091	1,178	902	729	408	177	51	5,778
VT	Burlington	28	65	207	539	891	1,349	1,513	1,333	1,187	714	353	90	8,269
VA	Cape Henry	0	0	0	112	360	645	694	633	536	246	53	0	3,279
	Lynchburg	0	0	51	223	540	822	849	731	605	267	78	0	4,166
	Norfolk	0	0	0	136	408	698	738	655	533	216	37	0	3,421
	Richmond	0	0	36	214	495	784	815	703	546	219	53	0	3,865
	Roanoke	0	0	51	229	549	825	834	722	614	261	65	0	4,150
	Wash Nat'l. Ap	0	0	33	217	519	834	871	762	626	288	74	0	4,224
WA	Olympia	68	71	198	422	636	753	834	675	645	450	307	177	5,236
	Seattle	50	47	129	329	543	657	738	599	577	396	242	117	4,424
	Seattle Boeing	34	40	147	384	624	763	831	655	608	411	242	99	4,838
	Seattle Tacoma	56	62	162	391	633	750	828	678	657	474	295	159	5,145
	Spokane	9	25	168	493	879	1,082	1,231	980	834	531	288	135	6,655
	Stampede Pass	273	291	393	701	1,008	1,178	1,287	1,075	1,085	855	654	483	9,281
	Tatoosh Is.	295	279	306	406	534	639	713	613	645	525	431	333	5,719
	Walla Walla	0	0	87	310	681	843	986	745	589	342	177	45	4,805
	Yakima	0	12	144	450	828	1,039	1,163	868	713	435	220	69	5,941
WV	Charleston	0	0	63	254	591	865	880	770	648	300	96	9	4,476
	Elkins	9	25	135	400	729	992	1,008	896	791	444	198	48	5,675
	Huntington	0	0	63	257	585	856	880	764	636	294	99	12	4,446
	Parkersburg	0	0	60	264	606	905	942	826	691	339	115	6	4,754
WI	Green Bay	28	50	174	484	924	1,333	1,494	1,313	1,141	654	335	99	8,029
	La Crosse	12	19	153	437	924	1,339	1,504	1,277	1,070	540	245	69	7,589
	Madison	25	40	174	474	930	1,330	1,473	1,274	1,113	618	310	102	7,863
	Milwaukee	43	47	174	471	876	1,252	1,376	1,193	1,054	642	372	135	7,635
WY	Casper	6	16	192	524	942	1,169	1,290	1,084	1,020	657	381	129	7,410
	Cheyenne	19	31	210	543	924	1,101	1,228	1,056	1,011	672	381	102	7,278
	Lander	6	19	204	555	1,020	1,299	1,417	1,145	1,017	654	381	153	7,870
	Sheridan	25	31	219	539	948	1,200	1,355	1,154	1,054	642	366	150	7,683

One of the most practical of weather statistics is the "heating degree-day." First devised some 60 years ago, the degree-day system has been in quite general use by the heating industry for more than 40 years.

Heating degree-days are the number of degrees the daily average temperature is below 65°F. Normally heating is not required in a building when the outdoor average daily temperature is 65°F. Heating degree-days are determined by subtracting the average daily temperatures below 65°F from the base, 65°F. A day with an average temperature of 50°F has 15 heating degree-days (65 − 50 = 15) while one with an average temperature of 65°F or higher has none.

Several characteristics make the degree-day figures especially useful. They are cumulative so that the degree-day sum for a period of days represents the total heating load for that period. The relationship between degree days and fuel consumption is linear, i.e., doubling the degree-days usually doubles the fuel consumption. Comparing normal seasonal degree-days in different locations gives a rough estimate of seasonal fuel consumption. For example, it would require roughly 4½ times as much fuel to heat a building in Chicago, Ill., where the mean annual total heating degree-days are about 6,200 than to heat a similar building in New Orleans, La., where the annual total heating degree-days are around 1,400. Using degree-days has the advantage that the consumption ratios are fairly constant, i.e., the fuel consumed per 100 degree-days is about the same whether the 100 degree-days occur in only 3 or 4 days or are spread over 7 or 8 days.

Appendix B-4

Mean Daily Solar Radiation (Langleys*)

	Location	Jan	Yr	Feb	Yr	Mar	Yr	Apr	Yr	May	Yr	Jun	Yr	Jul	Yr	Aug	Yr	Sep	Yr	Oct	Yr	Nov	Yr	Dec	Yr	Ann
AL	Annette	63	6	115	6	236	7	364	7	437	6	438	6	438	6	341	6	258	7	122	7	59	7	41	7	243
	Barrow	§		38	8	180	8	380	8	513	8	528	8	429	9	255	10	115	10	41	10	8		§		206
	Bethel	38	9	108	10	282	9	444	10	457	10	454	10	376	10	252	10	202	10	115	10	44	9	22	9	233
	Fairbanks	16	25	71	27	213	25	376	28	461	28	504	29	434	28	317	29	180	29	82	30	26	26	6	26	224
	Matanuska	32	6	92	6	242	4	356	7	436	7	462	6	409	6	314	6	198	6	100	6	38	6	15	7	224
AZ	Page	300	2	382	3	526	3	618	2	695	2	707	2	680	3	596	3	516	3	402	3	310	3	243	3	498
	Phoenix	301	11	409	11	526	11	638	11	724	11	739	11	658	11	613	11	566	11	449	11	334	11	281	11	520
	Tucson	315	5	391	5	540	4	655	6	729	5	699	5	626	6	588	6	570	6	442	6	356	6	305	6	518
AR	Little Rock	188	9	260	9	353	10	446	9	523	9	559	9	556	8	518	9	439	7	343	8	244	10	187	10	385
CA	Davis	174	18	257	17	390	18	528	18	625	18	694	18	682	18	612	18	493	18	347	19	222	19	148	19	431
	Fresno	184	31	289	31	427	31	552	30	647	31	702	32	682	32	621	31	510	31	376	32	250	31	161	32	450
	Inyokern (China Lake)	306	11	412	11	562	11	683	11	772	11	819	11	772	11	729	10	635	8	467	9	363	11	300	12	568
	LaJolla	244	19	302	18	397	19	457	20	506	19	487	21	497	22	464	22	389	22	320	21	277	20	[illegible]	20	380
	Los Angeles WBAS	248	10	331	10	470	10	515	10	572	9	596	9	641	9	581	10	503	10	373	10	289	10	241	10	463
	Los Angeles WBO	243	9	327	9	436	9	483	9	555	9	584	9	651	9	581	10	500	10	362	10	281	10	234	10	436
	Riverside§	275	8	367	8	478	9	541	9	623	9	680	9	673	9	618	9	535	9	407	9	319	9	[illegible]	9	481
	Santa Maria	263	11	346	11	482	11	552	10	635	11	694	11	680	11	613	11	524	11	419	11	313	11	252	11	481
	Soda Springs	223	4	316	4	374	4	551	4	615	3	691	4	760	3	681	1	510	3	357	4	248	4	162	3	459
CO	Boulder	201	5	268	4	401	4	460	4	460	4	525	5	520	5	439	5	412	4	310	4	222	4	162	4	367
	Grand Junction‡	227	9	324	9	434	8	546	8	615	9	708	8	676	8	595	8	514	8	373	10	260	10	212	10	456
	Grand Lake (Granby)	212	6	313	7	423	7	512	8	552	8	633	8	600	8	505	7	476	6	361	7	234	6	184	7	417
DC	Washington (C.O.)	174	3	266	3	344	2	411	2	551	2	494	2	536	2	446	3	375	3	299	3	211	3	166	3	356
	American University	158	39	231	39	322	39	398	39	467	39	510	39	496	39	440	38	364	38	278	38	192	39	141	39	333
	Silver Hill	177	7	247	6	342	7	438	7	513	7	555	7	511	7	457	7	391	8	293	8	202	7	156	6	357
FL	Apalachicola	298	10	367	10	441	10	535	10	603	9	578	9	529	9	511	9	456	9	413	10	332	10	262	10	444
	Belle Isle	297	10	330	10	412	10	463	10	483	10	464	10	488	11	461	10	400	10	366	11	313	11	291	10	397
	Gainesville	267	11	343	10	427	12	517	12	579	12	521	10	488	10	483	8	418	9	347	8	300	10	233	10	410
	Miami Airport	349	10	415	9	489	9	540	10	553	10	532	10	532	10	505	10	440	10	384	10	353	10	[illegible]	10	451
	Tallahassee	274	2	311	2	423	3	499	3	547	3	521	3	508	3	542	2	‡		‡		292	2	230	2	††
	Tampa	327	8	391	8	474	9	539	8	596	8	574	9	534	9	494	9	452	9	400	9	356	9	300	9	453
GA	Atlanta	218	11	290	11	380	22	488	22	533	11	562	11	532	10	508	10	416	10	344	11	268	11	211	11	396
	Griffin	234	9	295	9	385	10	522	11	570	11	577	11	556	11	522	11	535	11	368	11	283	11	201	11	413
HI	Honolulu	363	4	422	4	516	4	559	5	617	5	615	5	615	5	612	5	573	5	507	5	426	5	371	5	516
	Mauna Loa Obs.	522	2	576	2	680	2	689	3	727	3	‡		703	1	642	2	602	2	560	2	504	2	481	3	††
	Pearl Harbor	359	5	400	4	487	4	529	5	573	5	566	5	598	5	567	5	539	5	466	5	386	5	343	5	484
ID	Boise	138	10	236	9	342	9	485	9	585	10	636	9	670	10	576	10	460	10	301	11	182	11	124	10	395
	Twin Falls	163	20	240	20	355	20	462	21	552	20	592	18	602	20	540	20	432	19	286	20	176	20	131	19	378
IL	Chicago	96	19	147	19	227	19	331	19	424	19	458	18	473	19	403	18	403	19	207	20	120	20	[illegible]	20	253
	Lemont	170	6	242	6	340	6	402	6	506	6	553	6	[illegible]	6	498	6	398	5	275	5	165	5	138	6	352
IN	Indianapolis	144	10	213	10	316	10	396	10	488	9	543	11	541	10	490	11	405	11	293	11	[illegible]	11	[illegible]	11	345
IA	Ames	174	5	253	5	326	5	403	5	480	5	541	5	436	[illegible]	460	6	367	6	274	7	187	7	143	7	345
KS	Dodge City	255	7	316	7	418	7	528	7	568	7	650	7	642	[illegible]	592	9	493	9	380	9	285	10	234	10	447
	Manhattan	192	3	264	3	349	3	433	3	527	4	551	4	531	4	526	4	410	4	292	4	227	4	156	4	371
KY	Lexington	172	9	263	9	357	10	480	10	581	10	628	9	617	10	563	10	494	10	357	9	245	9	174	11	411
LA	Lake Charles	245	11	306	11	397	11	481	11	555	11	591	11	526	11	511	11	449	11	402	11	300	20	250	20	418
	New Orleans	214	14	259	14	335	15	412	16	449	14	443	13	417	15	416	15	383	15	357	13	278	13	198	14	347
	Shreveport	232	3	292	3	383	3	446	4	558	5	557	4	558	4	528	4	414	4	354	4	254	4	205	4	400
ME	Caribou	133	8	231	9	364	8	400	10	476	10	470	10	508	11	448	11	336	11	212	11	111	11	107	9	316
	Portland	152	7	235	8	352	7	409	8	514	[illegible]	539	9	561	9	488	8	383	7	278	9	157	[illegible]	157	9	350
MA	Amherst	116	2	‡		300	2	‡		411	2	514	2	‡		††		††		††		152	[illegible]	124	2	††
	Blue Hill	153	27	228	27	319	26	389	26	469	27	510	27	502	26	449	27	354	28	266	28	162	28	135	28	328
	Boston	129	16	194	17	290	17	350	17	445	16	483	16	486	16	411	16	334	17	235	17	136	16	115	15	301
	Cambridge	153	3	235	3	323	3	400	3	420	3	476	3	482	4	464	4	367	4	253	4	164	4	124	4	322
	East Wareham	140	13	218	13	305	12	385	14	452	14	508	14	495	14	436	14	365	13	258	14	163	14	140	13	322
	Lynn	115	2	209	2	300	2	394	2	454	2	549	4	528	4	412	3	341	2	241	3	135	3	107	3	317
MI	East Lansing	121	10	210	11	309	11	359	11	483	10	547	11	540	11	486	11	373	11	255	11	136	11	108	11	311
	Sault Ste. Marie	130	10	225	9	356	10	416	10	523	10	557	11	573	11	472	10	322	10	216	9	105	9	96	9	333
MN	St. Cloud	168	8	260	8	368	8	426	8	496	8	535	8	557	9	486	8	366	8	237	7	146	8	124	8	348
MO	Columbia (C.O.)	173	10	251	10	340	11	434	11	530	11	574	11	574	10	522	10	453	10	322	10	225	10	158	9	380
	University of Missouri	166	5	248	6	324	6	429	6	501	6	560	6	583	6	509	6	417	6	324	5	177	5	146	5	365
MT	Glasgow	154	6	258	8	385	7	466	8	568	8	605	8	645	9	531	10	410	10	267	8	154	8	116	7	388
	Great Falls	140	8	232	9	366	9	434	8	528	8	583	8	639	9	532	9	407	10	264	10	154	10	112	10	366
	Summit	122	3	162	2	268	3	414	3	462	3	493	3	560	2	510	2	354	2	216	2	102	2	76	2	[illegible]
NE	Lincoln	188	39	259	39	350	39	416	39	494	40	544	38	568	38	484	38	396	38	296	36	199	40	159	39	363
	North Omaha	193	3	299	1	365	3	463	3	516	3	546	4	568	4	519	4	410	4	298	4	204	4	170	4	379
NV	Ely	236		339	9	468	9	563	9	625	10	712	10	647	11	618	11	518	11	394	10	289	10	218	10	469
	Las Vegas	[illegible]	11	384	11	519	11	621	11	702	11	748	10	675	11	627	11	551	11	429	11	318	11	258	11	509
NJ	Seabrook	157	8	227	8	318	8	403	8	482	9	527	8	509	8	455	9	385	9	278	7	192	8	140	8	339
NH	Mt. Washington	[illegible]	2	218	2	238	2	‡		‡		‡		††		††		‡		‡		‡		96	2	††
NM	Albuquerque	303	13	386	13	511	13	618	13	686	13	726	13	683	12	626	13	554	14	438	15	334		276	14	512
NY	Ithaca	116	22	194	21	272	23	334	23	440	24	501	23	515	23	453	23	346	21	231	22	120	23	96	23	302
	Central Park	100	34	199	34	290	33	169	35	432	35	470	34	459	35	389	35	331	36	242	36	147	36	115	35	298
	Sayville	160	11	249	11	335	10	415	10	494	10	565	10	543	10	462	10	385	10	289	10	186	10	142	11	352
	Schenectady	130	8	200	9	273	9	338	9	413	9	448	8	441	8	397	8	299	8	218	8	128	8	104	8	282
	Upton	155	8	232	8	339	8	428	8	502	8	573	8	543	7	475	7	391	7	291	6	182	7	146	7	355
NC	Greensboro	200	7	276	9	354	9	469	9	531	10	564	10	544	10	485	10	406	10	322	10	243	10	197	8	383
	Hatteras	238	10	317	9	426	8	569	9	635	10	652	10	625	10	562	11	471	11	358	11	282	11	214	11	443
	Raleigh	235	3	302	2	‡		466	3	494	2	564	3	535	3	476	3	379	3	307	3	235	3	199	3	††
ND	Bismarck	157	[illegible]	250	8	356	6	447	8	550	8	590	9	617	10	516	11	390	11	272	11	161	10	124	10	369
OH	Cleveland	125	6	183	6	303	7	286	8	502	8	562	8	562	8	494	8	278	8	289	9	141	9	165	7	335
	Columbus	128	[illegible]	200	7	297	7	391	[illegible]	471	6	562	4	542	5	477	4	422	4	286	4	176	4	129	5	[illegible]
	Put-in-Bay	126	10	204	9	302	10	486	10	468	11	544	11	561	10	487	10	382	11	[illegible]	11	164	11	[illegible]	11	317

ore Footnotes are grouped at the end of the table

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Location	Jan	Yr	Feb	Yr	Mar	Yr	Apr	Yr	May	Yr*	Jun	Yr	Jul	Yr	Aug	Yr	Sep	Yr	Oct	Yr	Nov	Yr	Dec	Yr	Ann
OK Oklahoma City	[illegible]	10	319	10	409	9	494	10	536	10	615		610	8	591	4	48[illegible]	9	377	10	291	9	240	9	436
Stillwater	205	8	289	8	390	9	454	9	504	9	600	10	596	10	545	10	45[illegible]	11	354	10	269	9	209	8	405
OR Astoria	90	7	162	8	270	8	375	8	492	8	469	8	539	8	461	7	354	7	209	8	111	8	79	8	301
Corvallis	89	2	‡		287	3	406	3	51[illegible]	3	570	3	676	4	558	4	397	4	235	4	144	4	80	4	††
Medford	116	11	215	11	336	11	482	11	592	11	652	11	698	10	605	11	447	11	279	11	149	11	93	11	389
PA Pittsburgh	94	6	169	5	216	6	317	6	429	6	491	6	497	7	409	6	339	6	207	5	118	6	77	5	280
State College	133	19	201	19	295	20	380	20	456	20	518	20	511	20	444	20	358	20	256	20	149	20	118	20	318
RI Newport	155	23	232	22	334	23	405	23	477	23	527	24	513	24	455	24	377	24	271	24	176	24	139	24	338
SC Charleston	252	11	314	11	388	11	512	11	551	11	564	11	520	11	501	11	404	11	338	11	286	11	225	11	404
SD Rapid City	183	11	277	11	400	11	482	11	532	11	585	11	590	11	541	11	435	11	315	10	204	10	158	10	392
TN Nashville	149	18	228	19	322	19	432	19	503	18	551	18	530	17	473	17	403	17	308	19	208	18	150	19	355
Oak Ridge	161	11	239	11	331	11	450	11	518	11	551	11	526	11	478	11	416	11	318	11	213	10	163	11	364
TX Brownsville	297	10	341	10	402	10	456	10	564	10	610	9	627	8	568	11	475	11	411	11	296	11	263	10	442
El Paso	333	11	430	11	547	10	654	11	714	11	729	11	666	11	640	10	576	11	460	11	372	11	313	11	536
Ft. Worth	250	11	320	11	427	11	488	11	562	11	651	11	613	11	593	11	503	11	403	11	306	11	245	9	445
Midland	283	7	358	8	476	9	550	8	611	8	617	8	608	7	574	8	522	9	396	9	325	8	275	8	466
San Antonio	279	9	347	9	417	9	445	9	541	9	612	9	639	9	585	9	493	10	398	10	295	10	256	8	442
UT Flaming Gorge	238	2	298	2	443	2	522	2	565	2	650	2	599	3	538	3	425	3	352	3	262	3	215	3	426
Salt Lake City	163	8	256	8	354	8	479	8	570	7	621	7	620	6	551	7	446	8	316	8	204	8	146	9	394
VA Mt. Weather	172	2	274	2	338	2	414	2	508	2	525	3	510	3	430	3	375	3	281	2	202	2	168	2	350
WA North Head	‡		167	2	257	3	432	2	509	3	487	3	486	3	436	3	321	3	205	3	122	3	77	3	††
Friday Harbor	87	8	157	7	274	8	418	8	514	9	578	10	586	10	507	11	351	8	194	10	102	10	75	8	320
Prosser	117	4	222	4	351	4	521	5	616	4	680	4	707	4	604	4	458	4	274	4	136	4	100	4	399
Pullman	121	4	205	2	304	2	462	2	558	4	653	5	699	5	562	4	410	4	245	5	146	5	96	5	372
University of Washington	67	9	126	9	245	10	364	9	445	10	461	10	496	11	435	10	299	8	170	9	93	4	59	9	272
Seattle-Tacoma	75	9	139	9	265	9	401	9	503	9	511	9	566	9	452	10	324	10	188	10	104	9	64	10	300
Spokane	119	8	204	8	321	8	474	9	563	9	596	9	665	9	556	9	404	10	225	9	131	9	75	7	341
WI Madison**	148	46	220	46	313	45	394	47	466	47	514	47	531	47	452	47	348	47	241	47	145	44	115	46	324
WY Lander	226	8	324	9	452	9	548	11	58[illegible]	11	678	11	651	11	586	10	472	8	354	9	239	9	196	9	443
Laramie	216	3	295	3	424	3	508	3	554	3	643	3	606	3	536	3	418	3	324	3	229	3	186	4	408
Island Stations																									
Canton Island	588	9	626	7	634	7	604	9	561	9	549	8	550	9	597	9	640	9	651	9	600	8	572	8	597
San Juan, P.R.	404	5	481	4	580	4	622	4	519	5	536	6	639	5	549	6	531	6	460	6	411	6	411	6	512
Swan Island	442	6	496	7	615	6	646	6	625	6	544	8	588	8	591	7	535	8	457	7	394	8	382	8	526
Wake Island	438	7	518	7	577	7	627	7	642	8	656	6	679	7	623	7	587	6	525	7	482		421	7	560

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*Langley is the unit used to denote 1 gram calorie per square centimeter.

†From "Climatic Atlas of the United States," U.S. Government Printing Office, 1968.

‡Only one year of data for the month; no means computed

§Barrow is in darkness during the winter months.

¶Riverside data prior to March 1952 not used because of instrumental difficulties.

**Madison data after 1957 not used due to exposure influences.

††Indicates no data for the month (or incomplete data for the year)

Appendix B-5

Solar Position and Insolation Values

24 Degrees North Latitude

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
	AM	PM	Alt	Azm	Normal	Horiz.	South facing surface angle with horiz.				
							14	24	34	44	90
Jan 21	7	5	4.8	65.6	71	10	17	21	25	28	31
	8	4	16.9	58.3	239	83	110	126	137	145	127
	9	3	27.9	48.8	288	151	188	207	221	228	176
	10	2	37.2	36.1	308	204	246	268	282	287	207
	11	1	43.6	19.6	317	237	283	306	319	324	226
	12		46.0	0.0	320	249	296	319	332	336	232
	Surface daily totals				2766	1622	1984	2174	2300	2360	1766
Feb 21	7	5	9.3	74.6	158	35	44	49	53	56	46
	8	4	22.3	67.2	263	116	135	145	150	151	102
	9	3	34.4	57.6	298	187	213	225	230	228	141
	10	2	45.1	44.2	314	241	273	286	291	287	168
	11	1	53.0	25.0	321	276	310	324	328	323	185
	12		56.0	0.0	324	288	323	337	341	335	191
	Surface daily totals				3036	1998	2276	2396	2436	2424	1476
Mar 21	7	5	13.7	83.3	194	60	63	64	62	59	27
	8	4	27.2	76.8	267	141	150	152	149	142	64
	9	3	40.2	67.9	295	212	226	229	225	214	95
	10	2	52.3	54.8	309	266	285	288	283	270	120
	11	1	61.9	33.4	315	300	322	326	320	305	135
	12		66.0	0.0	317	312	334	339	333	317	140
	Surface daily totals				3078	2270	2428	2456	2412	2298	1022
Apr 21	6	6	4.7	100.6	40	7	5	4	4	3	2
	7	5	18.3	94.9	203	83	77	70	62	51	10
	8	4	32.0	89.0	256	160	157	149	137	122	16
	9	3	45.6	81.9	280	227	227	220	206	186	46
	10	2	59.0	71.8	292	278	282	275	259	237	61
	11	1	71.1	51.6	298	310	316	309	293	269	74
	12		77.6	0.0	299	321	328	321	305	280	79
	Surface daily totals				3036	2454	2458	2374	2228	2016	488
May 21	6	6	8.0	108.4	86	22	15	10	9	9	5
	7	5	21.2	103.2	203	98	85	73	59	44	12
	8	4	34.6	98.5	248	171	159	145	127	106	15
	9	3	48.3	93.6	269	283	224	210	190	165	16
	10	2	62.0	87.7	280	281	275	261	239	211	22
	11	1	75.5	76.9	286	311	307	293	270	240	34
	12		86.0	0.0	288	322	317	304	281	250	37
	Surface daily totals				3032	2556	2447	2286	2072	1800	246
Jun 21	6	6	9.3	111.6	97	29	20	12	12	11	7
	7	5	22.3	106.8	201	103	87	73	58	41	13
	8	4	35.5	102.6	242	173	158	142	122	99	16
	9	3	49.0	98.7	263	234	221	204	182	155	18
	10	2	62.6	95.0	274	280	269	253	229	199	18
	11	1	76.3	90.8	279	309	300	283	259	227	19
	12		89.4	0.0	281	319	310	294	269	236	22
	Surface daily totals				2994	2574	2422	2230	1992	1700	204

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Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
	AM	PM	Alt	Azm			South facing surface angle with horiz.				
					Normal	Horiz.	14	24	34	44	90
Jul 21	6	6	8.2	109.0	81	23	16	11	10	9	6
	7	5	21.4	101.8	195	98	85	73	59	44	13
	8	4	34.8	99.2	239	169	157	143	125	104	16
	9	3	48.4	94.5	261	231	221	207	187	161	18
	10	2	62.1	89.0	272	278	270	256	235	206	21
	11	1	75.7	79.2	278	307	302	287	265	235	32
	12		86.6	0.0	280	317	312	298	275	245	36
	Surface daily totals				2932	2526	2412	2250	2036	1766	246
Aug 21	6	6	5.0	101.3	35	7	5	4	4	4	2
	7	5	18.5	95.6	186	82	76	69	60	50	11
	8	4	32.2	89.7	241	158	154	146	134	118	16
	9	3	45.9	82.9	265	223	222	214	200	181	39
	10	2	59.3	73.0	278	273	275	268	252	230	58
	11	1	71.6	53.2	284	304	309	301	285	261	71
	12		78.3	0.0	286	315	320	313	296	272	75
	Surface daily totals				2864	2408	2402	2316	2168	1958	470
Sep 21	7	5	13.7	83.8	173	57	60	60	59	56	26
	8	4	27.2	76.8	248	136	144	146	143	136	62
	9	3	40.2	67.9	278	205	218	221	217	206	93
	10	2	52.3	54.8	292	258	275	278	273	261	116
	11	1	61.9	33.4	299	291	311	315	309	295	131
	12		66.0	0.0	301	302	323	327	321	306	136
	Surface daily totals				2878	2194	2342	2366	2322	2212	992
Oct 21	7	5	9.1	74.1	138	32	40	45	48	50	42
	8	4	22.0	66.7	247	111	129	139	144	145	99
	9	3	34.1	57.1	284	180	206	217	223	221	138
	10	2	44.7	43.8	301	234	265	277	282	279	165
	11	1	52.5	24.7	309	268	301	315	319	314	182
	12		55.5	0.0	311	279	314	328	332	327	188
	Surface daily totals				2868	1928	2198	2314	2364	2346	1442
Nov 21	7	5	4.9	65.8	67	10	16	20	24	27	29
	8	4	17.0	58.4	232	82	108	123	135	142	124
	9	3	28.0	48.9	282	150	186	205	217	224	172
	10	2	37.3	36.3	303	203	244	265	278	283	204
	11	1	43.8	19.7	312	236	280	302	316	320	222
	12		46.2	0.0	315	247	293	315	328	332	228
	Surface daily totals				2706	1610	1962	2146	2268	2324	1730
Dec 21	7	5	3.2	62.6	30	3	7	9	11	12	14
	8	4	14.9	55.3	225	71	99	116	129	139	130
	9	3	25.5	46.0	281	137	176	198	214	223	184
	10	2	34.3	33.7	304	189	234	258	275	283	217
	11	1	40.4	18.2	314	221	270	295	312	320	236
	12		42.6	0.0	317	232	282	308	325	332	243
	Surface daily totals				2624	1474	1852	2058	2204	2286	1808

1 BTUH/SQ. FT. = 3.152 W/m^2

NOTE:
1) Based on data in Table 1, p. 387 in ref. [3]; 0% ground reflectance; 1.0 clearness factor.
2) See Fig. 4, p. 394 in [3] for typical regional clearness factors.
3) Ground reflection not included on normal or horizontal surfaces.

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32 Degrees North Latitude

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
							South facing surface angle with horiz.				
	AM	PM	Alt	Azm	Normal	Horiz.	22	32	42	52	90
Jan 21	7	5	1.4	65.2	1	0	0	0	0	1	1
	8	4	12.5	56.5	203	56	93	106	116	123	115
	9	3	22.5	46.0	269	118	175	193	206	212	181
	10	2	30.6	33.1	295	167	235	256	269	274	221
	11	1	36.1	17.5	306	198	273	295	308	312	245
	12		38.0	0.0	310	209	285	308	321	324	253
	Surface daily totals				2458	1288	1839	2008	2118	2166	1779
Feb 21	7	5	7.1	73.5	121	22	34	37	40	42	38
	8	4	19.0	64.4	247	95	127	136	140	141	108
	9	3	29.9	53.4	288	161	206	217	222	220	158
	10	2	39.1	39.4	306	212	266	278	283	279	193
	11	1	45.6	21.4	315	244	304	317	321	315	214
	12		48.0	0.0	317	255	316	330	334	328	222
	Surface daily totals				2872	1724	2188	2300	2345	2322	1644
Mar 21	7	5	12.7	81.9	185	54	60	60	59	56	32
	8	4	25.1	73.0	260	129	146	147	144	137	78
	9	3	36.8	62.1	290	194	222	224	220	209	119
	10	2	47.3	47.5	304	245	280	283	278	265	150
	11	1	55.0	26.8	311	277	317	321	315	300	170
	12		58.0	0.0	313	287	329	333	327	312	177
	Surface daily totals				3012*	2084	2378	2403	2358	2246	1276
Apr 21	6	6	6.1	99.9	66	14	9	6	6	5	3
	7	5	18.8	92.2	206	86	78	71	62	51	10
	8	4	31.5	84.0	255	158	156	148	136	120	35
	9	3	43.9	74.2	278	220	225	217	203	183	68
	10	2	55.7	60.3	290	267	279	272	256	234	95
	11	1	65.4	37.5	295	297	313	306	290	265	112
	12		69.6	0.0	297	307	325	318	301	276	118
	Surface daily totals				3076	2390	2444	2356	2206	1994	764
May 21	6	6	10.4	107.2	119	36	21	13	13	12	7
	7	5	22.8	100.1	211	107	88	75	60	44	13
	8	4	35.4	92.9	250	175	159	145	127	105	15
	9	3	48.1	84.7	269	233	223	209	188	163	33
	10	2	60.6	73.3	280	277	273	259	237	208	56
	11	1	72.0	51.9	285	305	305	290	268	237	72
	12		78.0	0.0	286	315	315	301	278	247	77
	Surface daily totals				3112	2582	2454	2284	2064	1788	469
Jun 21	6	6	12.2	110.2	131	45	26	16	15	14	9
	7	5	24.3	103.4	210	115	91	76	59	41	14
	8	4	36.9	96.8	245	180	159	143	122	99	16
	9	3	49.6	89.4	264	236	221	204	181	153	19
	10	2	62.2	79.7	274	279	268	251	227	197	41
	11	1	74.2	60.9	279	306	299	282	257	224	56
	12		81.5	0.0	280	315	309	292	267	234	60
	Surface daily totals				3084	2634	2436	2234	1990	1690	370

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Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
	AM	PM	Alt	Azm			South facing surface angle with horiz.				
					Normal	Horiz.	22	32	42	52	90
Jul 21	6	6	10.7	107.7	113	37	22	14	13	12	8
	7	5	23.1	100.6	203	107	87	75	60	44	14
	8	4	35.7	93.6	241	174	158	143	125	104	16
	9	3	48.4	85.5	261	231	220	205	185	159	31
	10	2	60.9	74.3	271	274	269	254	232	204	54
	11	1	72.4	53.3	277	302	300	285	262	232	69
	12		78.6	0.0	279	311	310	296	273	242	74
	Surface daily totals				3012	2558	2422	2250	2030	1754	458
Aug 21	6	6	6.5	100.5	59	14	9	7	6	6	4
	7	5	19.1	92.8	190	85	77	69	60	50	12
	8	4	31.8	84.7	240	156	152	144	132	116	33
	9	3	44.3	75.0	263	216	220	212	197	178	65
	10	2	56.1	61.3	276	262	272	264	249	226	91
	11	1	66.0	38.4	282	292	305	298	281	257	107
	12		70.3	0.0	284	302	317	309	292	268	113
	Surface daily totals				2902	2352	2388	2296	2144	1934	736
Sep 21	7	5	12.7	81.9	163	51	56	56	55	52	30
	8	4	25.1	73.0	240	124	140	141	138	131	75
	9	3	36.8	62.1	272	188	213	215	211	201	114
	10	2	47.3	47.5	287	237	270	273	268	255	145
	11	1	55.0	26.8	294	268	306	309	303	289	164
	12		58.0	0.0	296	278	318	321	315	300	171
	Surface daily totals				2808	2014	2288	2308	2264	2154	1226
Oct 21	7	5	6.8	73.1	99	19	29	32	34	36	32
	8	4	18.7	64.0	229	90	120	128	133	134	104
	9	3	29.5	53.0	273	155	198	208	213	212	153
	10	2	38.7	39.1	293	204	257	269	273	270	188
	11	1	45.1	21.1	302	236	294	307	311	306	209
	12		47.5	0.0	304	247	306	320	324	318	217
	Surface daily totals				2696	1654	2100	2208	2252	2232	1588
Nov 21	7	5	1.5	65.4	2	0	0	0	1	1	1
	8	4	12.7	56.6	196	55	91	104	113	119	111
	9	3	22.6	46.1	263	118	173	190	202	208	176
	10	2	30.8	33.2	289	166	233	252	265	270	217
	11	1	36.2	17.6	301	197	270	291	303	307	241
	12		38.2	0.0	304	207	282	304	316	320	249
	Surface daily totals				2406	1280	1816	1980	2084	2130	1742
Dec 21	8	4	10.3	53.8	176	41	77	90	101	108	107
	9	3	19.8	43.6	257	102	161	180	195	204	183
	10	2	27.6	31.2	288	150	221	244	259	267	226
	11	1	32.7	16.4	301	180	258	282	298	305	251
	12		34.6	0.0	304	190	271	295	311	318	259
	Surface daily totals				2348	1136	1704	1888	2016	2086	1794

1 BTUH/SQ. FT. = 3.152 W/m²

NOTE:
1) Based on data in Table 1, p. 387 in ref. [3]; 0% ground reflectance; 1.0 clearness factor.
2) See Fig. 4, p. 394 in [3] for typical regional clearness factors.
3) Ground reflection not included on normal or horizontal surfaces.

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40 Degrees North Latitude

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
							South facing surface angle with horiz.				
	AM	PM	Alt	Azm	Normal	Horiz.	30	40	50	60	90
Jan 21	8	4	8.1	55.3	142	28	65	74	81	85	84
	9	3	16.8	44.0	239	83	155	171	182	187	171
	10	2	23.8	30.9	274	127	218	237	249	254	223
	11	1	28.4	16.0	289	154	257	277	290	293	253
	12		30.0	0.0	294	164	270	291	303	306	263
	Surface daily totals				2182	948	1660	1810	1906	1944	1726
Feb 21	7	5	4.8	72.7	69	10	19	21	23	24	22
	8	4	15.4	62.2	224	73	114	122	126	127	107
	9	3	25.0	50.2	274	132	195	205	209	208	167
	10	2	32.8	35.9	295	178	256	267	271	267	210
	11	1	38.1	18.9	305	206	293	306	310	304	236
	12		40.0	0.0	308	216	306	319	323	317	245
	Surface daily totals				2640	1414	2060	2162	2202	2176	1730
Mar 21	7	5	11.4	80.2	171	46	55	55	54	51	35
	8	4	22.5	69.6	250	114	140	141	138	131	89
	9	3	32.8	57.3	282	173	215	217	213	202	138
	10	2	41.6	41.9	297	218	273	276	271	[illegible]	176
	11	1	47.7	22.6	305	247	310	313	307	[illegible]	200
	12		50.0	0.0	307	257	322	326	320	305	208
	Surface daily totals				2916	1852	2308	2330	2284	2174	1484
Apr 21	6	6	7.4	98.9	89	20	11	8	7	7	4
	7	5	18.9	89.5	206	87	77	70	61	50	12
	8	4	30.3	79.3	252	152	153	145	133	117	53
	9	3	41.3	67.2	274	207	221	213	199	179	93
	10	2	51.2	51.4	286	250	275	267	252	229	126
	11	1	58.7	29.2	292	277	308	301	285	260	147
	12		61.6	0.0	293	287	320	313	296	271	154
	Surface daily totals				3092	2274	2412	2320	2168	1956	1022
May 21	5	7	1.9	114.7	1	0	0	0	0	0	0
	6	6	12.7	105.6	144	49	25	15	14	13	9
	7	5	24.0	96.6	216	214	89	76	60	44	13
	8	4	35.4	87.2	250	175	158	144	125	104	25
	9	3	46.8	76.0	267	227	221	206	186	160	60
	10	2	57.5	60.9	277	267	270	255	233	205	89
	11	1	66.2	37.1	283	293	301	287	264	234	108
	12		70.0	0.0	284	301	312	297	274	243	114
	Surface daily totals				3160	2552	2442	2264	2040	1760	724
Jun 21	5	7	4.2	117.3	22	4	3	3	2	2	1
	6	6	14.8	108.4	155	60	30	18	17	16	10
	7	5	26.0	99.7	216	123	92	77	59	41	14
	8	4	37.4	90.7	246	182	159	142	121	97	16
	9	3	48.8	80.2	263	233	219	202	179	151	47
	10	2	59.8	65.8	272	272	266	248	224	194	74
	11	1	69.2	41.9	277	296	296	278	253	221	92
	12		73.5	0.0	279	304	306	289	263	230	98
	Surface daily totals				3180	2648	2434	2224	1974	1670	610

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Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
							South facing surface angle with horiz.				
	AM	PM	Alt	Azm	Normal	Horiz.	30	40	50	60	90
Jul 21	5	7	2.3	115.2	2	0	0	0	0	0	0
	6	6	13.1	106.1	138	50	26	17	15	14	9
	7	5	24.3	97.2	208	114	89	75	60	44	14
	8	4	35.8	87.8	241	174	157	142	124	102	24
	9	3	47.2	76.7	259	225	218	203	182	157	58
	10	2	57.9	61.7	269	265	266	251	229	200	86
	11	1	66.7	37.9	275	290	296	281	258	228	104
	12		70.6	0.0	276	298	307	292	269	238	111
	Surface daily totals				3062	2534	2409	2230	2006	1728	702
Aug 21	6	6	7.9	99.5	81	21	12	9	8	7	5
	7	5	19.3	90.9	191	87	76	69	60	49	12
	8	4	30.7	79.9	237	150	150	141	129	113	50
	9	3	41.8	67.9	260	205	216	207	193	173	89
	10	2	51.7	52.1	272	246	267	259	244	221	120
	11	1	59.3	29.7	278	273	300	292	276	252	140
	12		62.3	0.0	280	282	311	303	287	262	147
	Surface daily totals				2916	2244	2354	2258	2104	1894	978
Sep 21	7	5	11.4	80.2	149	43	51	51	49	47	32
	8	4	22.5	69.6	230	109	133	134	131	124	84
	9	3	32.8	57.3	263	167	206	208	203	193	132
	10	2	41.6	41.9	280	211	262	265	260	247	168
	11	1	47.7	22.6	287	239	298	301	295	281	192
	12		50.0	0.0	290	249	310	313	307	292	200
	Surface daily totals				2708	1788	2210	2228	2182	2074	1416
Oct 21	7	5	4.5	72.3	48	7	14	15	17	17	16
	8	4	15.0	61.9	204	68	106	113	117	118	100
	9	3	24.5	49.8	257	126	185	195	200	198	160
	10	2	32.4	35.6	280	170	245	257	261	257	203
	11	1	37.6	18.7	291	199	283	295	299	294	229
	12		39.5	0.0	294	208	295	308	312	306	238
	Surface daily totals				2454	1348	1962	2060	2098	2074	1654
Nov 21	8	4	8.2	55.4	136	28	63	72	78	82	81
	9	3	17.0	44.1	232	82	152	167	178	183	167
	10	2	24.0	31.0	268	126	215	233	245	249	219
	11	1	28.6	16.1	283	153	254	273	285	288	248
	12		30.2	0.0	288	163	267	287	298	301	258
	Surface daily totals				2128	942	1636	1778	1870	1908	1686
Dec 21	8	4	5.5	53.0	89	14	39	45	50	54	56
	9	3	14.0	41.9	217	65	135	152	164	171	163
	10	2	20.[illegible]	29.4	261	107	200	221	235	242	221
	11	1	25.0	15.2	280	134	239	262	276	283	252
	12		26.6	0.0	285	143	253	275	290	296	263
	Surface daily totals				1978	782	1480	1634	1740	1796	1646

1 BTUH/SQ. FT. = 3.152 W/m²

NOTE: 1) Based on data in Table 1, p. 387 in ref. [3]; 0% ground reflectance; 1.0 clearness factor.

2) See Fig. 4, p. 394 in [3] for typical, regional clearness factors.

3) Ground reflection not included on normal or horizontal surfaces.

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48 Degrees North Latitude

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
							South facing surface angle with horiz.				
	AM	PM	Alt	Azm	Normal	Horiz.	38	48	58	68	90
Jan 21	8	4	3.5	54.6	37	4	17	19	21	22	22
	9	3	11.0	42.6	185	46	120	132	140	145	139
	10	2	16.9	29.4	239	83	190	206	216	220	206
	11	1	20.7	15.1	261	107	231	249	260	263	243
	12		22.0	0.0	267	115	245	264	275	278	255
	Surface daily totals				1710	596	1360	1478	1550	1578	1478
Feb 21	7	5	2.4	72.2	12	1	3	4	4	4	4
	8	4	11.6	60.5	188	49	95	102	105	106	96
	9	3	19.7	47.7	251	100	178	187	191	190	167
	10	2	26.2	33.3	278	139	240	251	255	251	217
	11	1	30.5	17.2	290	165	278	290	294	288	247
	12		32.0	0.0	293	173	291	304	307	301	258
	Surface daily totals				2330	1080	1880	1972	2024	1978	1720
Mar 21	7	5	10.0	78.7	153	37	49	49	47	45	35
	8	4	19.5	66.8	236	96	131	132	129	122	96
	9	3	28.2	53.4	270	147	205	207	203	193	152
	10	2	35.4	37.8	287	187	263	266	261	248	195
	11	1	40.3	19.8	295	212	300	303	297	283	223
	12		42.0	0.0	298	220	312	315	309	294	232
	Surface daily totals				2780	1578	2208	2228	2182	2074	1632
Apr 21	6	6	8.6	97.8	108	27	13	9	8	7	5
	7	5	18.6	86.7	205	85	76	69	59	48	21
	8	4	28.5	74.9	247	142	149	141	129	113	69
	9	3	37.8	61.2	268	191	216	208	194	174	115
	10	2	45.8	44.6	280	228	268	260	245	223	152
	11	1	51.5	24.0	286	252	301	294	278	254	177
	12		53.6	0.0	288	260	313	305	289	264	185
	Surface daily totals				3076	2106	2358	2266	2114	1902	1262
May 21	5	7	5.2	114.3	41	9	4	4	4	3	2
	6	6	14.7	103.7	162	61	27	16	15	13	10
	7	5	24.6	93.0	219	118	89	75	60	43	13
	8	4	34.7	81.6	248	171	156	142	123	101	45
	9	3	44.3	68.3	264	217	217	202	182	156	86
	10	2	53.0	51.3	274	252	265	251	229	200	120
	11	1	59.5	28.6	279	274	296	281	258	228	141
	12		62.0	0.0	280	281	306	292	269	238	149
	Surface daily totals				3254	2482	2418	2234	2010	1728	982
Jun 21	5	7	7.9	116.5	77	21	9	9	8	7	5
	6	6	17.2	106.2	172	74	33	19	18	16	12
	7	5	27.0	95.8	220	129	93	77	59	39	15
	8	4	37.1	84.6	246	181	157	140	119	95	35
	9	3	46.9	71.6	261	225	216	198	175	147	74
	10	2	55.8	54.8	269	259	262	244	220	189	105
	11	1	62.7	31.2	274	280	291	273	248	216	126
	12		65.5	0.0	275	281	301	283	258	225	133
	Surface daily totals				3312	2626	2420	2204	1950	1644	874

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
	AM	PM	Alt	Azm			South facing surface angle with horiz.				
					Normal	Horiz.	38	48	58	68	90
Jul 21	5	7	5.7	114.7	43	10	5	5	4	4	3
	6	6	15.2	104.1	156	62	28	18	16	15	11
	7	5	25.1	93.5	211	118	89	75	59	42	14
	8	4	35.1	82.1	240	171	154	140	121	99	43
	9	3	44.8	68.8	256	215	214	199	178	153	83
	10	2	53.5	51.9	266	250	261	246	224	195	116
	11	1	60.1	29.0	271	272	291	276	253	223	137
	12		62.6	0.0	272	279	301	286	263	232	144
	Surface daily totals				3158	2474	2386	2200	1974	1694	956
Aug 21	6	6	9.1	98.3	99	28	14	10	9	8	6
	7	5	19.1	87.2	190	85	75	67	58	47	20
	8	4	29.0	75.4	232	141	145	137	125	109	65
	9	3	38.4	61.8	254	189	210	201	187	168	110
	10	2	46.4	45.1	266	225	260	252	237	214	146
	11	1	52.2	24.3	272	248	293	285	268	244	169
	12		54.3	0.0	274	256	304	296	279	255	177
	Surface daily totals				2898	2086	2300	2200	2046	1836	1208
Sep 21	7	5	10.0	78.7	131	35	44	44	43	40	31
	8	4	19.5	66.8	215	92	124	124	121	115	90
	9	3	28.2	53.4	251	142	196	197	193	183	143
	10	2	35.4	37.8	269	181	251	254	248	236	185
	11	1	40.3	19.8	278	205	287	289	284	269	212
	12		42.0	0.0	280	213	299	302	296	281	221
	Surface daily totals				2568	1522	2102	2118	2070	1966	1546
Oct 21	7	5	2.0	71.9	4	0	1	1	1	1	1
	8	4	11.2	60.2	165	44	86	91	95	95	87
	9	3	19.3	47.4	233	94	167	176	180	178	157
	10	2	25.7	33.1	262	133	228	239	242	239	207
	11	1	30.0	17.1	274	157	266	277	281	276	237
	12		31.5	0.0	278	166	279	291	294	288	247
	Surface daily totals				2154	1022	1774	1860	1890	1866	1626
Nov 21	8	4	3.6	54.7	36	5	17	19	21	22	22
	9	3	11.2	42.7	179	46	117	129	137	141	135
	10	2	17.1	29.5	233	83	186	202	212	215	201
	11	1	20.9	15.1	255	107	227	245	255	258	238
	12		22.2	0.0	261	115	241	259	270	272	250
	Surface daily totals				1668	596	1336	1448	1518	1544	1442
Dec 21	9	3	8.0	40.9	140	27	87	98	105	110	109
	10	2	13.6	28.2	214	63	164	180	192	197	190
	11	1	17.3	14.4	242	86	207	226	239	244	231
	12		18.6	0.0	250	94	222	241	254	260	244
	Surface daily totals				1444	446	1136	1250	1326	1364	1304

1 BTUH/SQ. FT..= 3.152 W/m²

NOTE: 1) Based on data in Table 1, p. 387 in ref. [3]; 0% ground reflectance; 1.0 clearness factor.

2) See Fig. 4, p. 394 in [3] for typical regional clearness factors.

3) Ground reflection not included on normal or horizontal surfaces.

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56 Degrees North Latitude

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
							South facing surface angle with horiz.				
	AM	PM	Alt	Azm	Normal	Horiz.	46	56	66	76	90
Jan 21	9	3	5.0	41.8	78	11	50	55	59	60	60
	10	2	9.9	28.5	170	39	135	146	154	156	153
	11	1	12.9	14.5	207	58	183	197	206	208	201
	12		14.0	0.0	217	65	198	214	222	225	217
	Surface daily totals				1126	282	934	1010	1058	1074	1044
Feb 21	8	4	7.6	59.4	129	25	65	69	72	72	69
	9	3	14.2	45.9	214	65	151	159	162	161	154
	10	2	19.4	31.5	250	98	215	225	228	224	208
	11	1	22.8	16.1	266	119	254	265	268	263	243
	12		24.0	0.0	270	126	268	279	282	276	255
	Surface daily totals				1986	740	1640	1716	1742	1716	1598
Mar 21	7	5	8.3	77.5	128	28	40	40	39	37	32
	8	4	16.2	64.4	215	75	119	120	117	111	97
	9	3	23.3	50.3	253	118	192	193	189	180	154
	10	2	29.0	34.9	272	151	249	251	246	234	205
	11	1	32.7	17.9	282	172	285	288	282	268	236
	12		34.0	0.0	284	179	297	300	294	280	246
	Surface daily totals				2586	1268	2066	2084	2040	1938	1700
Apr 21	5	7	1.4	108.8	0	0	0	0	0	0	0
	6	6	9.6	96.5	122	32	14	9	8	7	6
	7	5	18.0	84.1	201	81	74	66	57	46	29
	8	4	26.1	70.9	239	129	143	135	123	108	82
	9	3	33.6	56.3	260	169	208	200	186	167	133
	10	2	39.9	39.7	272	201	259	251	236	214	174
	11	1	44.1	20.7	278	220	292	284	268	245	200
	12		45.6	0.0	280	227	303	295	279	255	209
	Surface daily totals				3024	1892	2282	2186	2038	1830	1458
May 21	4	8	1.2	125.5	0	0	0	0	0	0	0
	5	7	8.5	113.4	93	25	10	9	8	7	6
	6	6	16.5	101[illegible]	175	71	28	17	15	13	11
	7	5	24.8	89.3	219	119	88	74	58	41	16
	8	4	33.1	76.3	244	163	153	138	119	98	63
	9	3	40.9	61.6	259	201	212	197	176	151	109
	10	2	47.6	44.2	268	231	259	244	222	194	146
	11	1	52.3	23.4	273	249	288	274	251	222	170
	12		54.0	0.0	275	255	299	284	261	231	178
	Surface daily totals				3340	2374	2374	2188	1962	1682	1218
Jun 21	4	8	4.2	127.2	21	4	2	2	2	2	1
	5	7	11.4	115.3	122	40	14	13	11	10	8
	6	6	19.3	103.6	185	86	34	19	17	15	12
	7	5	27.6	91.7	222	132	92	76	57	38	15
	8	4	35.9	78.8	243	175	154	137	116	92	55
	9	3	43.8	64.1	257	212	211	193	170	143	98
	10	2	50.7	46.4	265	240	255	238	214	184	133
	11	1	55.6	24.9	269	258	284	267	242	210	156
	12		57.5	0.0	271	264	294	276	251	219	164
	Surface daily totals				3438	2526	2388	2166	1910	1606	1120

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Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
							South facing surface angle with horiz.				
	AM	PM	Alt	Azm	Normal	Horiz.	46	56	66	76	90
Jul 21	4	8	1.7	125.8	0	0	0	0	0	0	0
	5	7	9.0	113.7	91	27	11	10	9	8	6
	6	6	17.0	101.9	169	72	30	18	16	14	12
	7	5	25.3	89.7	212	119	88	74	58	41	15
	8	4	33.6	76.7	237	163	151	136	117	96	61
	9	3	41.4	62.0	252	201	208	193	173	147	106
	10	2	48.2	44.6	261	230	254	239	217	189	142
	11	1	52.9	23.7	265	248	283	268	245	216	165
	12		54.6	0.0	267	254	293	278	255	225	173
	Surface daily totals				3240	2372	2342	2152	1926	1646	1186
Aug 21	5	7	2.0	109.2	1	0	0	0	0	0	0
	6	6	10.2	97.8	112	34	16	11	10	9	7
	7	5	18.5	84.5	187	82	73	65	56	45	28
	8	4	26.7	71.3	225	128	140	131	119	104	78
	9	3	34.3	56.7	246	168	202	193	179	160	126
	10	2	40.5	40.0	258	199	251	242	227	206	166
	11	1	44.8	20.9	264	218	282	274	258	235	191
	12		46.3	0.0	266	225	293	285	269	245	200
	Surface daily totals				2850	1884	2218	2118	1966	1760	1392
Sep 21	7	5	8.3	77.5	107	25	36	36	34	32	28
	8	4	16.2	64.4	194	72	111	111	108	102	89
	9	3	23.3	50.3	233	114	181	182	178	168	147
	10	2	29.0	34.9	253	146	236	237	232	221	199
	11	1	32.7	17.9	263	166	271	273	267	254	223
	12		34.0	0.0	266	173	283	285	279	265	233
	Surface daily totals				2368	1220	1950	1962	1918	1820	1594
Oct 21	8	4	7.1	59.1	104	20	53	57	59	59	57
	9	3	13.8	45.7	193	60	138	145	148	147	138
	10	2	19.0	31.3	231	92	201	210	213	210	195
	11	1	22.3	16.0	248	112	240	250	253	248	230
	12		23.5	0.0	253	119	253	263	266	261	241
	Surface daily totals				1804	688	1516	1586	1612	1588	1480
Nov 21	9	3	5.2	41.9	76	12	49	54	57	59	58
	10	2	10.0	28.5	165	39	132	143	149	152	148
	11	1	13.1	14.5	201	58	179	193	201	203	196
	12		14.2	0.0	211	65	194	209	217	219	211
	Surface daily totals				1094	284	914	986	1032	1046	1016
Dec 21	9	3	1.9	40.5	5	0	3	4	4	4	4
	10	2	6.6	27.5	113	19	86	95	101	104	103
	11	1	9.5	13.9	166	37	141	154	163	167	164
	12		10.6	0.0	180	43	159	173	182	186	182
	Surface daily totals				748	156	620	678	716	734	722

1 BTUH/SQ. FT. = 3.152 W/m²

NOTE: 1) Based on data in Table 1, p. 387 in ref. [3]; 0% ground reflectance; 1.0 clearness factor.

2) See Fig. 4, p. 394 in [3] for typical regional clearness factors.

3) Ground reflection not included on normal or horizontal surfaces.

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64 Degrees North Latitude

Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
	AM	PM	Alt	Azm	Normal	Horiz.	South facing surface angle with horiz.				
							54	64	74	84	90
Jan 21	10	2	2.8	28.1	22	2	17	19	20	20	20
	11	1	5.2	14.1	81	12	72	77	80	81	81
	12		6.0	0.0	100	16	91	98	102	103	103
	Surface daily totals				306	45	268	290	302	306	304
Feb 21	8	4	3.4	58.7	35	4	17	19	19	19	19
	9	3	8.6	44.8	147	31	103	108	111	110	107
	10	2	12.6	30.3	199	55	170	178	181	178	[illegible]
	11	1	15.1	15.3	222	71	212	220	223	219	[illegible]
	12		16.0	0.0	228	77	225	235	237	232	226
	Surface daily totals				1432	400	1230	1286	1302	1282	1252
Mar. 21	7	5	6.5	76.5	95	18	30	29	29	27	25
	8	4	20.7	62.6	185	54	101	102	99	94	89
	9	3	18.1	48.1	227	87	171	172	169	160	153
	10	2	22.3	32.7	249	112	227	229	224	213	203
	11	1	25.1	16.6	260	129	262	265	259	246	235
	12		26.0	0.0	263	134	274	277	271	258	246
	Surface daily totals				2296	932	1856	1870	1830	1736	1656
Apr 21	5	7	4.0	108.5	27	5	2	2	2	1	1
	6	6	10.4	95.1	133	37	15	9	8	7	6
	7	5	17.0	81.6	194	76	70	63	[illegible]	43	37
	8	4	23.3	67.5	228	112	136	128	116	102	91
	9	3	29.0	52.3	248	144	197	189	176	158	145
	10	2	33.5	36.0	260	169	246	239	224	203	188
	11	1	36.5	18.4	266	184	278	270	255	233	[illegible]
	12		37.6	0.0	268	190	289	281	266	249	225
	Surface daily totals				2982	1644	2176	2082	1936	1736	1594
May 21	4	8	5.8	125.1	51	11	5	4	4	3	3
	5	7	11.6	112.1	132	42	13	11	10	9	8
	6	6	17.9	99.1	185	79	29	16	14	12	11
	7	5	24.5	85.7	218	117	86	72	56	39	28
	8	4	30.9	71.5	239	152	148	133	115	94	80
	9	3	36.8	56.1	252	182	204	190	170	145	128
	10	2	41.6	38.9	261	205	249	239	213	186	167
	11	1	44.9	20.1	265	219	278	264	242	213	193
	12		46.0	0.0	267	224	288	274	251	222	201
	Surface daily totals				3470	2236	2312	2124	1898	1624	1436
Jun 21	3	9	4.2	139.4	21	4	2	2	2	2	1
	4	8	9.0	126.4	93	27	10	9	8	7	6
	5	7	14.7	113.6	154	60	16	15	13	11	10
	6	6	21.0	100.8	194	96	34	19	17	14	13
	7	5	27.5	87.5	221	132	91	74	55	36	23
	8	4	34.0	73.3	239	166	150	133	112	88	73
	9	3	39.9	57.8	251	195	204	187	164	137	119
	10	2	44.9	40.4	258	217	247	230	206	177	157
	11	1	48.3	20.9	262	231	275	258	233	202	181
	12		49.5	0.0	263	235	284	267	242	211	189
	Surface daily totals				3650	2488	2342	2118	1862	1558	1356

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Date	Solar time		Solar position		BTUH/sq. ft. total insolation on surfaces						
	AM	PM	Alt	Azm	Normal	Horiz.	South facing surface angle with horiz.				
							54	64	74	84	90
Jul 21	4	8	6.4	125.3	53	13	6	5	5	4	4
	5	7	12.1	112.4	128	44	14	13	11	10	9
	6	6	18.4	99.4	179	81	30	17	16	13	12
	7	5	25.0	86.0	211	118	86	72	56	38	28
	8	4	31.4	71.8	231	152	146	131	113	91	77
	9	3	37.3	56.3	245	182	201	186	166	141	124
	10	2	42.2	39.2	253	204	245	230	208	181	162
	11	1	45.4	20.2	257	218	273	258	236	207	187
	12		46.6	0.0	259	223	282	267	245	216	195
	Surface daily totals				3372	2248	2280	2090	1864	1588	1400
Aug 21	5	7	4.6	108.8	29	6	3	3	2	2	2
	6	6	11.0	95.5	123	39	16	11	10	8	7
	7	5	17.6	81.9	181	77	69	61	52	42	35
	8	4	23.9	67.8	214	113	132	123	112	97	87
	9	3	29.6	52.6	234	144	190	182	169	150	138
	10	2	34.2	36.2	246	168	237	229	215	194	179
	11	1	37.2	18.5	252	183	268	260	244	222	205
	12		38.3	0.0	254	188	278	270	255	232	215
	Surface daily totals				2808	1646	2108	1008	1860	1662	1522
Sep 21	7	5	6.5	76.5	77	16	25	25	24	23	21
	8	4	12.7	72.6	163	51	92	92	90	85	81
	9	3	18.1	48.1	206	83	159	159	156	147	141
	10	2	22.3	32.7	229	108	212	213	209	198	189
	11	1	25.1	16.6	240	124	246	248	243	230	220
	12		26.0	0.0	244	129	258	260	254	241	230
	Surface daily totals				2074	892	1726	1736	1696	1608	1532
Oct 21	8	4	3.0	58.5	17	2	9	9	10	10	10
	9	3	8.1	44.6	122	26	86	91	93	92	90
	10	2	12.1	30.2	176	50	152	159	161	159	155
	11	1	14.6	15.2	201	65	193	201	203	200	195
	12		15.5	0.0	208	71	207	215	217	213	208
	Surface daily totals				1238	358	1088	1136	1152	1134	1106
Nov 21	10	2	3.0	28.1	23	3	18	20	21	21	21
	11	1	5.4	14.2	79	12	70	76	78	80	79
	12		6.2	0.0	97	17	89	96	100	101	100
	Surface daily totals				302	46	266	286	298	302	300
Dec 21	11	1	1.8	13.7	4	0	3	4	4	4	4
	12		2.6	0.0	16	2	14	15	16	17	17
	Surface daily totals				24	2	20	22	24	24	24

1 BTUH/SQ. FT. = 3.152 W/m²

NOTE:
1) Based on data in Table 1, p. 387 in ref. [3]; 0% ground reflectance; 1.0 clearness factor.
2) See Fig. 4, p. 394 in [3] for typical regional clearness factors.
3) Ground reflection not included on normal or horizontal surfaces.

APPENDIX C

Appendix
C-1

Table 1
THERMAL PROPERTY DATA

Material	Thermal Conductivity, k (Btu-ft/hr ft^2 ^{o}F)
Air	.015
Water	.35
Brick	.22 - .30
Concrete	.50 - .75
Glass	.42 - .50
Granite	1.08 - 2.33
Limestone	.33 - .75
Sandstone	.87 - 1.33
Wood	.14
Gypsum Wallboard	.0925
Corkboard	.022 - .025
Fiberglass batt	.025 - .030
Glass wool blanket	.022 - .023
Insulating boards	.027 - .031
Polystyrene	.022
Polyurethane	.011
Rock wool, loose	.024 - .030
Aluminum	55 - 110
Copper	15 - 65
Nickel	8 - 12
Silver, cast	242
Steel (~1% carbon)	21 - 25
Zinc, cast	60 - 65

C-1

Table 2
COEFFICIENTS OF TRANSMISSION OF WINDOWS

Window	(U-values)
Single glass .25"	1.10
Thermopane .5" airspace	.49
Storm windows 1 to 4" gap	.50

Table 3
R-VALUES

Material	R-Value
Plasterboard, 1" thick	0.45
Plywood, 1/4" thick	0.31
Paneling, softwood 1" thick	1.25
Paneling, hardwood 1" thick	0.95
Cork wall covering 1/8" thick	0.44
Acoustic tile	2.75
Terrazzo, 1" thick	0.08
Concrete, 1" thick	0.08
Linoleum flooring	0.05
Vinyl flooring	0.05
Rubber floor tiles	0.05
Carpet with fibrous pad	2.00
Air, 3/4" to 4"	0.96
Insulating board, 15/32"	1.11
Styrene foam, 1"	4.5

C-1

Table 3 (continued)

Material	R-Value
Mineral wool, 1"	3.3
Glass, single pane	0.88
Glass, two pane	1.54
Glass, thermopane	2.04
Glass, three pane	2.12
Glass, storms with 1" to 4" gap	2.00
For comparison 1" fiber glass	3.30

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Table 4

INSULATION (R-values)

Material Thickness (Inches)	Batts or Blankets Glass Fiber	Batts or Blankets Rock Wool	Loose Fill (Poured in) Glass Fiber	Loose Fill (Poured in) Rock Wool	Loose Fill (Poured in) Cellulose Fiber
1	3.38	3.66	2.20	2.75	3.66
2	6.76	7.32	4.40	5.50	7.32
3	10.14	10.98	6.60	8.25	10.98
4	13.52	14.64	8.80	11.00	14.64
5	16.90	18.30	11.00	13.75	18.30
6	20.28	21.96	13.20	16.50	21.96
7	23.66	25.62	15.40	19.25	25.62
8	27.04	29.28	17.60	22.00	29.28
9	30.42	32.94	19.80	24.75	32.94
10	33.80	36.60	22.00	27.50	36.60
11	37.18	40.26	24.20	30.25	40.26
12	40.56	43.92	26.40	33.00	43.92

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Table 5

RECOMMENDED R-Values

	FHA Minimum for Gas Heat	National Mineral Wool Assoc. for Oil Heating	TVA Electric Heating	Studies based on minimum life cost	Owen Corning
Ceilings	R-19	R-19 or 22	R-19	R-30	R-38
Walls	R-11	R-11	R-11	R-20	R-19
Floors over unheated space		R-11	R-11	R-20	R-22
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Table 6

RETROFITTING

Typical Old House	R-value	Retrofitted	
Roof	3	12" fiberglass	R=43
Wall	4	3½ blown	R=18
Basement	10	3½ fiberglass or 2" styrofoam	R=20
Ground Floor	5	6" fiberglass	R=25
Door	2	Add storm insu- lated door	R-3 R-10
Window	1	Add storm window shutters	R-10
Maine Audubon Society			

Appendix
C-2

Heat Loss for Typical Walls

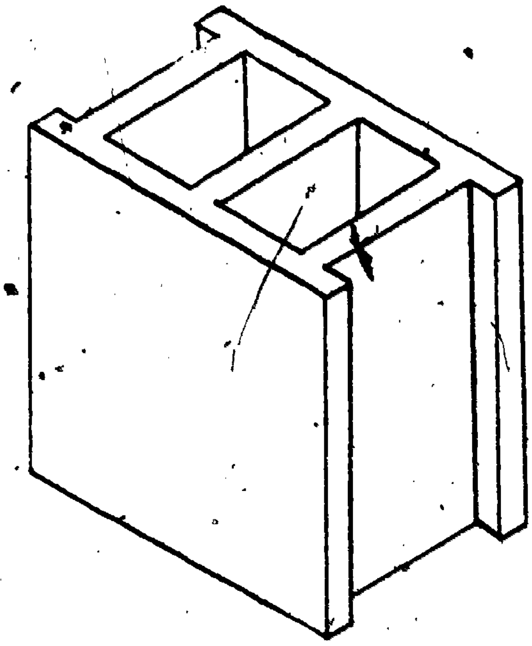

Figure 1

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Concrete block, sand and gravel aggregate, 8 in.	1.04
3. Inside surface (still air)	0.68
	1.89

$q = 37.04$ Btu/hr ft^2

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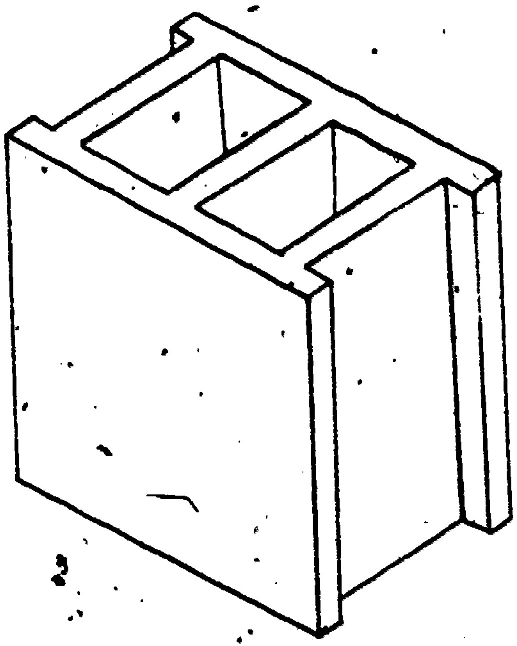

Figure 2

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Concrete block, lightweight aggregate, 8 in.	2.17
3. Inside surface (still air)	0.68
	3.02

$q = 23.18$ Btu/hr ft^2

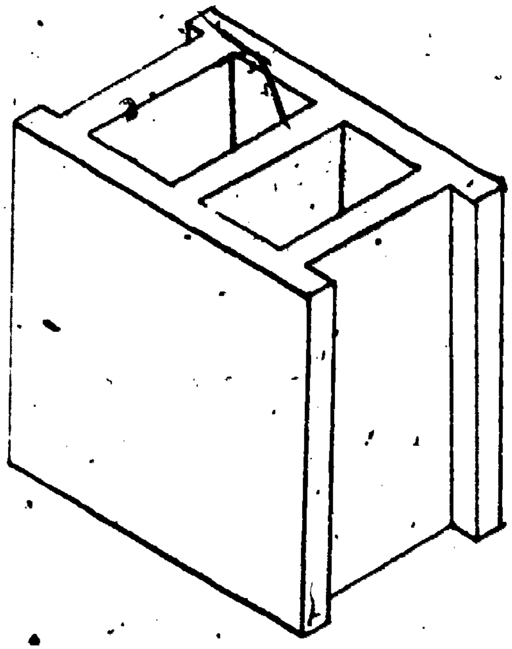

Figure 3

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Concrete block, sand and gravel aggregate, insulated with mineral wool, 8 in.	1.92
3. Inside surface (still air)	0.68
	2.77

$q = 25.27$ Btu/hr ft^2

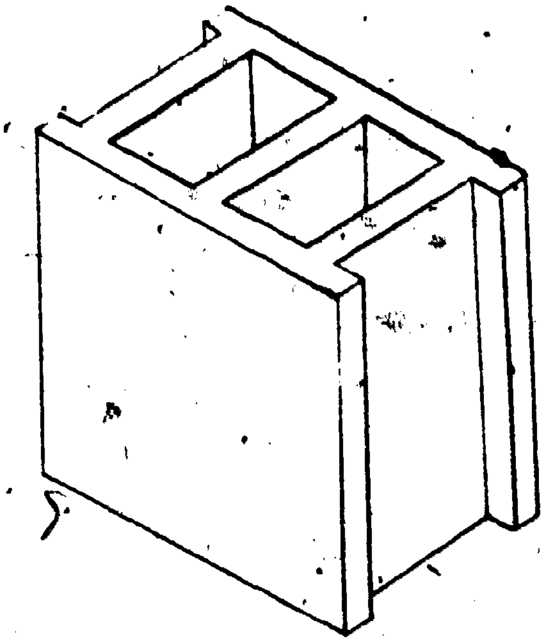

Figure 4

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Concrete block, lightweight aggregate, insulated with mineral wool, 8 in.	5.00
3. Inside surface (still air)	0.68
	5.85

$q = 11.97$ Btu/hr ft^2

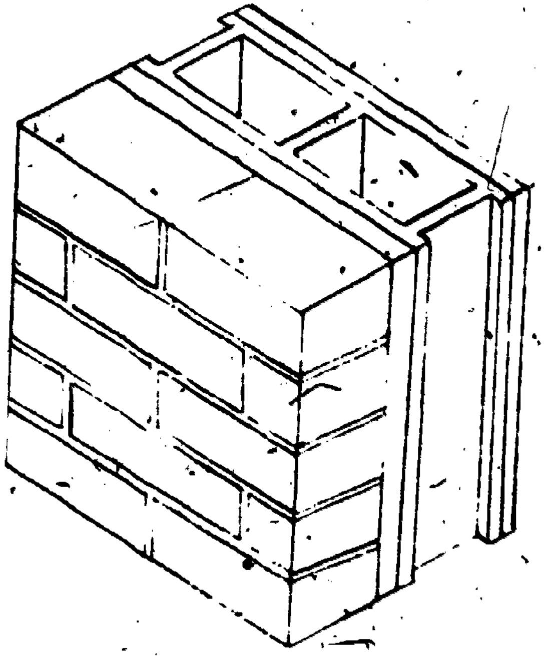

Figure 5

CONSTRUCTION	RESISTANCE
1. Face brick, 3.625 in.	.50
2. Rigid polystrene extruded, 1 in.	.36
3. Concrete block, lightweight aggregate, 4 in.	1.49
4. Plaster, .375 in.	.03
5. Outside surface, (15 m.p.h. wind)	0.17
6. Inside surface (still air)	0.68
	3.23

$q = 21.64$ Btu/hr ft^2

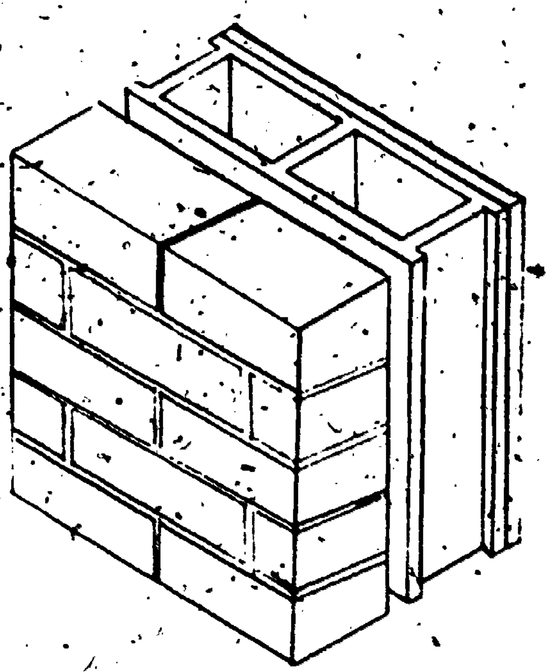

Figure 6

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Face brick, 3.625 in.	0.50
3. Non-reflective air space, 1.00 in.	1.12
4. Concrete block, lightweight aggregate, 4.00 in.	1.49
5. Plaster, sand aggregate, .375 in.	0.08
6. Inside surface (still air)	0.68
	4.04

$$q = 17.35 \text{ Btu/hr ft}^2$$

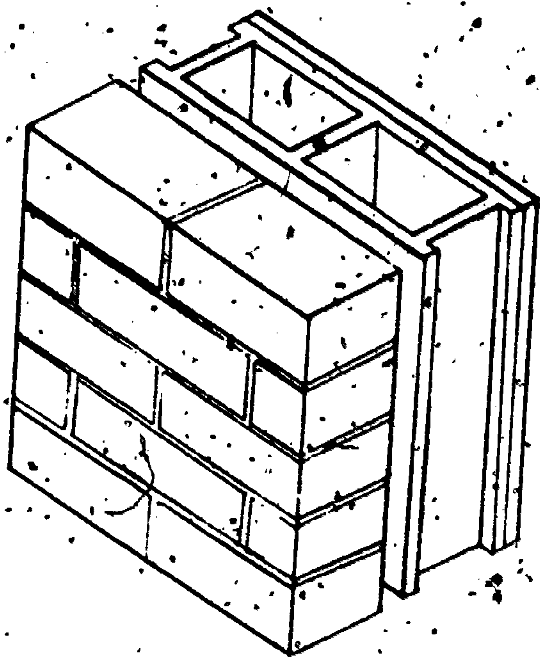

Figure 7

CONSTRUCTION	RESISTANCE
1. Face brick, 3.625 in.	0.50
2. Outside surface (15 m.p.h. wind)	0.17
3. Air space, 1 in.	1.12
4. Concrete block, lightweight aggregate, insulated with mineral wool, 4 in.	2.50
5. Plaster, .375 in.	0.03
6. Inside surface (still air)	0.68
	5.00

q= 13.99 Btu/hr ft^2

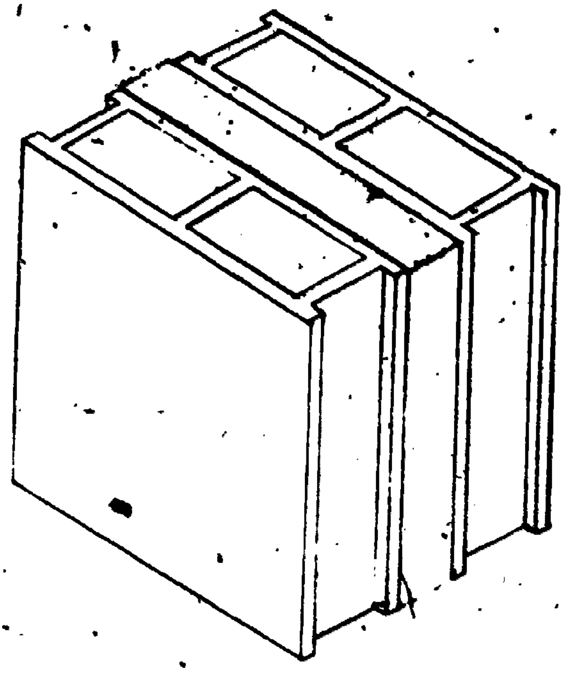

Figure 8

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Concrete block, lightweight aggregate, 4 in.	1.49
3. Polyurethane foam, 2 in.	15.15
4. Concrete block, lightweight aggregate, 4 in.	1.49
5. Inside surface (still air)	0.68
	18.98

$q = 3.69$ Btu/hr ft^2

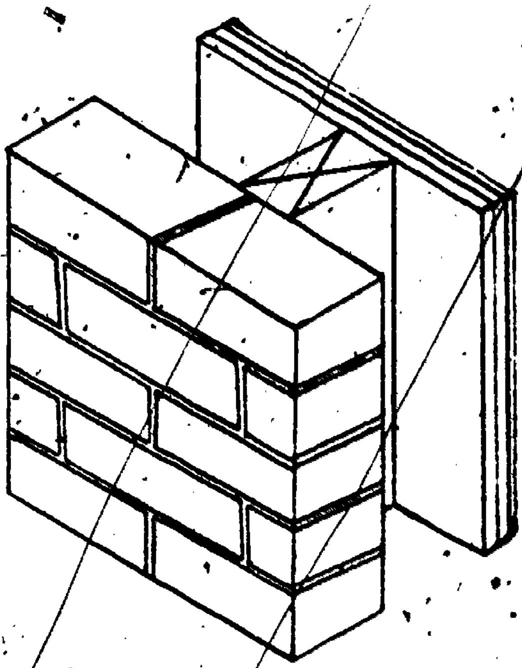

Figure 9

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Face brick, 3.625 in.	0.50
3. 2" x 4" studs @ 16" o.c.	4.38
4. Air space, 3.50 in.	1.14
5. Impregnated sheathing, .75 in.	2.04
6. Plywood, .75 in.	.93
7. Gypsum board, .50 in.	.45
8. Inside surface (still air)	0.68
	10.29

$q = 6.80$ Btu/hr ft^2

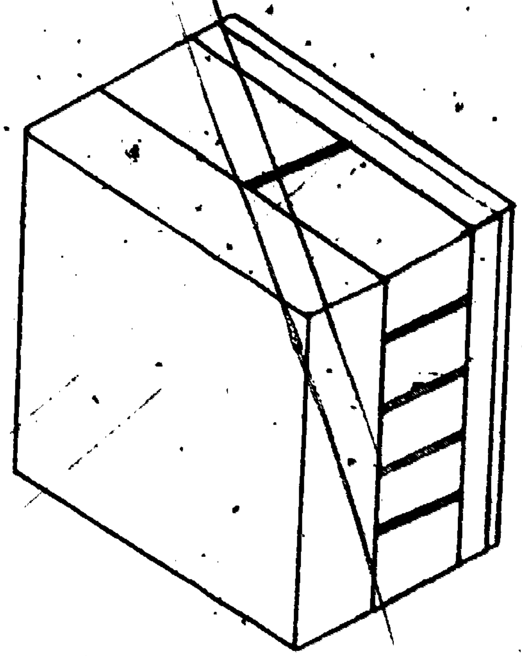

Figure 10

CONSTRUCTION	RESISTANCE
1. Marble, 3.00 in.	.33
2. Face brick, 3.625 in.	.50
3. Pine, 1.00 in.	1.39
4. Plaster, .75 in.	1.56
5. Outside surface, (15 m.p.h. wind)	0.17
6. Inside surface (still air)	0.68
	4.63

$q = 15.10$ Btu/hr ft^2

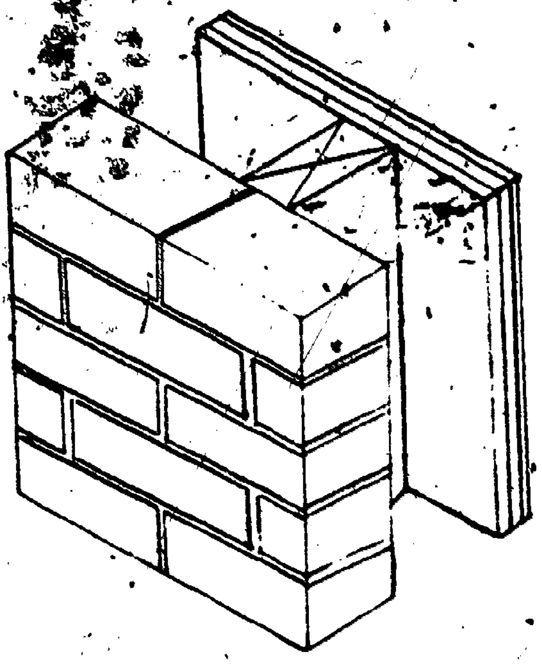

Figure 11

CONSTRUCTION	RESISTANCE
1. Outside surface (15 m.p.h. wind)	0.17
2. Face brick, 3.625 in.	0.50
3. 2" x 4" studs @ 16" o.c.	4.38
4. 3.5 in. polyurethane insulation	26.52
5. Impregnated sheathing, .75 in.	2.04
6. Plywood, .75 in.	.93
7. Gypsum board, .50 in.	.45
8. Inside surface (still air)	0.68
	35.67

$q = 1.962$ Btu/hr ft^2

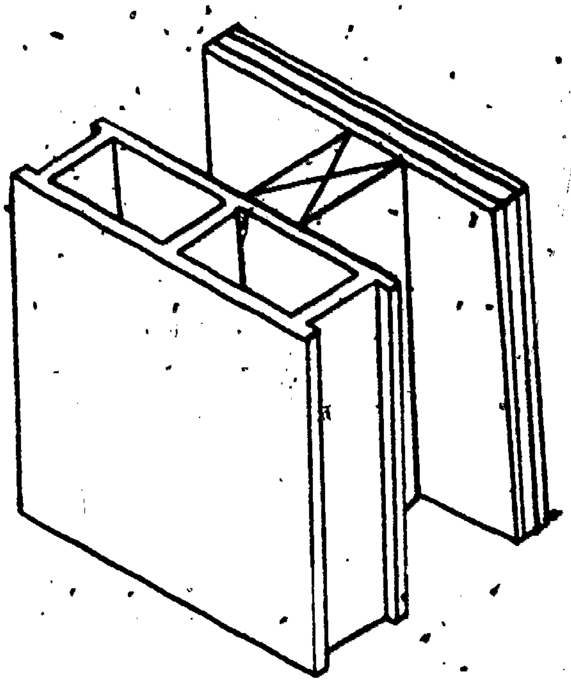

Figure 12

CONSTRUCTION	RESISTANCE
1. Concrete block, lightweight aggregate, 4.00 in.	1.47
2. Outside surface, 15 m.p.h. wind	0.17
3. 2" x 4" studs @ 16 in. o.c.	4.38
4. Impregnated wood sheathing, .75 in.	2.04
5. Plywood, .75 in.	.93
6. Gypsum board, .50 in.	.45
7. Inside surface (still air)	0.68
	10.12

$q = 6.92$ Btu/hr ft^2

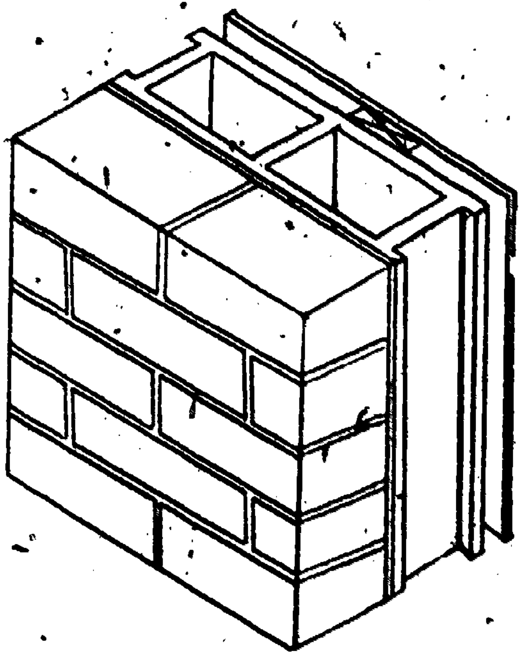

Figure 13

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. Cement mortar, 0.5 in.	0.10
4. Concrete block, cinder aggregate, 4.00 in.	1.47
5. Reflective air space, 0.75 in.	2.77
6. Nominal 1" x 3" vertical furring	0.94
7. Gypsum wallboard, .5 in.	0.45
8. Inside surface (still air)	0.68
	7.08

$q = 9.88$ Btu/hr ft^2

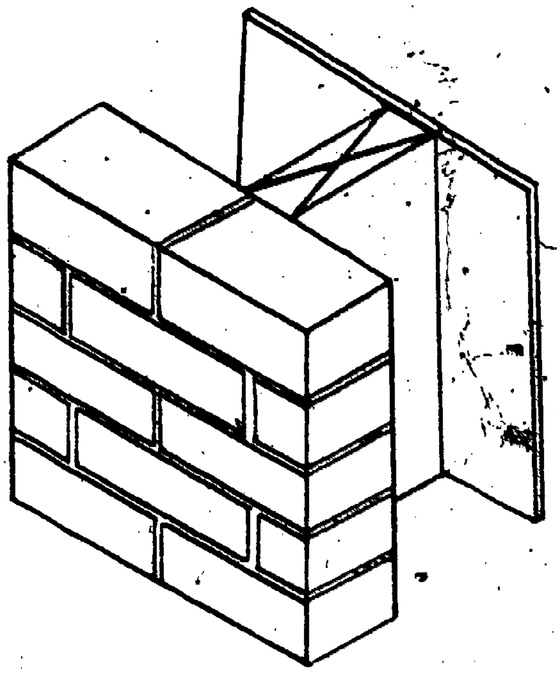

Figure 14

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. 2" x 6" studs	6.88
4. Air space, 5.50 in.	1.16
5. Gypsum board, 0.5 in.	0.45
6. Inside surface (still air)	0.68
	9.84

$q = 7.11$ Btu/hr ft^2

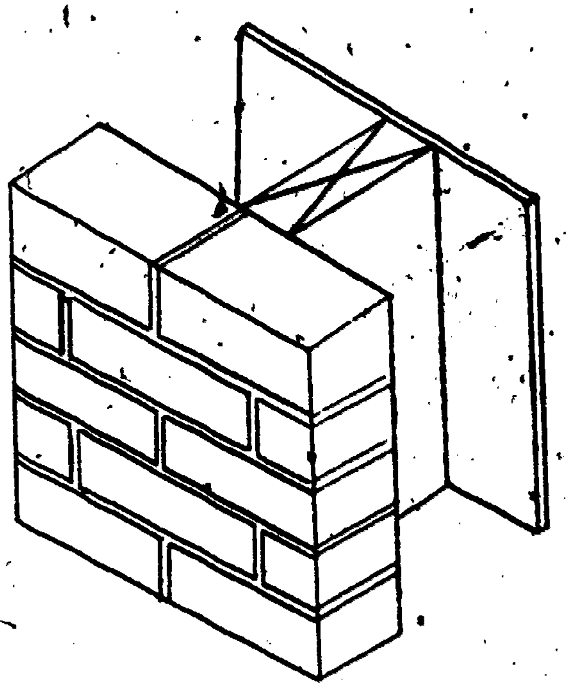

Figure 15

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. 2" x 6" studs	6.88
4. Polyurethane insulation, 5.50 in.	41.67
5. Gypsum board, 0.5 in.	0.45
6. Inside surface (still air)	0.68
At framing: R = 8.683 Between framing: R =	43.47

Average R factor at the studs is = 37.67

$q = 1.77$ Btu/hr ft^2

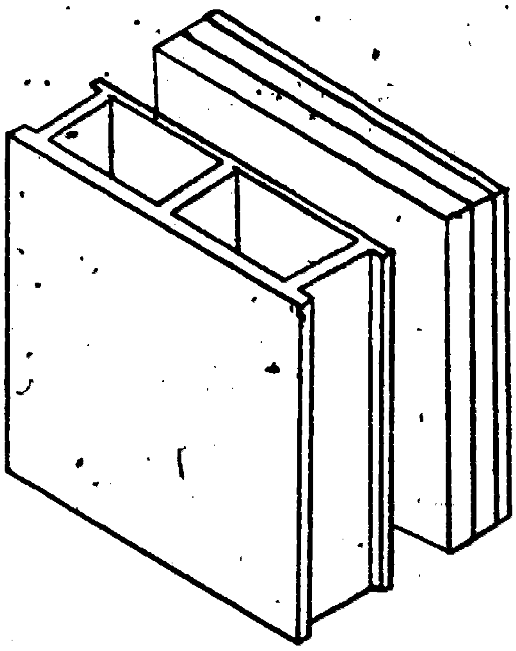

Figure 16

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Concrete block, lightweight aggregate, insulated with mineral wool, 4 in.	2.50
3. Air space, 2 in.	1.12
4. Polyurethane, 1in.	7.58
5. Wood siding, 1 in.	0.67
6. Gypsum board, .50 in.	0.45
7. Inside surface (still air)	0.68
	12.87

$q = 5.439$ Btu/hr ft^2

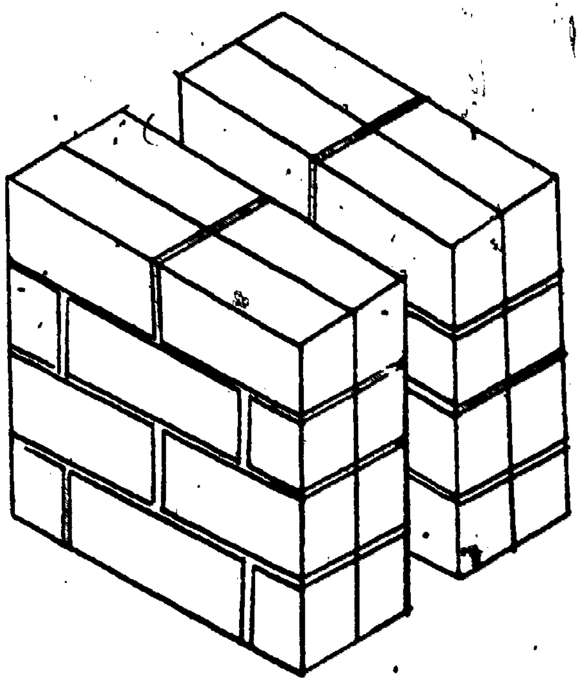

Figure 17

CONSTRUCTION	RESISTANCE
1. 2 wythes of bricks, 4.50 in.	0.62
2. Air space, 2 in.	1.15
3. 2 wythes of bricks, 4.50 in.	0.62
4. Outside surface, 15 m.p.h. wind	0.17
5. Inside surface (still air)	0.68
	3.24

$q = 21.54$ Btu/hr ft^2

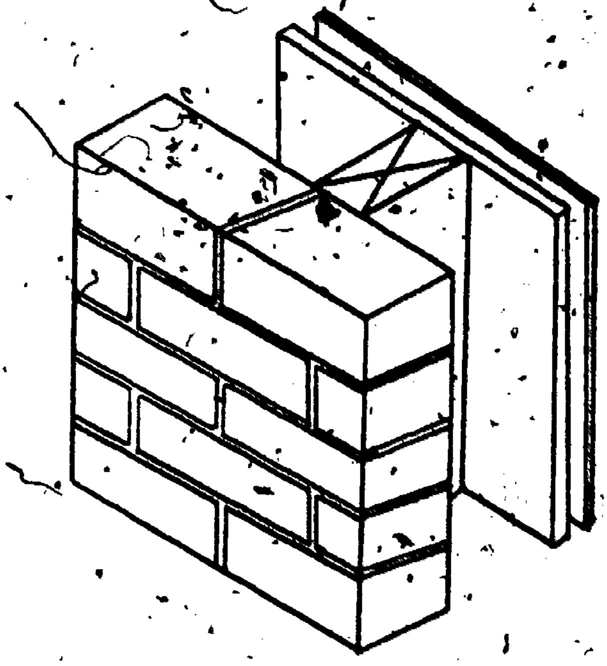

Figure 18 .

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. Wood studs, 2" x 4"	4.38
4. Air, 3.50 in.	1.16
5. Plywood, .75 in.	0.93
6. Reflective air space, .75 in.	2.77
7. Gypsum board, .5 in.	0.45
8. Inside surface (still air)	0.68
	11.21

$q = 6.24$ Btu/hr ft^2

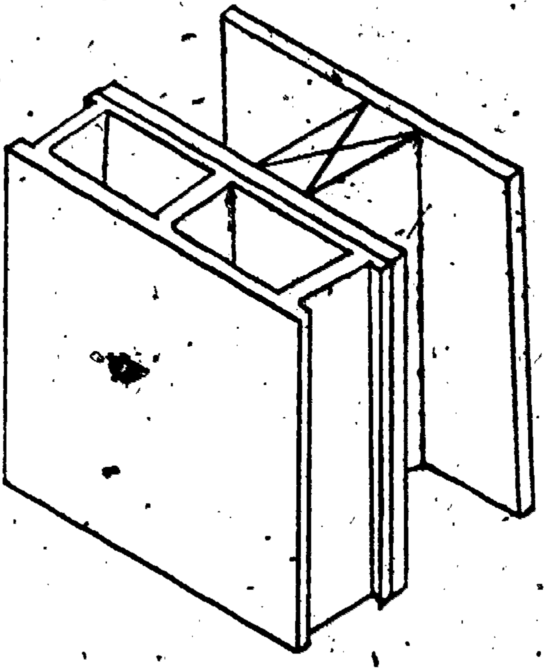

Figure 19

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Concrete block, lightweight aggregate, insulated with mineral wool, 4 in.	2.50
3. Plywood, .75 in.	0.93
4. Wood studs, 2" x 4"	4.38
5. Polyurethane, 3.50 in.	26.52
6. Plywood, .75 in.	0.93
7. Inside surface (still air)	0.68
	36.11

$q = 1.98$ Btu/hr ft^2

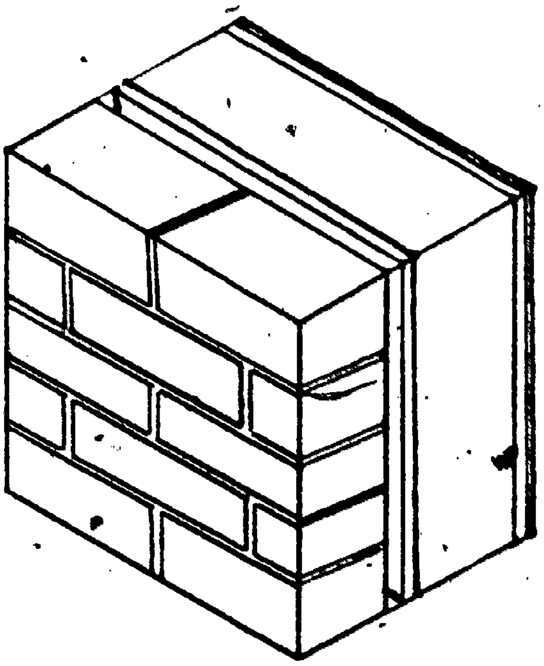

Figure 20

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. Reflective air space, .75 in.	2.77
4. Polyurethane, 4.50 in.	34.09
5. Plywood, .75 in.	0.93
6. Plywood, .75 in.	0.93
7. Gypsum wallboard, .375 in.	0.32
8. Inside surface (still air)	0.68
	40.39

$q = 1.73$ Btu/hr ft^2

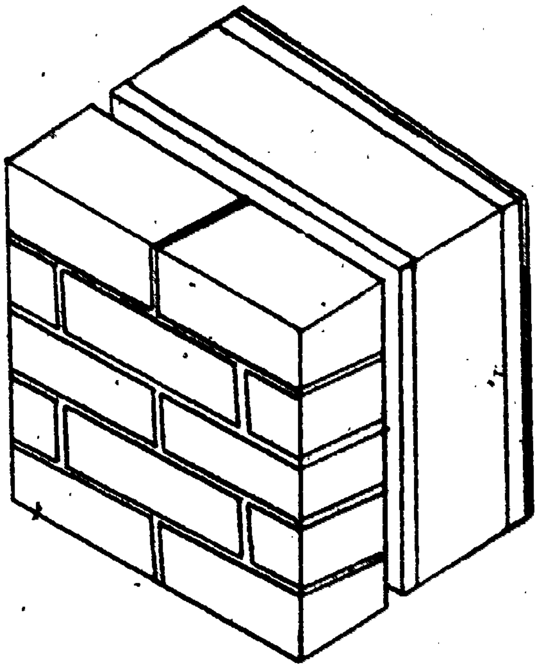

Figure 21

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. Reflective air space, .75 in.	2.77
4. Polystyrene, 4.50 in.	17.04
5. Plywood, .75 in.	0.93
6. Plywood, .75 in.	0.93
7. Gypsum board, .375 in.	0.32
8. Inside surface (still air)	0.68
	23.34

$q = 2.99$ Btu/hr ft^2

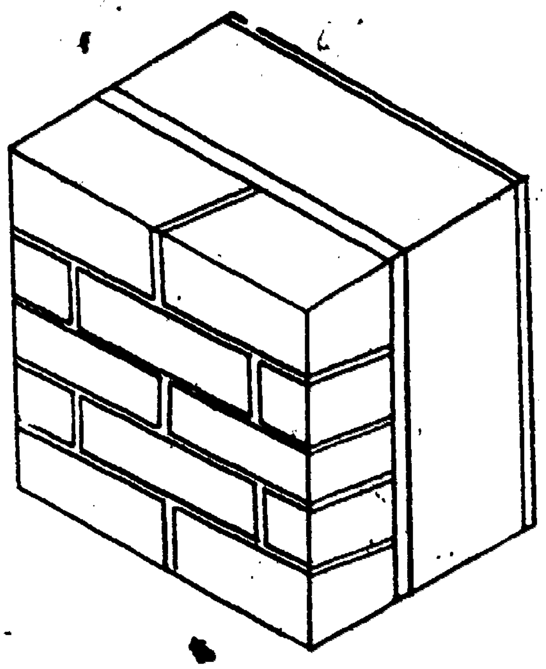

Figure 22

CONSTRUCTION	RESISTANCE
1. Outside surface, 15 m.p.h. wind	0.17
2. Face brick, 3.625 in.	0.50
3. Wood sheathing, .75 in.	2.04
4. Polystyrene, 4.50 in.	17.04
5. Gypsum wallboard, .50 in.	0.45
6. Inside surface (still air)	0.68
	20.88

$q = 3.35$ Btu/hr ft^2

APPENDIX D

ESTIMATED ANNUAL ENERGY CONSUMPTION OF APPLIANCES (KILOWATT-HOURS)

Major

Air Conditioner (room) - 860
Air Conditioner (central) - 1240
Clothes Dryer - 993
Dishwasher - 363
Freezer (16 cu ft.) - 1190
Freezer (frostless, 16.5 cu ft.) - 1820
Range - 700
Range (self-cleaning) - 730
Refrigerator (12 cu. ft.) - 728
Refrigerator (frostless, 12 cu. ft.) - 1217
Refrigerator/Freezer (12.5 cu. ft.) - 1500
Refrigerator/Freezer (frostless, 17.5 cu. ft.) - 2250
Washing Machine (automatic) - 103
Washing Machine (wringer type) - 76
Water Heater - 4811

Kitchen

Blender - 15
Broiler - 100
Carving Knife - 8
Coffee Maker - 140
Deep Fryer - 83
Egg Cooker - 14
Frying Pan - 186
Hot Plate - 90
Mixer - 13
Microwave Oven - 190
Roaster - 205
Sandwich Grill - 33
Toaster - 39

Kitchen (continued)

T[illegible]sh Compacter - 50
Waffle Iron - 22
Waste Disposer - 30

Heating & Cooling

Air Cleaner - 216
Electric Blanket - 147
Dehumidifier - 377
Fan (attic) - 291
Fan (furnace) - 43
Fan (rollaway) - 138
Fan (window) - 170
Heater (portable) - 176

Heating & Cooling (continued)

Heating Pad - 10
Humidifier - 163
Iron (hand) - 144

Health & Beauty

Germicidal Lamp - 141
Hair Dryer - 14
Heat Lamp (infrared) - 13
Shaver - 1.8
Sun Lamp - 16
Toothbrush - 0.5
Vibrator - 2

Entertainment

Radio - 86
Radio/Record Player - 109
TV:
  Black & White:
    Tube type - 350
    Solid state - 120
  Color:
    Tube type - 660
    Solid state - 440

Housewares

Clock - 17
Floor Polisher - 15
Serving Machine - 11
Vacuum Cleaner - 46

Reference: "Tips for Energy Savers", Federal Energy Administration, August 1977

APPENDIX E

GLOSSARY

ABSORPTIVITY. The ratio of the incident radiant energy absorbed by a surface to the total radiant energy falling on the surface.

ACCELERATION. The time rate of change of velocity in either speed or direction.

ALBEDO. The ratio of the light reflected by a surface to the light falling on it.

ALTERNATING CURRENT. An electric current whose direction of flow is changed at periodic intervals (many times per second).

AMPERE. A unit of measure for an electric current; rate of flow of electric current.

ATOMIC ENERGY. Energy derived from the mass converted into energy in nuclear transformations.

BARREL. Although seldom put in actual "barrels," crude oil is measured in a unit called the barrel, equal to 42 U.S. gallons. One barrel of crude oil has the same energy as 350 pounds of coal.

BASE LOAD. The minimum amount of power demanded of a utility (electric or gas) over a given period of time.

BLACKOUT. A situation in which all power is cut off from electrical - generating facilities; or can be caused by storm damage, equipment failure, or overloaded utility equipment.

BREEDER REACTOR. A nuclear chain reactor in which a greater number of fissionable atoms are produced than the number of parent atoms consumed.

BRITISH TERMAL UNIT (BTU). The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near its point of maximum density (39.1°F).

BROWNOUT. The deliberate lowering of voltage (and thus the power supplied to all users) by electric utility companies; employed when demand for power exceeds generating capacity.

CALORIE. The amount of heat necessary to raise one kg of water by one degree Celsius. Uncapitalized, the calorie is the amount of heat required to raise one gram of H_2O one °C.

CAPACITY. The maximum load for which a generator, transmission circuit, power plant, or system is rated.

CELSIUS SCALE: The temperature scale using the ice point as 0 and the steam point as 100, with 100 equal divisions or degrees between.

CHEMICAL ENERGY. The kind of energy that may be released when a chemical reaction takes place.

CIRCUIT. The complete path traversed by an electric current.

COAL. Solid, combustible, organic hydrocarbon formed by the decomposition of vegetable material under pressure and heat below the earth's surface.

COAL GASIFICATION. The conversion of coal to a gas suitable for use as a fuel.

COLLECTOR EFFICIENCY. The ratio of the energy collected by a solar collector to the radiant energy incident on the collector.

COMBUSTION. Burning; technically, a rapid oxidation accompanied by the release of energy in the form of heat and light.

CONDUCTION (ELECTRICAL). The process of carrying an electrical current.

CONSERVATION OF MATTER AND ENERGY (LAW OF). Matter and energy are interchangeable; the total amount of energy and matter in the universe remains constant.

CONSERVATION OF MECHANICAL ENERGY (LAW OF). The sum of the potential and kinetic energy of an ideal energy system remains constant.

CONVECTION. The transfer of energy by moving masses of matter.

CONVENTIONAL HYDROELECTRIC PLANT. A hydroelectric power plant that utilizes streamflow only once as the water passes downstream, as opposed to a pumped-storage plant which recirculates all or a portion of the streamflow.

COULOMB. The amount of charge delivered by an electrical current of one ampere flowing for one second.

CRUDE OIL. Liquid fuel formed from the fossils of animals and plants at the bottom of ancient seas; petroleum as it comes from the ground.

CURRENT (ELECTRIC). The rate of movement of electricity.

CURTAILMENT. Cutting back the use of energy resources in an emergency as opposed to conserving or wisely using energy resources.

DENSITY. The mass per unit volume.

DIRECT CURRENT. An electric current that flows in only one direction through a circuit.

DIRECT ENERGY CONVERSION. The process of changing any other form of energy into electricity without machinery; for example, a battery which changes chemical energy into electricity.

EER. Energy efficiency ratio; Btu's divided by wattage.

ELECTRICAL ENERGY. The energy associated with electric charges and their movement; measured in kilowatt-hours.

ENERGY. The capability of doing work. Potential energy is energy due to position of one body with respect to another or relative parts of the same body. Kinetic energy is due to motion.

ENTROPY. A measure of the unavailability of energy to do useful work; every spontaneous process in nature is characterized by an increase in the total entropy of the bodies concerned in the process.

ENVIRONMENT. The sum of all external conditions and influences affecting the life, development, and ultimately the survival of an organism.

EUTECTIC SALT. A material used to store heat by melting. Heat is later released for use as the material solidifies.

EVAPORATION. The change from liquid to gas in which molecules escape from the surface of the liquid.

FEEDSTOCK: Energy resources used as raw materials in the production of products rather than as fuels for burning.

FIRST LAW OF THERMODYNAMICS (also called the LAW OF CONSERVATION OF ENERGY). Energy can neither be created nor destroyed.

FISSION. A nuclear reaction in which the atom is split into two approximately equal masses. There is also the emission of extremely great quantities of energy since the sum of the masses of the two new atoms is less than the mass of the parent atom.

FLYWHEEL. Energy storage based on the principle that a spinning wheel stores mechanical energy.

FORCE. That property which changes the state of rest or motion in matter measured by the rate of change in momentum; the force (F) required to produce an acceleration (a) in a mass (m) is given by $F = ma$.

FOSSIL FUELS. Coal, oil, natural gas, shale, peat; originating from geologic deposits of ancient plant and animal life under millions of years of heat and pressure.

FRICTIONAL FORCE. Force required to move one surface across another.

FUEL. A substance used to produce heat energy.

FUEL CELL. A device in which fuel and oxygen are combined to produce electricity.

FUSION. A nuclear reaction involving the combination of smaller atomic nuclei or particles into larger ones with the release of energy from mass transformation; also called a thermonuclear reaction because of the extremely high temperature required to sustain it.

GAS. A state of matter in which the molecules are practically unrestricted by cohesive forces; a gas has neither definite shape nor volume.

GAOLINE. A mixture of hydrocarbons obtained from petroleum.

GENERATOR. A device that converts heat or mechanical energy into electrical energy.

GEOTHERMAL ENERGY. The heat energy available in the earth's subsurface, believed to have been produced by natural radioactivity; the temperature increases by about 1°F for each 100 feet of depth.

GRAM. A unit of mass in the cgs system.

GROSS NATIONAL PRODUCT (GNP). A measure of economic activity; the total market value of all goods and services produced in a country (depreciation and other allowances for capital consumption are not deducted).

HEAT. Energy possessed by a substance in the form of internal kinetic energy; transferred by conduction, convection, or radiation.

HEAT CAPACITY. That quantity of heat required to increase the temperature of a system or substance one degree Celsius.

HEAT ENERGY. Energy that causes an increase in the temperature of an object; it may change the object from solid to liquid or from liquid to gas.

HEAT OF FUSION. The heat absorbed by a body when undergoing a phase change from a solid to a liquid with no change in temperature.

HEAT OF SOLIDIFICATION. Heat released by a substance when undergoing a phase change from a liquid to a solid with no change in temperature (numerically equal to the heat of fusion).

HIGH-SULPHUR CONTENT. Generally, coal or oil that contains more than one percent of sulphur by weight.

HORSEPOWER. Unit of power in the English system.

HYDROELECTRIC PLANT. An electric power plant in which the turbine-generators are driven by falling water.

INCIDENT ANGLE. The angle between the direction of the sun and the perpendicular (normal) to the surface on which sunlight is falling.

INSOLATION. Sunlight or solar radiation, including wavelengths of ultraviolet (<0.4 microns), visible (0.4 microns to 0.7 microns), and infrared radiation (> 0.7 microns). Total insolation includes both direct and diffuse insolation.

INSULATION. A substance that can slow down the flow of heat or sound from one material to another.

JOULE. A metric unit measure of work; the energy produced by a force of one newton operating through a distance of one meter (joule = newton-meter).

KILOCALORIE. 1000 calories.

KILOWATT (kw). 1000 watts

KILOWATT-HOUR (kwh). The amount of work or energy delivered during the steady consumption of one kilowatt of power for a period of one hour.

LATENT HEAT. A physical property of material indicating the amount of heat in calories or BTU's absorbed when a material changes from a solid to a liquid (fusion) or from a liquid to a gas (vaporization). Energy is given up when a gas condenses or when a liquid solidifies.

LIGHT. Visible radiant energy.

LIQUEFIED NATURAL GAS (LNG). Natural gas that has been changed into a liquid by cooling to about -160^{o}C at which point it occupies about 1/600 of its gaseous volume at normal atmospheric pressure, thus reducing the cost of shipping and storage.

LIQUID. A state of matter in which the molecules are relatively free to change their positions with respect to each other but restricted by cohesive forces so as to maintain a relatively fixed volume.

LOW-SULPHUR CONTENT. Generally, used to describe coal or oil which is one percent or less sulphur by weight.

MASS. A measure of the weight of matter in an object. The weight of an object depends on its mass. The United States standard measure is the avoirdupois pound as defined by 1/2.20462 kilograms.

MEGAWATT (MW). A unit of power equal to 1,000 kilowatts or one million watts; usually used to describe the capacity of power plants.

METHANE. Colorless, nonpoisonous, and flammable gaseous hydrocarbon (CH_4); emitted by marshes and by dumps undergoing decomposition; the principal constituent of natural gas.

MOLECULE. The smallest unit or quantity of matter which can exist by itself, yet retain all the properties of the original substance.

MOMENTUM. Quantity of motion measured by the product of mass and velocity.

MOTION. Continuous change of location or position of a body.

NATURAL GAS. Mixtures of hydrocarbon gases and vapors occurring naturally in certain geologic formations, usually associated with oil.

NEUTRON. A constituent particle of all nuclei of mass number greater than 1.

NEWTON. A unit of force necessary to accelerate one kilogram one m/sec^2.

NONRENEWABLE RESOURCES. Near-term depletable energy resources, such as the fossil fuels (coal, gas, and oil).

NUCLEAR POWER PLANT. One in which heat for creating steam is provided by fission rather than combustion of fossil fuel.

NUCLEAR POWER. Electric power produced from a power plant by converting the energy obtained from nuclear reaction.

NUCLEAR REACTION. A change in an atomic nucleus, such as fission, fusion, neutron capture, or radioactive decay, as distinct from a chemical reaction, which is limited to changes in electron structure surrounding the nucleus.

OFF-PEAK POWER. Energy supplied during periods of relatively low system demands.

OMM. The basic unit of electrical resistance of a conductor.

OIL SHALE. A sedimentary rock containing solid organic matter (kerogen) that yields amounts of oil.

OPEC. The Organization of Petroleum Exporting Countries.

PEAKING DEMAND. The maximum peak load that can be supplied by a generating unit, station, or system in a stated period of time.

PHASE CHANGE. The process involved when a material changes from a solid to a liquid or a liquid to a gas, each requiring an absorption of energy with no temperature change; or when the material changes from a gas to a liquid to a solid, each requiring a loss of energy with no temperature change.

PHOTOVOLTAIC CELLS. (Solar cells): Semiconducting devices that convert sunlight directly into electric power.

PLUTONIUM. A fissionable element, artifically produced by neutron bombardment of U^{238}.

POWER. The time-rate at which work is done.

PRESSURE. Force per unit area.

PUMPED STORAGE PLANT. A hydroelectric power plant which generates electric energy for peak load use by utilizing water pumped into an elevated storage reservoir during off-peak periods.

PYRANOMETER. An instrument for measuring sunlight intensity. It usually measures total (direct plus diffuse) insolation over a broad wavelength range.

PYRHELIOMETER. An instrument that measures the intensity of the direct beam radiation (direct insolation) from the sun. The diffuse component is not measured.

RADIATION. The emission and propagation of energy through space or through [illegible] material medium in the form of waves.

RENEWABLE RESOURCES: Nondepletable resources.

RESERVES. The amount of a natural resource which can be recovered by present-day techniques and under present economic conditions.

RESERVOIR. A pond, lake, tank or basin, natural or man-made, used for the storage, regulation, and control of water.

RESOURCES. The estimated total quantity of natural resources, including prospective undiscovered mineral reserves.

SECOND LAW OF THERMODYNAMICS. One of the two laws which govern the conversion of energy; sometimes called the "heat tax," it can be stated in several equivalent forms, all of which describe the inevitable passage of energy from a useful to a less useful form in any energy conversion.

SOLAR CELL. An electric cell which converts radiant energy from the sun into electrical energy.

SOLAR ENERGY. Radiant energy from the sun.

SOLID. A state of matter in which the relative motion of the molecules is restricted and they tend to retain a definite fixed position relative to each other with a definite shape and volume.

SOLID WASTE. Unwanted or discarded material with insufficient liquid content to be free flowing.

SOUND ENERGY. A kind of energy carried by molecules that vibrate so that longitudinal waves are formed.

SPECIFIC HEAT. A physical property of materials that indicates the amount of heat required to raise the temperature of one pound of material one degree Fahrenheit, measured in BTU/lb °F; or one gram of material one degree Celsius measured in calorie/g°C.

STATIC ELECTRICITY: Electricity at rest.

STEAM-ELECTRIC PLANT. A plant in which the turbines connected to the generators are driven by steam.

STOCKPILE. A storage pile or reserve supply of an essential raw material.

STORAGE CELL. An electrochemical cell in which the reacting materials are renewed by the use of a reverse current from an external source.

STRIP-MINING. A process in which rock and topsoil strata covering ore or fuel deposits are scraped away by mechanical shovels.

TEMPERATURE. Average translational kinetic energy of the molecules of a substance due to heat agitation.

THERMAL POLLUTION. Degradation of water quality by the introduction of a heated effluent; primarily a result of the discharge of cooling waters from industrial processes, particularly from electrical power generation.

THERMODYNAMICS. The science and study of the relationship between heat and other forms of energy.

TRANSFORMER. A machine which can increase or decrease the voltage of an alternating current of electricity.

TRANSMISSION LINES. Wires or cables by which high voltage electric power is moved from point to point.

VOLT. Unit of potential difference required to make a current of one amp flow through a resistance of ohm; V = joules/coulombs.

WATT. A unit of power equal to the transfer of one joule of energy per second; /watt = /volt x /ampere.

WEIGHT. The measure of gravitational force acting on a mass; W = Fgrav = Mg.

WORK. A force acting through a distance.