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ABSTRACT

This minicourse was prepared for use with secondary physics students in the Dallas Independent School District and is one option in a physics program which provides for the selection of topics on the basis of student career needs and interests. This minicourse was aimed at providing students with a knowledge of the physics factors that determine the sensation of climatic comfort and the energy requirements for maintaining this comfort. The minicourse was designed for independent student use with close teacher supervision and was developed as an ESEA Title III project. A rationale, behavioral objectives, student activities, and resource packages are included. Student activities and resource packages include defining temperature, calibrating a thermometer, defining heat, investigating conduction, connection, radiation, specific heat, heat of fusion, insulating material, humidity, and dew point, and calculating heating loads. (GS)

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CAREER ORIENTED PRE-TECHNICAL PHYSICS

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Climatizing The Home

Minicourse

PRELIMINARY EDITION

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March 25, 1974

This Mini Course is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Mini Course contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through Mini Course activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Mini Course.

I commend it to your use.

Sincerely yours,

Nolan Estes

Nolan Estes
General Superintendent

mfs

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CAREER ORIENTED PRE-TECHNICAL PHYSICS TITLE III ESEA PROJECT

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CAREER ORIENTED PRE-TECHNICAL PHYSICS

CLIMATIZING THE HOME

MINICOURSE

RATIONALE (What this minicourse is about)

People's habits, clothing, housing, and general life styles are geared to their environment, and climate is a basic part of this environment. Historically, people have developed living spaces so as to become less dependent upon natural climatic conditions. Primitive living spaces included caves, cliff dwellings, igloos, tents, teepees, hogans, sod huts, bamboo shelters, etc. And in our modern technocracy we enjoy such climate-conquering mechanical devices as heaters, air conditioners, fans, filters, humidifiers, de-humidifiers, heat pumps, etc., to bring about optimal independence of natural atmospheric conditions in our living spaces.

The non-scientific terms, hot, sultry, cool, chilly, and cold have been used to describe climatic conditions. But because of individual perceptual differences, these terms are scientifically vague. Such terms reflect both psychological and physiological differences between observers. One observer may think perhaps it is a hot day, while a second observer feels "just right." Perceptions of climatic conditions can depend upon age, sex, state of health, activity, nutrition, etc. In general, however, the sensation of comfort can be related largely to the conditions that bring about heat exchanges between the body and the environment. If the removal of body heat is in equilibrium with the body's heat production, a person likely feels comfortable.

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In this minicourse you will study some of the technical physics factors that determine the sensation of climatic comfort: heat of the air, moisture content of the air, heat exchanges within the confines of the living space, etc. Also, you will learn how to estimate heating and cooling <u>loads</u> (energy requirements) for maintaining climatic comfort within a living place.

The technology of climate control relates to a wide variety of specialized careers. For example, related work is found in architectural design, air conditioning technology, air conditioning engineering, and home economics. Related jobs occur in the manufacture, distribution, and sales of climate control devices for use in industry, commerce, residences, public transportation, and private automobiles.

Climate control is a multi-billion dollar industry in the United States and job prospects seem excellent. The two most prevalent ways workers enter the industry are through on-the-job training and through formal course work. The latter has advantages in terms of job preferences, pay scale, and opportunity for advancement. Some high schools offer related courses; many community colleges offer one and two-year certificated programs, and certain colleges or universities offer both two and four-year degree programs in the field of climate control technology.

You are expected to keep a notebook during this minicourse. The notebook is to contain all problems, notes, experiments, and exercises. Your grade for this minicourse will be determined partially by the content and quality of the material in this notebook.

In addition to RATIONALE, this minicourse contains the following sections:

1) TERMINAL BEHAVIORAL OBJECTIVES (Specific things you are expected to learn from the minicourse)

2) ENABLING BEHAVIORAL OBJECTIVES (Learning "steps" which will enable you to eventually reach the terminal behavioral objectives)

3) ACTIVITIES (Specific <u>things to do</u> to help you learn)

4) RESOURCE PACKAGES (Specific instructions for performing the learning <u>Activities</u>, such as procedures, references, laboratory materials, etc.)

5) EVALUATION (Tests to help you learn and to determine whether or not you satisfactorily reach the terminal behavioral objectives)
   a) Self-test(s) with answers, to help you learn more.
   b) Final tests, to measure your overall achievement.

TERMINAL BEHAVIORAL OBJECTIVES

Upon the completion of this minicourse, you will be able to:

1) measure wet bulb and dry bulb temperatures, and relate these to comfort control.

2) demonstrate a knowledge of heat transfer, and explain how heat transfer properties of different materials relate to comfort control.

3) calculate water vapor content in the air, and relate this to climate control.

4) estimate the summer and winter <u>heat loads</u> (energy requirements) of a living space.

ENABLING BEHAVIORAL OBJECTIVE	ACTIVITY	RESOURCE PACKAGE
<u>ENABLING BEHAVIORAL OBJECTIVE #1</u>: Convert temperature in Fahrenheit degrees to Celsius (centigrade) degrees, and conversely.	<u>ACTIVITY 1-1</u> Read Resource Package 1-1 and perform the activity in Resource Package 1-2; then check by using Resource Package 1-3.	<u>RESOURCE PACKAGE 1-1</u> "Temperature" <u>RESOURCE PACKAGE 1-2</u> "Temperature Problems" <u>RESOURCE PACKAGE 1-3</u> "Answers to Temperature Problems"
<u>ENABLING BEHAVIORAL OBJECTIVE #2</u>: Calibrate a Fahrenheit thermometer.	<u>ACTIVITY 2-1</u> Complete the activities in Resource Package 2-1.	<u>RESOURCE PACKAGE 2-1</u> "Calibrating a Thermometer"
<u>ENABLING BEHAVIORAL OBJECTIVE #3</u>: Determine the temperature needed for a specific climate control.	<u>ACTIVITY 3-1</u> Complete Resource Package 3-1.	<u>RESOURCE PACKAGE 3-1</u> "Temperature Readings"
<u>ENABLING BEHAVIORAL OBJECTIVE #4</u>: Identify the different forms of heat and calculate thermal capacities of different materials.	<u>ACTIVITY 4-1</u> Read Resource Package 4-1. <u>ACTIVITY 4-2</u> Complete Resource Package 4-2. <u>ACTIVITY 4-3</u> Complete Resource Package 4-3.	<u>RESOURCE PACKAGE 4-1</u> "Heat Energy" <u>RESOURCE PACKAGE 4-2</u> "Investigating Conduction" <u>RESOURCE PACKAGE 4-3</u> "Investigating Convection"

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ENABLING BEHAVIORAL OBJECTIVE	ACTIVITY	RESOURCE PACKAGE
<u>ENABLING BEHAVIORAL OBJECTIVE #4:</u>	<u>ACTIVITY 4-4</u>	<u>RESOURCE PACKAGE 4-4</u>
(See Page 4 for statement of this objective.)	Complete Resource Package 4-4.	"Investigating Radiation"
	<u>ACTIVITY 4-5</u>	<u>RESOURCE PACKAGE 4-5</u>
	Complete Resource Package 4-5	"Investigating Specific Heat"
	<u>ACTIVITY 4-6</u>	<u>RESOURCE PACKAGE 4-6</u>
	Complete Resource Package 4-6.	"Investigating Heat of Fusion"
	<u>ACTIVITY 4-7</u>	<u>RESOURCE PACKAGE 4-7</u>
	Complete Resource Package 4-7. This is an independent kind of study. If you feel really lost, your instructor will help you. But this study is designed as an opportunity for you to do something on your own!	"Investigating Insulation Materials"
<u>ENABLING BEHAVIORAL OBJECTIVE #5:</u>	<u>ACTIVITY 5-1</u>	<u>RESOURCE PACKAGE 5-1</u>
Describe the effect water vapor has upon climate control.	Study Resource Package 6-1.	"Humidity"
<u>ENABLING BEHAVIORAL OBJECTIVE #6:</u>	<u>ACTIVITY 6-1</u>	<u>RESOURCE PACKAGE 6-1</u>
Compute the dew point.	Complete Resource Package 6-1.	"Investigating Dew Point"

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ENABLING BEHAVIORAL OBJECTIVE #7:	ACTIVITY 7-1	RESOURCE PACKAGE 7-1
Compute relative humidity and identify its effect upon climate control.	Complete Resource Package 7-1.	"Investigating Humidity and Comfort"
ENABLING BEHAVIORAL OBJECTIVE #8:	ACTIVITY 8-1	RESOURCE PACKAGE 8-1
Estimate the summer and winter energy loads for a given space.	Study Resource Package 8-1.	"Heat Loads"
	ACTIVITY 8-2	RESOURCE PACKAGE 8-2
	Complete Resource Package 8-2.	"Calculating Heat Loads"

EVALUATION:

When you have completed this minicourse, turn in your notebook to be graded. Ask your instructor for any additional evaluation he/she may have in mind.

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RESOURCE PACKAGE 1-1

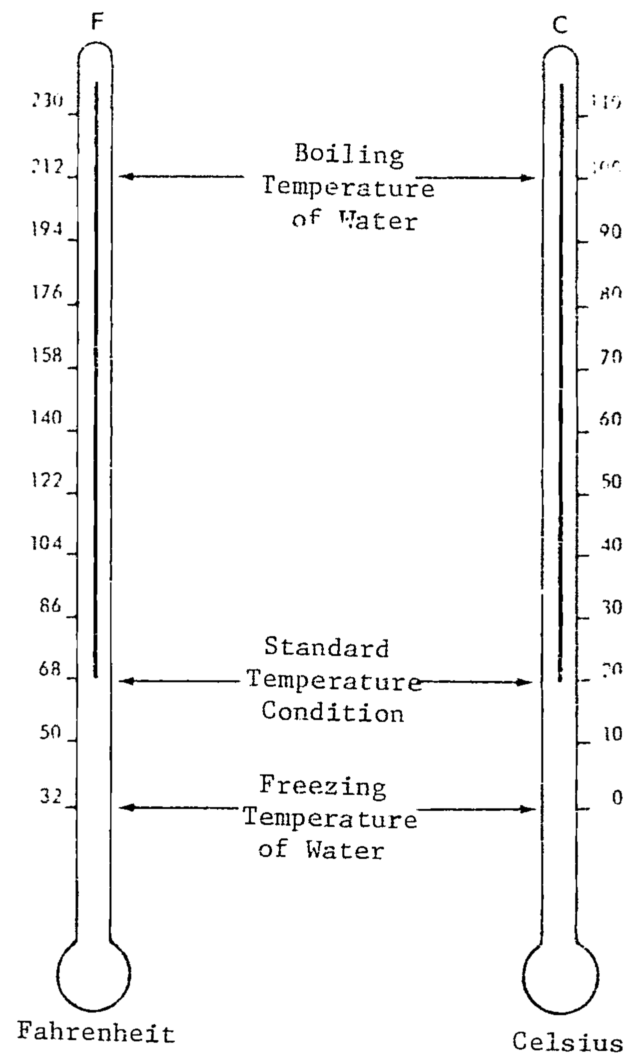
TEMPERATURE

Techologists are continually striving to make living and working environments more comfortable. One of the important factors in bringing about a comfort sensation is temperature control.

The air temperature in the United States varies from a low of about -55° F to a high of around 120° F. But the temperature of the human body must normally remain at about 98.6° F. The average atmospheric temperature in our Nation's temperate zones is below body temperature, so clothing is generally required to conserve body heat. During times when the atmospheric temperature is above body temperature, clothing may be required to block out solar energy while the body loses heat by evaporation of perspiration, by exhalation, etc. Indoors heating in some instances and cooling in other instances is necessary to maintain a temperature that is comfortable; this temperature is normally considered to be 72° F.

Temperature may be defined as the level of <u>heat</u> in a substance, where the agreed base level may be associated with melting ice, boiling water, or some other well-defined physical <u>phenomenon</u> (event). The temperature of a substance does NOT indicate an amount of heat, but indicates the relative level of warmth or the ability of the substance to transmit heat to a cooler body (a body of lower temperature level). Temperature can be likened somewhat to being <u>taller than</u>; NO indication of amount of height is implied, but only a relative measure of height condition.

Temperature is measured by an instrument called a thermometer. The common thermometer measures temperature by the expansion of a liquid such as alcohol or mercury. The usual liquid thermometer consists of a glass tube of uniform bore, a liquid reservoir bulb at the bottom, and a quantity of liquid of higher heat expansion ability than the glass tube. Because the glass does not expand and contract nearly as much as does the liquid when temperature changes, the liquid rises and falls in the tube while the glass tube appears to stay fixed in length. The glass tube is calibrated (marked) in terms of a temperature scale. The calibration most commonly used in America is in terms of the Fahrenheit scale, while most of the world uses the metric-system Celsius (centrigrade) scale. The Celsius scale is the one used by scientists all over the world; the Fahrenheit scale is the one most used in the heating and cooling industry in the United States. (See Fig. 1)



TEMPERATURE SCALES
Fig. 1

The Fahrenheit scale consists of 180 equal divisions between the boiling temperature and the freezing temperature of water. The freezing temperature is arbitrarily set at 32 degrees above zero. Thus, water at one atmosphere of pressure freezes at 32° F and water boils at 212° F (32° F + 180° F)*.

The Celsius (centigrade) scale has its freezing point of water at zero (0). The boiling temperature is then set 100 divisions above the freezing temperature, or at 100° C.

In modern thermometry, it is the <u>triple point</u> of water which is used to calibrate these kinds of thermometers. You can read about triple point in the <u>Physics of Toys</u> minicourse.

It is sometimes necessary to convert temperature in Fahrenheit degrees to Celsius degrees, or conversely. For this purpose formulas have been developed. In the formulas, the numeral 32 shows up because the Fahrenheit zero is located 32 units below the Centigrade zero; the fractions 9/5 and 5/9 show up because the distance of the boiling point and the freezing point of water is 180 degrees on the Fahrenheit scale and 100 degrees on the Centigrade scale: $\frac{180}{100} = \frac{9}{5}$ and $\frac{100}{180} = \frac{5}{9}$.

*Pressure affects boiling and freezing points. So called <u>standard conditions</u> are 1 atmosphere for pressure and 0° C for temperature.

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To convert Centigrade degrees to Fahrenheit degrees:

$$^{\circ}F = \left(\frac{180}{100} \times \text{Temp. } ^{\circ}C\right) + 32$$

or

$$= \frac{9}{5} \times {^{\circ}C} + 32$$

EXAMPLE: Convert 25° C to F degrees.

$$^{\circ}F = \frac{9}{5} \times 25 + 32$$

$$= 45 + 32$$

$$= 77$$

To convert Fahrenheit degrees to Centigrade degrees:

$$^{\circ}C = \frac{100}{180} \times (\text{Temp. } ^{\circ}F - 32)$$

or

$$^{\circ}C = \frac{5}{9} \times ({^{\circ}F} - 32)$$

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EXAMPLE: Convert 77° F to C degrees.

$$^{\circ}C = \frac{5}{9} \times (77 - 32)$$

$$= \frac{5}{9} \times (45)$$

$$= 25$$

RESOURCE PACKAGE 1-2

TEMPERATURE PROBLEMS

Using the formula $^{o}F = \frac{9}{5} \times {^{o}C} + 32$ or $^{o}C = \frac{5}{9} \times (^{o}F - 32)$, making the following conversions:

1) 78^{o} F to ^{o}C

2) 20^{o} C to ^{o}F

3) 5^{o} F to ^{o}C

4) 432^{o} F to ^{o}C

5) -15^{o} C to ^{o}F

RESOURCE PACKAGE 1-3

ANSWERS TO TEMPERATURE PROBLEMS

1) $^{\circ}C = \frac{5}{9} \times (78 - 32)$

$= \frac{5}{9} \times 46$

$^{\circ}C = 25.6$

2) $^{\circ}F = (\frac{9}{5} \times 20) + 32$

$= 36 \div 32$

$^{\circ}F = 68$

3) $^{\circ}C = \frac{5}{9} \times (5 - 32)$

$= \frac{5}{9} \times (-27)$

$^{\circ}C = -15$

4) $^{\circ}C = \frac{5}{9} \times (432 - 32)$

$= \frac{5}{9} \times 400$

$^{\circ}C = 222.2$

5) $^{\circ}F = \left[\frac{9}{5} \times (-15)\right] + 32$

$= -27 + 32$

$^{\circ}F = 5$

RESOURCE PACKAGE 2-1

CALIBRATING A THERMOMETER

It is often important in technical physics that one be able to determine temperature precisely. All thermometers have a greater or lesser precision. Inexpensive thermometers are often quite imprecise, and even school laboratory thermometers are sometimes as much as one degree in error at certain points along the scale. Thermometer imprecision can be detected and corrected for whenever precision temperature readings are needed. In this Resource Package you will learn to discover error points along a thermometer and how to plot correction graphs for these errors.

Get these materials together:

- 2 Fahrenheit scale thermometers
- glass funnel
- glass jar
- distilled water
- steam boiler
- Bunsen burner
- cracked, distilled-water ice
- hand lens magnifier
- graph paper
- ruler

Fill the funnel with cracked ice, support it in a jar, and insert the two thermometers. See Fig. 1 B. Allow the thermometers to remain in the ice for about 5 minutes; then slowly withdraw each thermometer until you can see the top of the mercury column. Using the magnifier, read the thermometer; estimate

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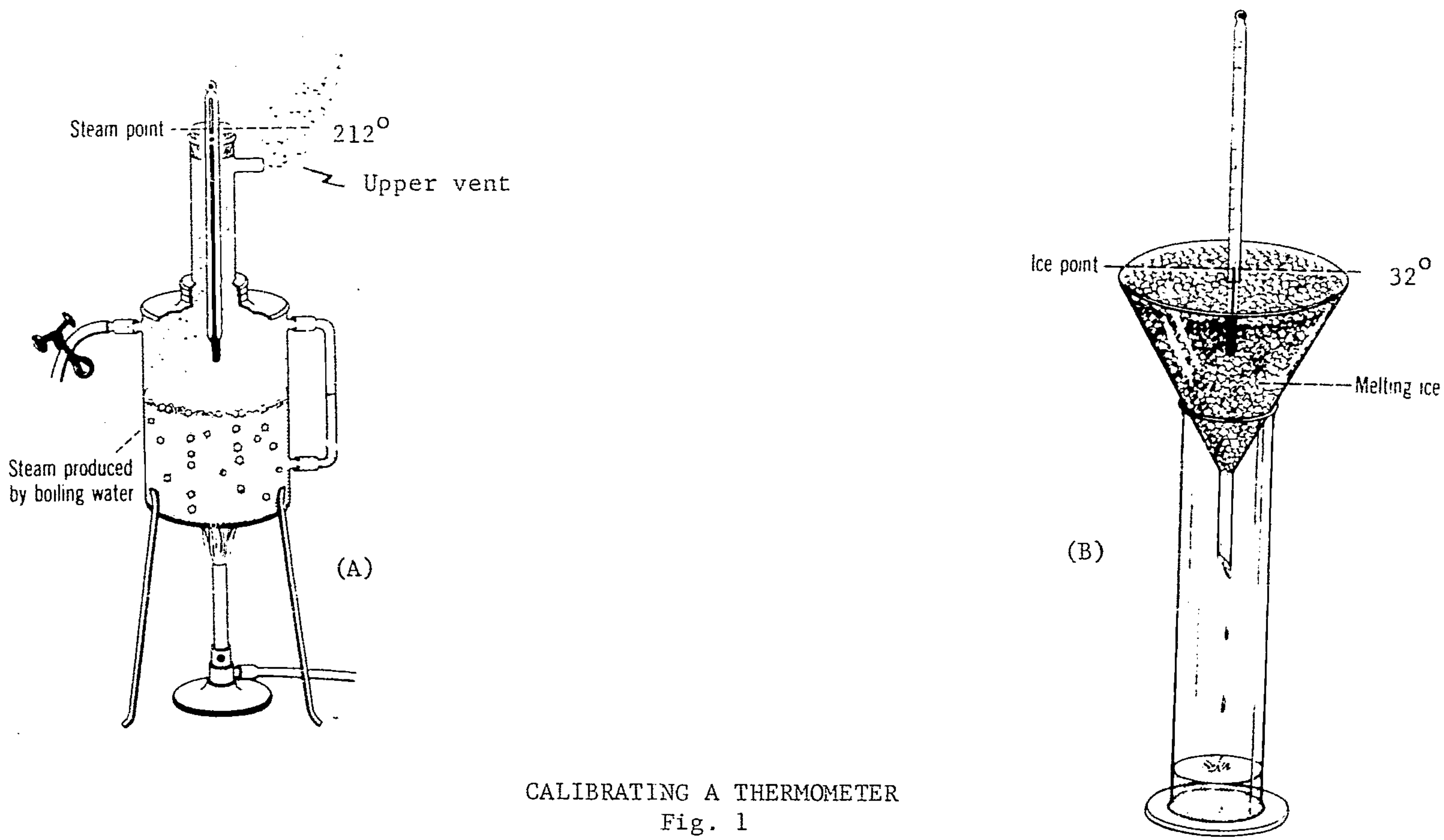
to tenths of a degree. Record the reading for each thermometer, and number or otherwise identify each thermometer.

Assemble the boiler, support, and burner. See Fig. 1 A. Carefully insert the thermometer through the



CALIBRATING A THERMOMETER
Fig. 1

cork in the top of the stack. (CAUTION: A severe cut can result from carelessness here! Try lubricating the stopper and thermometer with water or glycerin before inserting the thermometer. If you have trouble, DON'T force it! Call the instructor.) Adjust the thermometer so that the 212° mark is just visible above the cork. (Second CAUTION: The upper vent in the stack should be open to allow the steam to escape freely.) Bring the water to a boil and let the boiling continue for about 5 minutes. Then read the thermometer carefully with the aid of the magnifier and record the reading. This should be done for both thermometers.

The boiling point at any locality varies from day to day, depending upon the atmospheric pressure. With each change of 1 mm of mercury in the standard pressure measure of 760 mm, the boiling point falls (or rises) .065 Fahrenheit degrees. Thus, if the mercury reads 750 mm (10 mm below standard) the boiling point is 10 x .065, or .650 Fahrenheit degrees below 212° F. This gives a true boiling point of 211.35° (Which should be recorded as 211.4 , since the thermometer cannot be read to hundredths and we have agreed to record temperatures to nearest-tenth values).

Now, read the barometer and calculate the true boiling point. This calculation should be made and recorded for each thermometer. The true freezing point will be taken as 32° without corrections. Put your data in a chart, such as the one in Fig. 3.

Find the corrections which must be added algebraically to the readings of your thermometer to give the

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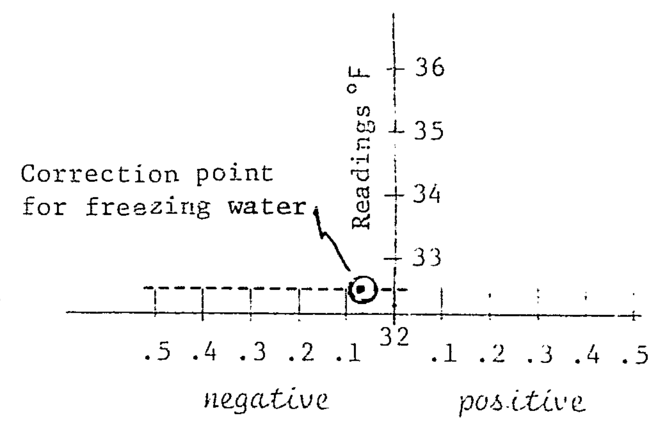
true temperatures at the freezing and boiling points. The algebraic sign of this correction is very important. For example, suppose your thermometer reads 32.5° F at the melting point of ice. Since the reading should be 32° F, you must add a negative .5° (-.5°) to the positive 32.5° which your thermometer reads. The correction at 32.5° F. is therefore -.5°. Or suppose that the thermometer reads 211.0° F on a day when the correct boiling point is 211.3° F. The corrections is +.3°, because when that correction is added algebraically to the reading of the thermometer it gives 211.3° F, which is the true boiling point.

Corrections should be made for both thermometers.

In the center of a sheet of cross-section (graph) paper, draw a vertical line to represent the scale readings of the thermometer. See Fig. 2. Choose the largest possible convenient scale and number the divisions by 10's from 32° to 212°. Using a scale of one-tenth of a degree (0.1) for each space, lay off a scale of positive corrections to the right and negative corrections to the left of the 32° mark of the vertical scale. For the correction graph, there are only two known points; it is highly important that these points be located correctly.



CORRECTIONS
Fig. 2

Suppose the correction at the freezing point is $-.5^{\circ}$ when the thermometer reads 32.5° F. The coordinates of this point on the graph are: (1) for the ordinate (vertical or y-value) the actual reading of the thermometer while in melting ice, in this case 32.5°, and (2) for the abscissa (horizontal or x-value) the correction point shift. To locate this, find 32.5° on the vertical scale and then shift $.5^{\circ}$ to the left.

On your correction graph mark the location of the correction point for freezing with a small dot. Draw a small circle around this dot so that you can easily identify it (See Fig. 2). In a similar manner, locate the correction point at the boiling point reading. This point will not lie on 212° unless the thermometer reads exactly 212° while in steam. Draw a small identification circle around this dot, also.

Connect the two correction points (circled dots) with a straight line. This correction graph will give the correction which must be added algebraically to your thermometer reading to give the true temperature.

Draw the correction graph for the second thermometer on the same set of axes (same vertical and horizontal lines). Label each graph with the number of the thermometer with which it is to be used. You can even color one graph to help distinguish it. Save these graphs. They should be used whenever you need to know the correct temperature.

Barometer reading ______________ mm.

Thermometer Number	1	2
Observed Freezing Point		
True Freezing Point		
Freezing Point Correction		
Observed Boiling Point		
True Boiling Point		
Boiling Point Correction		

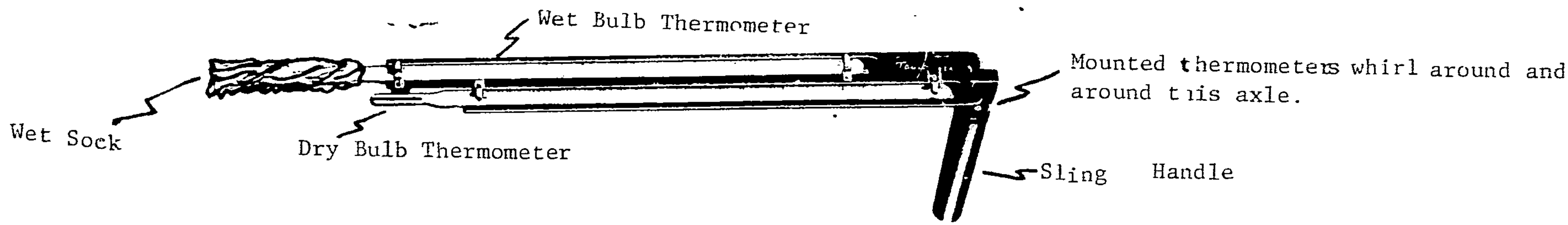
SUGGESTED DATA CHART
Fig. 3

RESOURCE PACKAGE 3-1

TEMPERATURE READINGS

There are two important types of temperature readings used in climate control. One is the dry bulb (db) temperature; the other is the wet bulb (wb) temperature.

Dry bulb temperature is the kind measured by an ordinary thermometer. Wet bulb temperature can be measured by placing a wet cloth around the bulb of a thermometer; when this "wet" thermometer is moved rapidly through the air, a temperature lower than the dry bulb temperature is recorded.



SLING PSYCHROMETER
Fig. 1

A sling psychrometer is the instrument often used to determine wet bulb and dry bulb readings. See Fig. 1. It is essentially a wet bulb thermometer and a dry bulb thermometer mounted side-by-side on a common base so that they can be whirled (slung) around and around in a circle to keep the water-impregnated wick (wet sock) in motion through the air.

Investigation: You are to keep a daily record of the following temperature data for each day you study this minicourse (See Number 4, below for a suggested data format.):

1) The dry bulb and wet bulb temperatures inside and outside your classroom during this same class period each day. Construct a graph of your dry bulb and wet bulb readings. Enter the new data each day. The abscissa (x-value; horizontal value) could be the date and the ordinate (y-value; vertical value) could be the temperatures in $^{\circ}F$ or $^{\circ}C$.

   If you do not have a psychrometer, improvise a method for mounting two thermometers to be whirled in a circle. The mounting should be in such a manner that the thermometer does not come off the base. BE CAREFUL WHIRLING THE PSYCHROMETER. Better still, place the thermometers side by side in front of a fan . . . this is safer and requires no whirling!

2) The highest temperature and lowest temperature of the day for each day. If you do not have the special kind of thermometer which measures this, the information can be obtained from a TV weather report or a newspaper weather report.

3) The degree day temperature for each day. The degree day is a term used to indicate the heating or cooling need for a certain day. For example, usually heat is not required when the mean temperature for each 24-hour period is 65° F. EACH DEGREE of declination (drop) below 65° F in outdoor temperature, averaged over a 24-hour period, is ONE degree day. Suppose that a mean 24-hour temperature was 50° F; this is an average of 15 degrees below 65° F for one day and would be designated as 15 degree days. The average number of degree days over a given period of time is used to estimate the fuel requirements for a heating or cooling system.

Mathematically speaking, one can see that the degree day is computed by taking the mean (average) of the highest and the lowest temperatures for a day and subtracting from 65 (65° F).

EXAMPLE: The lowest recorded temperature for a certain day was 28° F. The highest temperature for the same day was 36° F. The mean temperature for the day was $\frac{(28 + 36)^{\circ}}{2}$ F = $\frac{64^{\circ}}{2}$ F = 32 degrees F. The degree day computation tells us to subtract this low of 32° from 65°, or $(65 - 32)F^{\circ} = 33$ degree days.

4) Comment also on your reactions to the indoor and the outdoor climatic conditions for each day; i.e., cold, warm, wet, dry, sticky, hot, clammy, etc.

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Your information could be arranged somewhat as follows:

Date: June 3, 1975 Time: 9:30 a.m.

	Inside	Outside
Dry Bulb Temperature:	68° F	90° F
Wet Bulb Temperature:	60° F	85° F

Daily High: 92° F

Daily Low: 70° F

Degree Days:

$$\frac{(70 + 92)^{\circ}}{2} = \frac{162^{\circ}}{2} = 81^{\circ}$$

$$(65 - 81)^{\circ} = -16 \text{ degree days}$$

Comments: Outside was too warm and sticky; very uncomfortable. Inside was comfortable.

Your records should be kept neatly, since you will use these data in later exercises.

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RESOURCE PACKAGE 4-1

HEAT ENERGY

If comfort is to be achieved in winter and summer climatizing systems, the designer must know both the production and the heat loss of the system. As mentioned earlier, the heat-gain heat-loss ratio directly affects human comfort.

Heat is the name for an <u>energy quality</u> of a physical system which is responsible for physical changes of various types: melting, freezing, expanding, vaporizing, etc. A more thorough treatment of the nature of heat can be found in the <u>Physics of Toys</u> minicourse.

Heat is said to "flow" from a warmer substance to a cooler substance; that is, from a substance of higher temperature to one of lower temperature. Just as water will flow downhill to the lowest possible energy level, heat "flows" down the temperature hill to a lower thermal energy level. In this "heat flow" process, colder objects will be warmed and warmer ones will be cooled. The rate of energy flow depends upon the steepness of the temperature hill (temperature difference) as well as upon the properties of the material through which the heat energy flows.

Heat transfer (flow) through a material is a molecular phenomenon (happening). All substances are made up of atoms and molecules which are in constant rapid motions representing various molecular energy states (conditions). As the temperature of a substance is increased, the thermal energy states of its molecule increase; and as the temperature decreases, these energy states decrease. These energy states result in linear-vibrational and rotational-vibrational motions of molecules. When a substance of high temperature comes into contact with a cooler substance, the molecules of the hotter substance impart some of their energy to the molecules of the cooler substance. Therefore, in the transfer of heat from one substance to another the more energetic molecule loses energy and the less energetic molecule gains energy.

There are three ways that heat energy is said to be transferred: CONDUCTION, CONVECTION, and RADIATION. The simplest mode of heat transfer is called conduction; it is the direct transfer of heat energy from one part of a solid substance to an adjacent part, or from one solid substance to another solid substance, because of direct contact. A piece of iron with one end in a fire will soon become heated from end to end. This is an example of heat transfer by conduction. Heat travels by contact between adjacent iron molecules.

The mode of heat transfer called convection is the transfer of heat energy from one place to another by the circulating particles of a fluid (all gases and liquids are fluids). Convection is simply a conduction process with non-solids; warmer fluid always rises and cooler fluid always falls. The molecules of the warmer fluid contact cooler molecules, give up some heat energy, become cooler themselves and fall. This process of rising and falling fluid particles is called convection, and the swirling molecules generate fluid currents called convection currents. Convection may be used to cool or to heat a space. A common example is the movement of heat-laden air from a furnace into the rooms of a home.

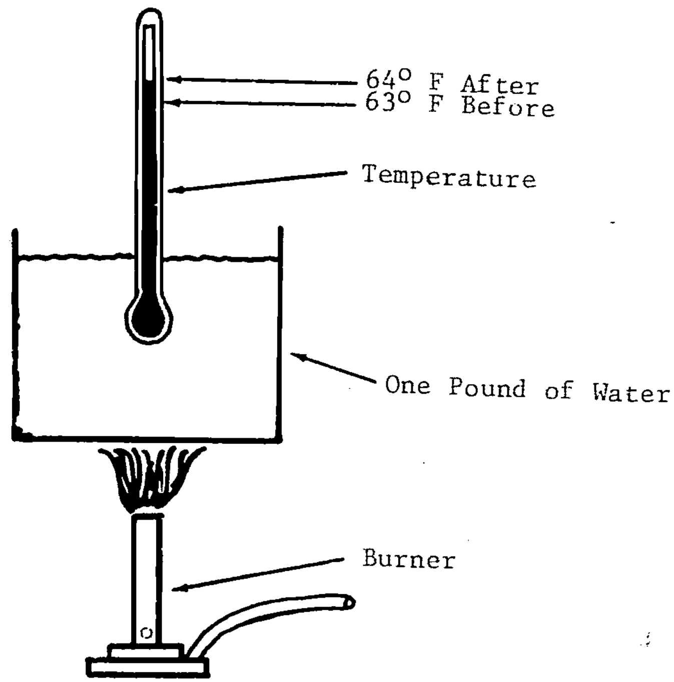
The hot air gives up its heat energy, sinks to the floor, and is then returned to the furnace for re-heating.

The mode of heat transfer called radiation is really NOT a transfer of heat energy but is an energy transformation! The earth receives energy from the sun by radiation. The radiant electromagnetic energy rays from the sun are transformed into heat energy when they strike the earth and are absorbed. This absorbed electromagnetic energy is then transformed to heat energy within the absorbing material.

More radiant energy is absorbed by dark-colored rough objects than by light-colored smooth objects. In addition to differences in absorption properties, substances differ in their abilities to conduct heat. In general, substances which are good conductors of electricity are good conductors of heat, and vice-versa. Substances which are poor conductors of heat are called insulators.

Radiation can be a cooling process. All warmer objects radiate energy to cooler objects (sun to earth, for example); any hotter substance will always lose heat energy to cooler surrounding spaces (or substances) through the radiation transformation process. (See The Physics of Toys minicourse for a broader treatment of heat energy.)

There is no instrument for measuring the heat energy transfered by conduction, convection or radiation. Therefore, heat energy received or lost by a system must be calculated. The unit of heat energy is the BTU (English) or the calorie (metric). The BTU is most often used in our heating and cooling industry; it is defined as the amount of heat energy required to raise the temperature of 1 pound of water one degree Fahrenheit (more precisely, to change the temperature from 63^{o} F to 64^{o} F when the pressure is one atmosphere). See Fig. 1.



THE BTU
Fig. 1

A dimensional unit used in calculations that involve large heat loads is the term (1 term = 100,000 BTU). To find the term load for a heat installation, divide the total load in BTU by 100,000. For example, the total load for an apartment building is 5,005,000 BTU. What is the load in terms?

$$\frac{5,005,000 \text{ BTU}}{100,000 \text{ BTU/term}} = 50.05 \text{ terms.}$$

If one heats a substance, its temperature generally rises*. The heat energy resulting in a temperature change is sometimes called sensible heating.

Sensible heat varies with the kind and the quantity of a substance. The technical physics term for the amount of heat energy necessary to change the temperature of a substance is specific heat. More precisely, specific heat is defined in the English system as the amount of heat energy associated with a change of one degree Fahrenheit in one pound of substance. **In the metric system, specific heat is the heat energy associated with a temperature change of one degree Celsius in one gram of a substance. The specific heat of water is 1.0 BTU/lb/F^{o} or 1 cal/gm/C^{c}; specific heats of some common substances are given in the following table:

*Special cases exist where the temperature does NOT rise, such as during a change of phase.
**More precisely, specific heat values assume a constant pressure or a constant volume during the temperature change. For this course, all specific heat discussions assume a constant pressure during the temperature change.

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MATERIAL	SPECIFIC HEAT	MATERIAL	SPECIFIC HEAT
ALUMINUM	0.225	GYPSUM	0.259
ASBESTOS	0.200	MERCURY	0.033
BRASS	0.104	OAK	0.570
BRICK	0.220	PETROLEUM	0.500
CAST IRON	0.119	PINE	0.670
CINDERS	0.180	SOIL	0.440
CONCRETE	0.165	STONE	0.208
COPPER	0.095	WATER	1.000
CORK	0.485	ZINC	0.093
GLASS	0.163		

Heat energy input (or output) required to change a unit amount (lb, kg, g, etc.) of a material by a unit degree (F^o, C^o, etc.) is calculated from the equation:

$$H = m\, C \Delta T$$

Where:

H is the heat energy gained (added) or lost (removed) from the material, in calories or BTU.

m is the "amount" of material.

C is the specific heat of the material at constant pressure.

ΔT is the interval of temperature change of the material (rise or fall in temperature) assuming the material undergoes no phase changes (changes of state) such as melting, freezing, vaporizing, etc. When a change of phase occurs, an <u>additional</u> gain or loss of heating energy must be accounted for.

EXAMPLE: How much heat energy will be required to raise the temperature of 62.4 lb of water from 40° F to 80° F?

$$H = m\,C\,\Delta T$$

$$\text{Heat Input} = (\text{Weight})\ (\text{Specific Heat})\ (\text{Degree Change In Temperature})$$

$$= (62.4\ \text{lb})\ \left(\frac{1\ \text{BTU}}{\text{lb}\ \text{F}^{\circ}}\right)^{*}\ (80 - 40)\ \text{F}^{\circ}$$

$$= 62.4\ \text{BTU} \times 40$$

$$= 2496\ \text{BTU}$$

*See Specific Heat of water in the Table on the preceding page.

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EXAMPLE: How much heat energy must be removed to cool 50 lb of water from 80° F to 35° F?

$$\text{Heat Removed} = \text{Weight} \times \text{Specific Heat} \times \text{Degree Change In Temperature}$$

$$= (50 \text{ lb}) \left(\frac{1 \text{ BTU}}{\text{lb F}^{\circ}}\right) (80 - 35) \text{ F}^{\circ}$$

$$= 50 \text{ BTU} \times 45$$

$$= 2250 \text{ BTU}$$

EXAMPLE: How many BTU of energy must be removed to cool an oak door from 80° F to 72° F? The door weighs 20 lbs.

$$\text{Heat} = \text{Weight} \times \text{Specific Heat} \times \text{Temperature}$$

$$= 20 \text{ lb} \times \frac{0.570 \text{ BTU}}{\text{lb F}^{\circ}} (80 - 72) \text{ F}^{\circ}$$

$$= 20 \text{ lb} \times 0.570 \frac{\text{BTU}}{\text{lb F}^{\circ}} \times 8 \text{ F}^{\circ}$$

$$= 91.2 \text{ BTU}$$

How many BTU's must be removed if the door is made of pine? Which would be the better door for insulation purposes, the oak or the pine? Keep this calculation and answer in your notes, for evaluation by your instructor upon completion of this Resource Package.

An interesting phenomenon of all substances is their ability to change their phase (state), such as from solid to liquid, liquid to gas, solid to gas, gas to solid, etc. Changes of state can occur without a change in temperature! However, even though no temperature change occurs for a phase change, heat energy must ALWAYS be added to or removed from a substance to change its state. We term the heat energy associated with a change of state latent (hidden) heat. Latent heats for special phase changes include: heat of fusion, heat of vaporization, heat of sublimation, heat of condensation, etc. Write out definitions for these and other latent heats and turn them in with your notes to be evaluated when you complete the mini-course.

The figure below (Fig. 2 shows a temperature-heat energy graph for one pound of water at atmospheric pressure, heated from -40° F (solid) through melting and then on through vaporization.

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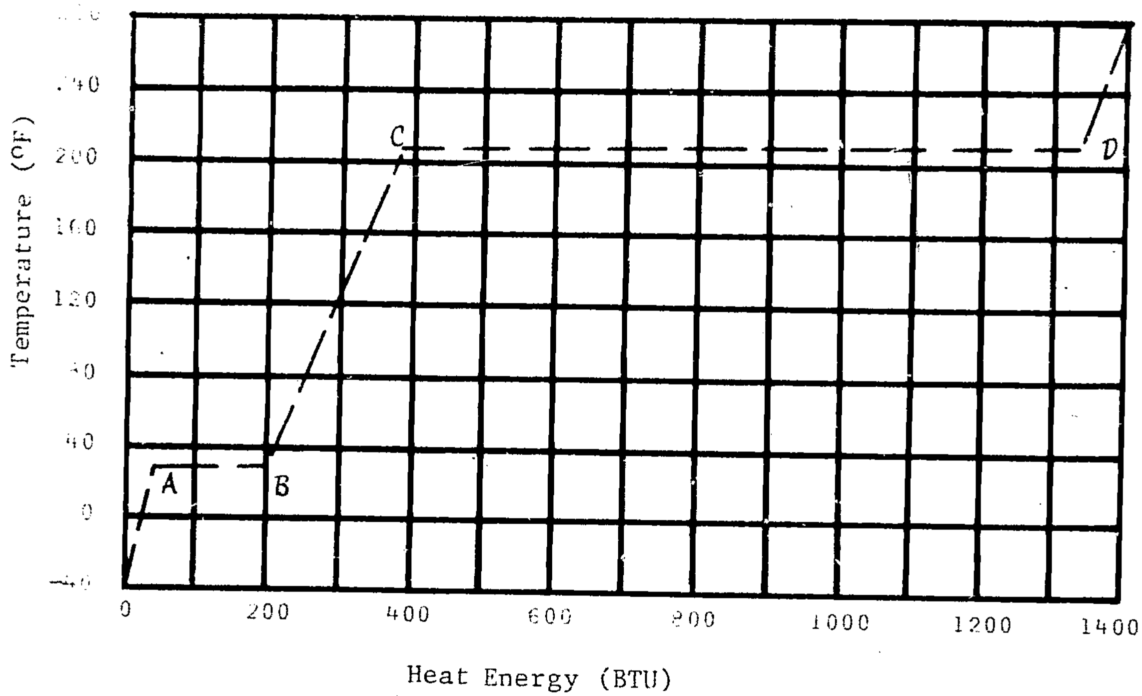

From O to A, heat energy was added to change the ice from -40° F to 32° F.

From A to B, about 144 BTU were added to melt the ice. Note that the temperature did not change.

From B to C, 180 BTU were added to heat the ice water from 32° F to 212° F.

From C to D, 970 BTU were added to vaporize the water. Note that the temperature did not change.

GRAPH OF TEMPERATURE VS HEAT ENERGY
Fig. 2

Note that considerable heat energy (144 BTU) was added between points A and B and the temperature did not change. This added energy, which was required just to change solid ice at 32° F to liquid ice water at 32° F (without changing the temperature of the ice or the ice water) is sometimes called latent heat of melting. During the reverse operation, ice water at 32° F to ice at 32° F, the same quantity of heat energy is known as _latent heat of fusion_. Also, between points C and D, 970 BTU were added to the system and the temperature did not change. This heat energy was required to change hot water at 212° F to steam at 212° F, and is called _latent heat of vaporization_. Latent heat of vaporization turns out to be considerably greater than latent heat of fusion or of melting. For example, to either melt or to freeze water (both at 32° F) requires 144 BTU/lb, but to vaporize water or to condense steam at 212° requires 970 BTU/lb.

In review, temperature change and phase change can be accomplished by adding or removing heat energy through convection, conduction, or radiation processes. The heat energy resulting in a temperature change is known as sensible heat, and varies with each substance. The comparative property that each substance possesses to change its temperature as its heat energy changes is known as specific heat. Finally, the heat energies necessary for phase changes are termed latent heats.

RESOURCE PACKAGE 4-2

INVESTIGATING CONDUCTION

The transfer of heat by conduction is heat energy transfer by contact between a particle and its adjacent particle. This transfer always occurs in a direction toward a lower temperature region. Just as a ball rolls down a grade, heat energy conducts down a <u>temperature gradient</u>. This gradient is a function of temperature difference; the greater the difference, the steeper the gradient.

<u>Investigation</u>: Drip some wax from a lighted candle onto a metal rod at regular intervals along the rod. Press the head of a tack against the soft wax and wait for the wax to harden. With the tacks on the bottom side of the rod, heat the rod by placing one end near a heat source. Watch the progress of heat conduction, as one tack after another drops off.

Scrape the wax off the metal rod. Mark the rod with a <u>Tempilstik</u> or waxy crayon, spacing the marks evenly along the length of the rod. Heat one end of the rod and watch as the crayon marks soften or melt successively (one after another) along the rod.

Place a quarter in the center of an old cotton handkerchief or similar type cloth, and wrap the coin <u>tightly</u>. With a flat surface of the coin facing upward, apply a lighted match to that part of the handkerchief or cloth in direct contact with the flat surface of the coin (It is important that the cloth

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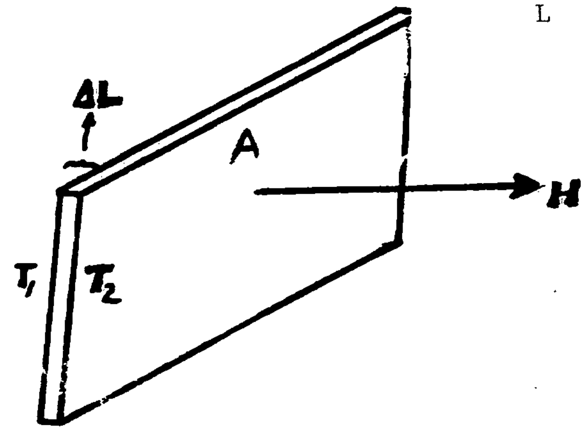
be tightly wrapped). In your notebook, write a simple account of the observed result.

Cut a narrow strip of gummed paper, moisten it, and wrap it in a spiral fashion around a long nail. Hold one end of the nail with a pair of pliers, or similar instrument, and heat its entire length with a flame. Again, record your observations, and briefly account for them.

Conduction of heat is important in getting heat from the combustion chamber of a furnace into the hot air system or the hot water system of a living space. Good heat conductors, such as iron, facilitate this transfer. To keep heat from transferring, poor conductors (insulators) such as wood are used.

The amount of heat energy that transfers by conduction varies directly with the time, Δt, the surface area through which it transfers, A, and the temperature gradient $\frac{\Delta T}{L}$. Stated as an equation:

$$H = (kA\,\Delta t)\frac{\Delta T}{L}$$



FACTORS IN CONDUCTION CALCULATIONS
Fig. 1

Temperature gradient ΔT is simply the difference in temperature of each side of the conducting slab $(T_2 - T_1)$ divided by the slab thickness ΔL. The area, A, is measured at right angles to the direction of heat transfer. See Fig. 1. The constant, k, represents the thermal conductivity of the material. This constant is a property of the material used; k values can be found in the Handbook of Chemistry and Physics, or other such reference. Common dimensional units for the heat energy transferred are: H in BTU, A in square feet, Δt in hours, ΔT in F^{o}, and ΔL in inches. The thermal conductivity, k, is expressed in $BTU/(ft^2\ hr\ F^{o}/\ in)$. The corresponding dimensional units for k in the metric system are $cal/(cm^2\ sec\ C^{o}/cm)$.

EXAMPLE: A 6' x 12' picture window has a thermal conductivity constant of 7.3 $BTU/(ft^2\ \text{-hr-}\ F^{o}/\ in)$. The glass is 1/2 inch thick. Assuming that the outside temperature is 95^{o} F and the inside temperature is 72^{o} F, how much heat is conducted through the glass in 30 minutes?

Solution:

$$H = (kA\ \Delta t)\ \frac{\Delta T}{L}$$

Where

$$k = 7.3\ \text{BTU}/(\text{ft}^2\text{-hr-}\ {}^{o}\text{F/in})$$

$$A = 6' \times 12' = 72\ \text{ft}^2$$

$$\Delta t = \frac{30\ \text{min}}{60\ \text{min/hr}} = .5\ \text{hr}$$

$$\Delta L = 1/2\ \text{in} = .5\ \text{in}$$

$$\Delta T = T_2 - T_1 = (95^{o}\ \text{F} - 72^{o}\ \text{F}) = 23\ \text{F}^{o}$$

Substituting these values into the equation:

$$H = 7.3\ \text{BTU}/(\text{ft}^2\text{-hr-}\ \text{F}^{o}/\text{in}) \times 72\ \text{ft}^2 \times .5\ \text{hr} \times \frac{32\text{F}^{o}}{.5\ \text{in}}$$

$$\cong 16{,}800\ \text{BTU}$$

If the glass were 1 inch thick, what would be the amount of heat energy conducted in this same time interval? Is there a relationship between thickness and thermal conductivity of a material?...between thickness and amount of heat energy conducted?

EXERCISE: Calculate the heat energy transfer through the glass in your classroom. Remember, heat energy transfers from a higher temperature to a lower temperature. Use a time interval of 30 minutes. Gather these data:

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k = ____________________

A = ____________________ ft^2 (total area door glass, windows, sky light, etc.)

Δt = ____________________ minutes

ΔL = ____________________ inches

$\Delta T = T_2$ (larger temperature) - T_1 (smaller temperature)

= ____________________ F^o

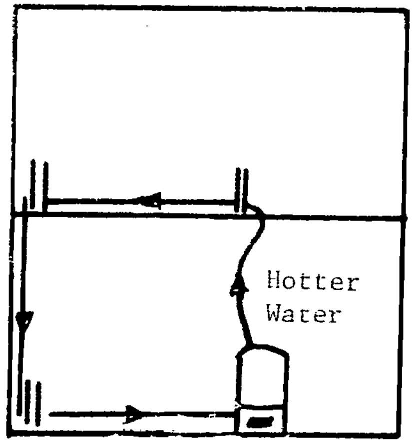
Then use the conduction equation.

RESOURCE PACKAGE 4-3

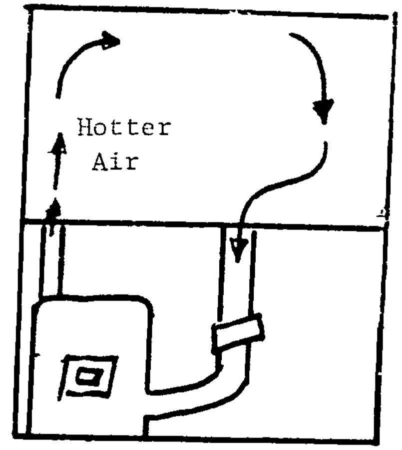
INVESTIGATING CONVECTION

Heat transfer by convection takes place by contact between the molecules of a circulating fluid and the molecules of the material it contacts. This contacted material can be a solid, a liquid, or a gas. The amount of heat energy transferred per unit of time is affected by the velocity and nature of the convecting medium, the area and form of the surfaces contacted, and the temperature difference between the convecting fluid and the material contacted.

The heating of buildings is frequently accomplished largely through convection. In a hot-air heating system, air heated by contact with a furnace expands, becomes lighter, and rises because it is forced upward by denser, cooler air below it (it literally "floats" in the colder air). As the heated air rises, cooler air comes into contact with the furnace. A circulation pattern called a <u>convection current</u> is thus established, and continues as long as heat energy is supplied to the fluid system. See Fig. 1. If the heat source is removed, convection currents will continue until there is a uniform temperature throughout the fluid medium.



Water Heater



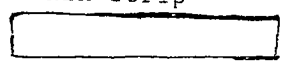
Hot Air Furnace

CONVECTION WATER
Fig. 1

Try this:

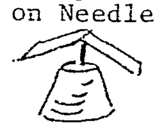
1) Insert the eye of a needle into a cork, which will serve as a base. Fold a thin strip in half and balance the folded paper on the needle, as shown.

Thin Strip



Thin Strip Folded

Strip Balanced on Needle



Hold your hand near one side of the paper, and close to it. The paper should begin turning. The presence of the warm hand should be sufficient to set into motion small convection currents which will move the paper.

2) Convection currents can be made visible to the eye. Place a beaker of water over a flame. Adjust the flame so that it is applied to only one side of the beaker. Drop a crystal of potassium permanganate into the water. Purple streamers will be seen to rise, tracing the upward movement of the hot water. Colored streamers of cold water will be seen descending on the side opposite the heat source. These streamers are the visible convection currents.

Convection is an effective method of heat transfer, and it must be considered in designing a climatizing system. If large air spaces are left within a house wall, for example, convection currents can set up readily and much heat energy may be transferred. If air spaces in walls are broken up into small isolated regions, no major convection currents are possible and little heat is transferred by convection. Insulating materials used in the walls of a refrigerator or a house are often porous materials, such as cork, rockwool, glass wool, or the like; these materials are not poor conductors in themselves but because of the many isolated, small air spaces associated with them they become very poor conductors.

Make a list of possible sources of heat transfer by convection in your classroom. Describe how this convection transfer could be minimized.

RESOURCE PACKAGE 4-4

INVESTIGATING RADIATION

As mentioned earlier, heat energy is not really transferred by radiation. All bodies emit and absorb <u>radiant energy</u>. Radiant energy is another name for <u>electromagnetic energy</u>, which differs greatly from heat energy. Although all bodies emit and absorb radiant energy, bodies hotter than their environment emit more than they absorb. Colder bodies absorb more radiant energy than they emit to their environment.

Radiant energy exhibits the following characteristics:

1) It has wave-like properties*.

2) It can travel at the ultimate speed in our universe, 186,000 mi/sec!

3) Its many forms can be related to its wavelength; some common forms include:

   a) cosmic rays
   b) x-rays
   c) radar waves
   d) microwaves
   e) radio waves
   f) visible light
   g) ultra-violet light
   h) black light

*See the minicourses <u>Physics of Communication</u>, <u>Physics of Toys</u>, or <u>Physics of Musical Instruments</u> for further discussion of waves.

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4) It travels in straight lines through space.

5) It obeys the wave relation, $v = f\lambda$

where v is wave speed

f is wave frequency

λ is wave length

6) The more energetic the radiation :

a) the higher the frequency
b) the shorter the wave length

Let's see how people confuse radiant energy with heat energy. Well, obviously sunlight warms us! But what is perhaps misleading is that radiant solar energy is what reaches us from the sun 93,000,000 miles away. Heat energy does NOT reach us from the sun! This radiant energy is transformed into heat energy upon absorption of the radiant energy by the molecules of our bodies. Heat energy is NOT transferred from sun to earth; radiant solar energy makes the trip and is then transformed (converted) to heat energy.

Try this (Record your observations):

1) Place a radiometer in direct sunlight or under a heat lamp. Watch it spin. Move it out of the direct light and watch the radiometer slow down. Place an opaque material between the radiometer and the light source. Since radiation travels in straight lines, the radiometer will find itself in a "shadow" and will slow down perceptibly.

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2) Use a flat mirror to reflect radiation from a light source toward the radiometer. Observe the radiometer activity. Radiant heat waves can be reflected, refracted (bent) and focused (bent). Use a curved mirror in place of the flat mirror and observe the results.

3) Paint four (4) 250-ml Erlenmeyer flasks (or other glass containers) black, green, red, and white, respectively. You use can tempera paint from the art room, or similar paint. Fill each flask with boiling water, being careful not to spill water on the paint surface. Place a cork with a thermometer in the top of each flask. Make sure the thermometer does not touch the glass surface. Place each flask in the sunlight or under a heat lamp. The flasks should be isolated from one another; you can place each on a ring stand, with the ring stands equal distances from the light source, for example.

Keep a record of time and temperature for each flask every 5 minutes for 30 minutes. Make a graph of your observations (temperature-vs-time graph for each flask). Which surface color seems best for radiant heating? . . .for radiant cooling?

One sees that some materials, particularly those of a dull, dark color and rough surface are better absorbers of radiant energy. It is interesting that the good absorbers are also good radiators of energy. On the other hand, materials which are light-colored or shiny and smooth reflect radiation better and absorb radiation less; these poor <u>absorbers</u> are likewise poor

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emitters of radiation.

The pipes and tanks of solar water heaters are painted a flat (non-shiny) black so that they can better absorb energy from the sun. Snow and ice will melt first from an asphalt pavement, and last from a white concrete sidewalk. The dark asphalt absorbs more heat energy, even though its immediate surface is covered by snow or ice.

Because of a peculiar property of glass, the interior of a greenhouse is maintained by radiation at an energy level (and temperature) well above the outside. The glass is transparent to visible light and readily admits sunlight into the greenhouse. This sunlight is absorbed by the plants, the soil, and other interior objects. When the sun has set, the temperature of the atmosphere outside the greenhouse drops. The plants and other absorbers inside the greenhouse thereby end up at a higher temperature than their outside environment. When this happens the objects inside the greenhouse become the radiating objects. Although warmer than the outside environment, the plants and interior objects of the greenhouse are obviously much colder than the sun so they emit long wavelength (less energetic) radiant rays. Glass is opaque to this long wavelength type of radiation. Glass was transparent to the more energetic, shorter wavelength solar radiation and transmitted this energy readily into the greenhouse. But the glass will not transmit the radiations

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from plants and interior objects, so it reflects these longer wavelength radiations. Therefore, the energy is trapped inside the greenhouse. Heat can escape by conduction through the walls but not by radiation, so the greenhouse stays warmer all through the sun-less hours.

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RESOURCE PACKAGE 4-5

INVESTIGATING SPECIFIC HEAT

The specific heat of a substance is the heat energy necessary to change the temperature of a unit quantity of the substance by one degree. There are two general kinds of specific heats, one for constant pressure conditions and one for constant volume conditions. For all work in this course, constant pressure specific heat is used.

During this exercise you will determine the specific heat of a metal.

Apparatus:

- Calorimeter (insulated styrofoam cup can be used)
- lab boiler (or beaker in which water can be heated)
- chunk of metal
- Fahrenheit thermometer (can use a Celsius thermometer)
- Bunsen burner (or other heat source)
- ring stand
- wire gauze
- platform balance
- string

Symbols and conversions:

lb = 0.0022 x grams

$F = \frac{9}{5} C \div 32$

ΔH = change in heat energy

M = mass

C = specific heat

ΔT = change in temperature (T_2 - T_1)

Procedure:

a) Record measurements in a table similar to Table 1. Fill the boiler or beaker about half full of water and place it over the Bunsen burner. The beaker should sit on the ring stand, and the wire gauze should be between the ring and the beaker base. Have your instructor check your set-up before igniting the burner.

b) While waiting for the water to boil, measure and record the quantity of metal (mass) of the calorimeter cup (lbs = 0.0022 x grams). Then fill the cup about half full of cool water. Calculate the mass of the cool water by subtracting the mass of the cup from the mass of cup-plus-water. Put the cup in the calorimeter jacket and cover it.

c) Measure the mass of the piece of metal you are using. Using string, lower the metal into the boiling water. Let the metal remain in the boiling water for about 5 minutes.

d) Measure and record the temperature of the cool water.

e) Measure and record the temperature of the boiling water. This will also be the temperature of the metal you placed in the boiling water.

f) Remove the metal from the boiler and quickly lower it into the cool water in the calorimeter cup. Replace the calorimeter cover at once. Stir gently with the thermometer until the thermometer reads a constant temperature (stops dropping). Record this temperature as the final temperature of the mixture.

g) Determine the change in temperature of the metal (ΔT_m) and the change in the temperature of the cool water (ΔT_W) and cup (ΔT_C). Always use corrected temperature readings (Resource Package 2-1).

h) Calculate the heat energy gained by the water and the cup. Use this expression:

$$H = (M_W C_W \Delta T_W) + (M_C C_C \Delta T_C)$$

i) The heat gained by the water and cup must have come from the hot metal. Therefore, ΔH is also equal to the heat energy given up by the metal

$$\Delta H = M_m C_m \Delta T_m$$

Substitute your obtained values of ΔH, M_m and ΔT_m and calculate the specific heat of the metal.

j) Check your experimental value for the specific heat of the metal against a standard accepted value. Your instructor will show you how to do this.

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TABLE 1

Mass of calorimeter cup (lb), M_c	
Mass of cup plus cool water (lb), $M_c + M_w$	
Mass of cool water (lb), M_w	
Mass of metal (lb), M_m	
Temperature of cool water (^oF), T_{1w}	
Initial temperature of cup (^oF), T_{1c}	
Temperature of hot metal (^oF), T_{2m}	
Final temperature of mixture (^oF), T_{mx}	
Final temperature of cup (^oF), T_{mx}	
t metal (^oF), $(T_{1m} - T_{mx})$	
t cool water (^oF), $(T_{1w} - T_{mx})$	
t cup (^oF), $(T_{1w} - T_{mx})$	

A thought to ponder:

The equation used to find the specific heat of the metal was based upon the Conservation of Energy Principle. You assumed that the heat energy lost by the hot metal was equal to the heat energy

<u>gained</u> by the warmed water and cup container. In other words, the total heat energy for the <u>system</u> of cup, metal, and water was conserved:

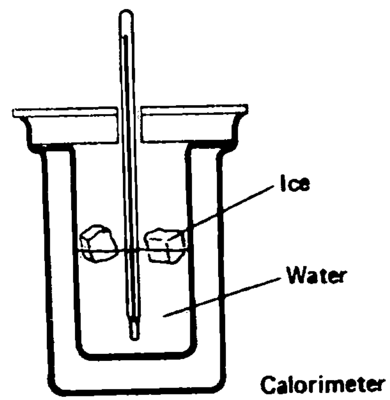
$$\Delta H_{metal} = \Delta H_{cup\ +\ water}$$

RESOURCE PACKAGE 4-6

INVESTIGATING HEAT OF FUSION

Apparatus needed:

- calorimeter
- 400-ml Pyrex beaker
- Fahrenheit thermometer
- ice cubes or crushed ice at 0° C
- towel (or paper towels)
- lab gas burner
- platform balance
- ring stand
- wire gauze



In a solid, molecules are locked within a crystalline structure by molecular forces. If the solid is to change state (phase) and become a liquid, its molecules must absorb energy. A liquid phase is a higher energy phase than a solid phase. Energy absorbed by a solid can decrease the crystalline bonds between molecules. When these bonds between the molecules become small enough, the molecules gain enough freedom to "slide over one another" and the solid becomes a liquid.

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in general, as solids absorb heat energy the distances between their molecules increase. The molecules gain potential energy in relation to one another, in much the same manner as a spring gains potential energy when it is stretched. As heat energy is absorbed and the potential energy increases, the molecules vibrate with increased amplitudes about their normal "fixed" positions in the solid material. These vibrations can result in the expansion of a hot material, since these heat-agitated molecules need more "elbow room."

So when heat energy is absorbed or lost by a material, the substance can expand or contract, can change temperature, or can change phase. But in all instances, a phase change does <u>not</u> result in a temperature change!

You will now investigate a common phase change, the heat of fusion of ice. The quantity of heat energy absorbed by a solid in becoming a liquid is called the <u>heat of fusion</u>. Each substance has a unique heat of fusion. The heat of fusion of ice is 143.4 BTU/lb in the English system and is 80 cal/g in the metric system.

<u>Procedure (to measure the heat of fusion of ice)</u>:

1) Record all measurements in a table similar to Table 1. Use the set-up shown on the preceding page.

2) Remove the calorimeter cup and determine its mass (M_1).

3) Warm some water in the beaker to about 104° F. Add this warm water to the calorimeter cup until it is about half full. Measure and record the mass of the cup-plus-warm water (M_2).

4) From the measurements of Steps 2 and 3, calculate the mass of the warm water (M_2-M_1).

5) Place the cup back in the calorimeter and cover it. Measure the temperature of the warm water (T_1).

6) Select two or three medium-sized pieces of ice and wipe them dry. Carefully place the ice in the calorimeter cup. Replace the cover at once. Insert the thermometer and stir <u>gently</u>. As soon as the ice has melted completely and the new volume of water has reached a steady temperature, record this temperature as the <u>final temperature of the mixture</u> (T_4).

7) Remove the cup. Determine the mass of the cup-plus-water and ice. Calculate and record the mass of the ice (M_3-M_2). You are now ready to use the Conservation of Energy principle to find the heat of fusion (melting) of the ice.

8) Calculate the heat energy lost by the warm water and the warm calorimeter cup.

9) The ice absorbs heat energy in changing to a liquid. It is then water at 32° F. Calculate the heat energy absorbed by the ice water in changing its temperature from 32°F to the final temperature of the mixture (T_4).

10) The difference between the heat energy given up by the warm water and the cup (Calculation 8)

and the heat energy absorbed by the ice water in changing its temperature from 32° F to the final temperature (Calculation 9) must be the heat energy absorbed by the ice to change its state. Calculate the heat energy used for this purpose.

11) Divide the heat energy absorbed by all the ice during the change in state (Calculation 10) by the mass of the ice. This ratio gives the heat energy per unit mass needed to effect the change in the state of ice; i.e., the latent heat of fusion of ice.

12) Compare your experimental value of the latent heat of fusion to the accepted value. Ask your instructor to show you how to calculate your per cent error:

$$\text{Error} = \frac{(\text{Standard Value - Experimental Value})}{\text{Standard Value}}$$

% Error = Error expressed as per cent

TABLE 1

DATA FOR HEAT OF FUSION

Mass of calorimeter cup (lb) M_1	
Mass of cup-plus-warm water, M_2	
Mass of warm water, $M_2 - M_1$	
Temperature of warm water (^oF), T_1	
Initial temperature of cup, T_2	
Temperature of ice when melted, T_3	32^o F
Final temperature of mixture, T_4	
Final temperature of cup, T_4	
Mass of cup-plus-water and ice, M_3	
Mass of ice, $M_3 - M_2$	
T warm water, $T_1 - T_4$	
T cup, $T_1 - T_4$	

RESOURCE PACKAGE 4-7

INVESTIGATING INSULATION MATERIALS

Is an inch-thick piece of insulation board twice as effective as a half-inch piece in retarding the transfer of heat? How do the heat transfer properties of different types of insulating materials compare? These are the kinds of questions you will attempt to answer for yourself by completing this Resource Package.

Select three different types of insulating materials and try to devise a suitable experiment for determining the effectiveness of each material in retarding heat transfer.

Keep a record of this investigation for evaluation by your instructor. Diagrams, reference materials, notes, and calculations are relevant kinds of records. If your investigation seems meritorious, your instructor will ask you to share your findings and procedures with your classmates (for their enlightenment and for your extra credit!).

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RESOURCE PACKAGE 5-1

HUMIDITY

Health and comfort depend not only on air temperature, but also on humidity. Our atmosphere always has a water vapor content. Because body comfort is closely related to moisture losses through pores and lungs, it is necessary to consider how the air can absorb body moisture and how moisture in the air affects the release of moisture from the body.

Air moisture is water vapor (a gas). It is colorless, odorless, tasteless, invisible and perfectly dry*. In its other forms this water vapor moisture is responsible for such atmospheric conditions as sleet, snow, hail, clouds, fog, rain, etc. Water vapor can exist in air which is at a temperature below freezing. Water vapor can change state (phase) by skipping its more usual phase sequence. For example, snow represents a phase change directly from vapor to solid (skipping the liquid or rain phase); and the solid phase (snow or ice) can change directly to the vapor phase (skipping the melting or liquifying phase).**

When water is visibly present, the region above its surface always contains invisible water vapor molecules. These vapor molecules exert a pressure on the water surface and upon their container walls if the water is in an enclosed system. The vapor molecules are at a higher energy state than the water

*Be careful with the word moisture. It is a non-scientific word; like the word germ, moisture is used by the man on the street (the lay person) to represent a large and ill-defined collection of ideas and things.

**On glacial fields, for example, evaporation of ice and snow is a significant phenomenon!

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molecules. The ratio of liquid water molecules to water vapor molecules for a given system is a function of pressure, volume, and temperature. A temperature-pressure table for water and its vapor is shown as Fig. 1.

Air Tempera-ture (deg F)	Pressure of Saturated Vapor (psia)	Weight of Water Vapor for Saturation of 1 Lb of Dry Air		1 Lb of Dry Air Above 0 F (BTU)	1 Lb of Dry Air Saturated (BTU)
		*Grains	Pounds		
0	0.01853	5.50	0.0007852	0.000	0.8317
5	0.02400	7.12	0.001017	1.200	2.280
10	0.03090	9.18	0.001311	2.400	3.795
15	0.03963	11.77	0.001682	3.599	5.392
20	0.0539	16.03	0.002290	4.802	7.249
22	0.0587	17.46	0.002494	5.282	7.949
24	0.0638	18.99	0.002713	5.762	8.665
26	0.0693	20.64	0.002949	6.243	9.401
28	0.0752	22.42	0.003203	6.723	10.156
30	0.0816	24.35	0.003479	7.203	10.934
32	0.0886	26.43	0.003776	7.683	11.736
34	0.0961	28.67	0.004296	8.163	12.563
36	0.1041	31.07	0.004439	8.644	13.417
38	0.1126	33.64	0.004806	9.124	14.298
40	0.1217	36.41	0.005201	9.604	15.207
42	0.1315	39.38	0.005626	10.084	16.146
44	0.1420	42.55	0.006079	10.564	17.117
46	0.1532	45.93	0.006561	11.045	18.126
48	0.1652	49.55	0.007079	11.525	19.172
50	0.1780	53.42	0.007632	12.005	20.261
52	0.1918	57.57	0.008224	12.485	21.394
54	0.2063	62.01	0.008859	12.965	22.571
56	0.2219	66.77	0.009539	13.446	23.796
58	0.2384	71.85	0.01026	13.926	25.069
60	0.2561	77.28	0.01104	14.406	26.397

Continued from page 62

Air Tempera-ture (deg F)	Pressure of Saturated Vapor (psia)	Weight of Water Vapor for Saturation of 1 Lb of Dry Air *Grains	Pounds	1 Lb of Dry Air Above 0 F (BTU)	1 Lb of Dry Air Saturated (BTU)
62	0.2749	83.07	0.01187	14.886	27.785
64	0.2949	89.25	0.01275	15.366	29.235
66	0.3162	95.83	0.01369	15.847	30.752
68	0.3388	102.84	0.01469	16.327	32.336
70	0.3628	110.30	0.01576	16.807	33.994
72	0.3883	118.25	0.01689	17.287	35.728
74	0.4153	126.72	0.01810	17.767	37.545
76	0.4440	135.75	0.01939	18.248	39.451
78	0.4744	145.36	0.02077	18.728	41.452
80	0.5067	155.61	0.02223	19.208	43.554
82	0.5409	166.52	0.02379	19.69	45.76
84	0.5772	178.11	0.02544	20.17	48.08
86	0.6153	190.41	0.02720	20.65	50.51
88	0.6556	203.44	0.02906	21.13	53.07
90	0.6980	217.27	0.03104	21.61	55.75
92	0.7429	231.98	0.03314	22.09	58.57
94	0.7902	247.62	0.03532	22.57	61.54
96	0.8403	264.25	0.03775	23.05	64.67
98	0.8930	281.92	0.04027	23.53	67.96
100	0.9487	300.70	0.04296	24.01	71.44
105	1.1009	352.9	0.0504	25.21	80.99
110	1.274	413.6	0.0591	26.41	91.92
115	1.470	484.3	0.0692	27.61	104.46
120	1.691	567.1	0.0810	28.81	119.02
125	1.941	663.8	0.0948	30.01	135.76
130	2.221	777.2	0.1110	31.21	155.26

PROPERTIES OF MIXTURES OF AIR AND SATURATED WATER VAPOR (-0° F To 130° F; 29.92 in Hg)

$*1 \text{ grain} = \frac{\text{lb}}{7{,}000}$

The table gives the amount of heat energy in a quantity of air for temperatures over the range 0° F to 130° F; gives the pressure exerted by the vapor at each of these temperatures; and gives the heat energy increase associated with this quantity of air if it is saturated (holding as much water vapor as it can hold at the specific temperature and pressure). For example, locate 72° F in the table; the air when dry has only 17.287 BTU per pound; but if the air is saturated its energy is 35.728 BTU/lb.

Fig. 1 also shows that there are only 118.25 grains of water vapor (moisture) per lb of dry air at 72° F, but that air at 130° F contains 777.2 grains of water and, when saturated, has 155.26 BTU/lb of heat energy. It is important to notice that there is more available heat energy in hot "wet" air than there is in hot "dry" air.

Although not shown in Fig. 1, it is of interest to atmospheric physicists, meteorologists, weather forecasters, etc., that "wet" air is LIGHTER than "dry" air! Can you guess why this might be, knowing that "wet" air is more energetic than dry air at the same temperature, and knowing what you do about molecular energies and phase changes?

Besides knowing how much heat energy is present in the air at a specific temperature, it is also important in comfort control to know how much moisture is in the air and how close the air is to becoming saturated. Saturated air is holding all of the water vapor it can possibly hold at a specific temperature and pressure.

One simple method for finding the temperature at which a given quantity of air will become saturated is to slowly cool a polished or shiny-surfaced material (which is initially at the same temperature as the air being tested for <u>saturation temperature</u>). As this surface is cooled, it eventually reaches a temperature at which a film of condensed water vapor appears on its surface (<u>dew</u>). The temperature at which the surface <u>fogs</u> or "dews" is the <u>saturation temperature</u> for the air sample, and is known also as the <u>dew point temperature</u> or <u>dew point</u>.

An indirect way to determine the moisture content of the air is to use a psychrometer, the wet bulb and dry bulb thermometer device described earlier in Resource Package 3-1 and shown in Fig. 2, below.

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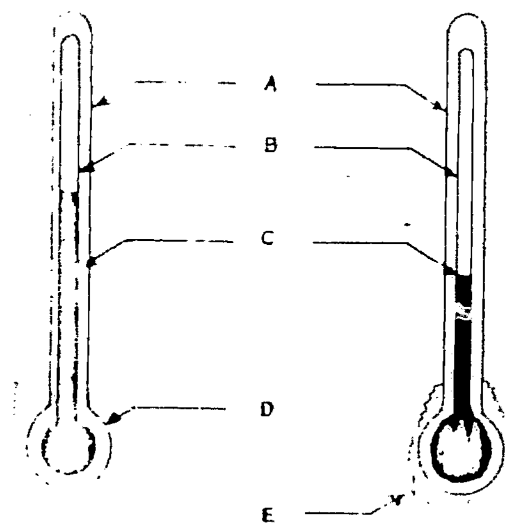


A-Thermometers B-Mercury column
C-Wet bulb column distance below dry bulb reading
D-Dry bulb E-Wick over wet bulb

DRY BULB AND WET BULB THERMOMETERS
Fig. 2

If the air sampled is saturated, no water will evaporate from the cloth wick of the wet bulb and its temperature reading will be the same as that of the dry bulb thermometer. If the air is not saturated, water will evaporate from the wick of the wet bulb thermometer and will lower its temperature reading.

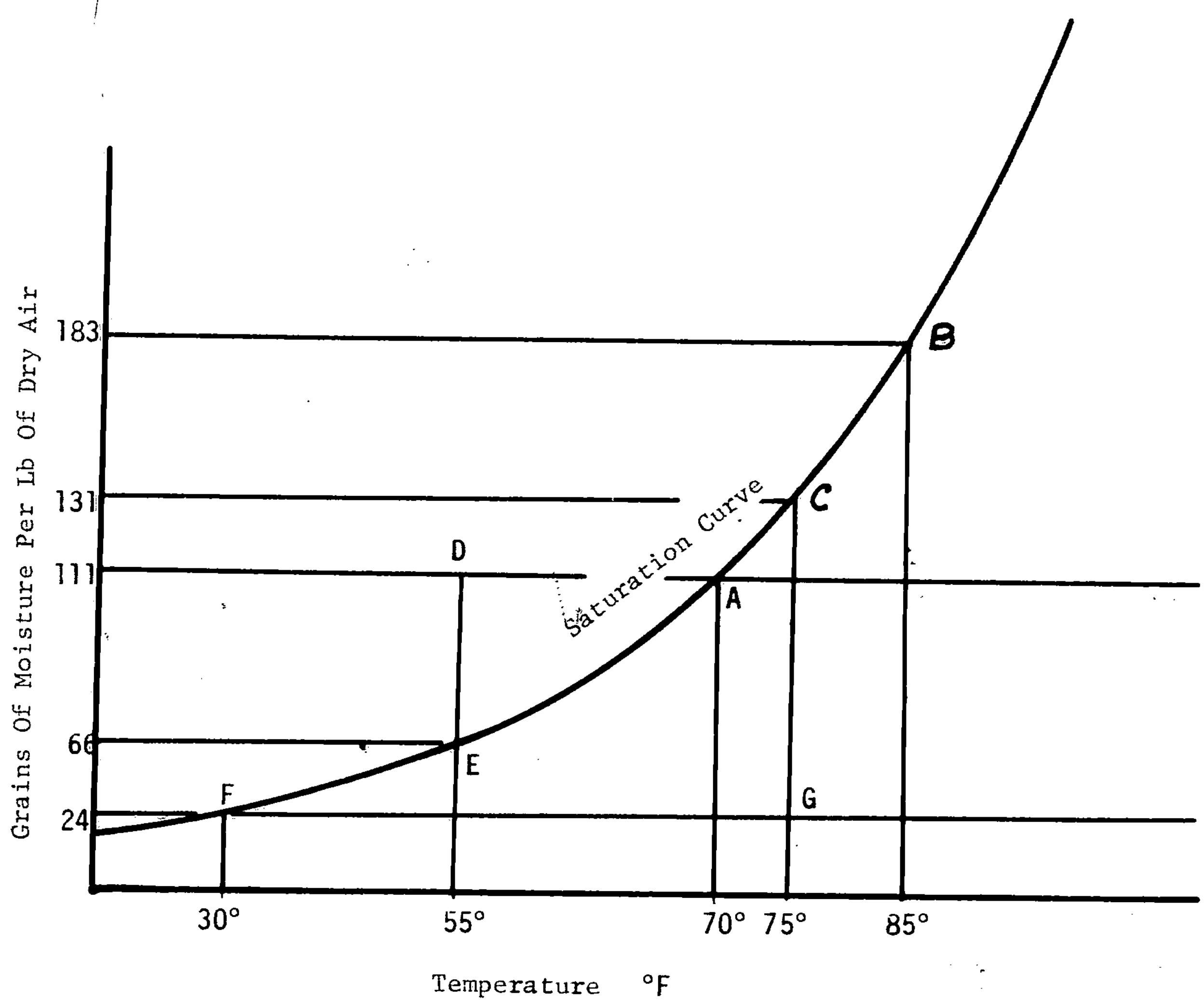
Evaporation is a cooling process; the latent heat of vaporization of water is 972 BTU/lb. The difference between the wet bulb thermometer reading and the dry bulb reading depends upon how "dry" the air is (upon the air's water vapor content). Knowing the wet and dry bulb readings, one can go to a table and look up the water vapor content of the air sampled.

The presence of water vapor in the air is a condition described as humidity. Humidity is often measured in two ways: (1) absolute humidity, and (2) relative humidity. Absolute humidity is the actual amount of water vapor in an air sample. The amount of water vapor is frequently measured in grains, where one grain is 1/7,000 of a pound. Relative humidity is the amount of water vapor present in a given sample of air, as compared to the amount of vapor the air sample would hold if it were saturated. Relative humidity is expressed as a percentage; 50% relative humidity, for example, means that the air sampled is containing one-half as much water vapor as it could contain if it were saturated.

The amount of water vapor that the air will hold depends upon the temperature of the air. Warm air holds more vapor than cool air. The amount of water vapor in the air also affects the rate of evaporation of perspiration from the body and consequent body comfort, the evaporation rate being greater for "drier" air. A person can feel warmer in "moist" air than in "dry" air at the same temperature.

It is possible to calculate the total amount of water vapor that will be present in saturated air; of course, air saturates with greater or lesser amounts of water vapor depending upon the temperature of the air. If the quantity of water vapor present is calculated in grains for each saturation temperature, then a graph can be made which looks like Fig. 3.

Notice that a saturation graph is not straight. The upward curve of the graph tells us that as air temperature increases, the water vapor it can contain increases non-linearly; i.e., if we double the temperature, we do NOT double the vapor content; if we treble the temperature, we do NOT increase the vapor content three times over, etc.



WATER SATURATION CURVE
Fig. 3

Look again at the water saturation curve in Fig. 3. Point A shows there are 111 grains of water vapor per pound of dry air when saturated at 70° F (100% relative humidity). The saturated condition at 85° F is shown at point B, where 183 grains of water vapor are present at saturation. If a sample of air contained 111 grains at 85° F, then the relative humidity would be the ratio of the grains present to the total number of grains for saturation at 85° F:

$$\frac{111 \text{ grains}}{185 \text{ grains}} \times (100\%) = 60 \text{ per cent relative humidity.}$$

Suppose we had our saturated sample at climate point A, Fig. 3. The horizontal line from A (70°) out to the vertical line B (85°) represents what happens when air is warmed; the temperature increases and the <u>relative humidity</u> decreases, since as the temperature goes up so does the water vapor requirement for saturation (from 111 grains to 183 grains). Point D represents what happens when air is cooled. The vapor represented by the distance D to E is condensed out of the air, since the air at the temperature corresponding to D (55° F) can hold only 66 grains of water vapor. The amount of moisture that is removed is (111 - 66) grains = 45 grains.

A typical winter condition in home climatization is represented by point F. Saturated air is taken in from outdoors at 30° F and 100 per cent relative humidity. This air holds 24 grains of vapor. If the air is heated to 75° F and no moisture is added, the new position will be represented at point G.

What would the relative humidity be at point G? Since the saturation curve indicates the air at 75° F can hold 131 grains of water vapor, and since only 24 grains are present, the relative humidity would be:

$$\frac{24 \text{ grains}}{131 \text{ grains}} \times (100\%) = 18.3\% \text{ relative humidity.}$$

A relative humidity of 18% is too "dry" for comfort; for example, evaporation will take place too rapidly from the skin and nasal passages. In addition, moisture will be removed from objects and materials inside the home; woodwork and wooden furniture may shrink until their joints separate.

Instruments used to measure relative humidity directly are called hygrometers. The simplest hygrometer consists of a human hair. Hair expands and contracts in response to the water vapor content of the air, and when this expansion-contraction has been calibrated an efficient hygrometer results.

Fig. 4 is an example of how tables and charts have been worked out using wet bulb and dry bulb thermometer readings to indicate relative humidity, heat content , steam content, and moisture content of a sample of air.

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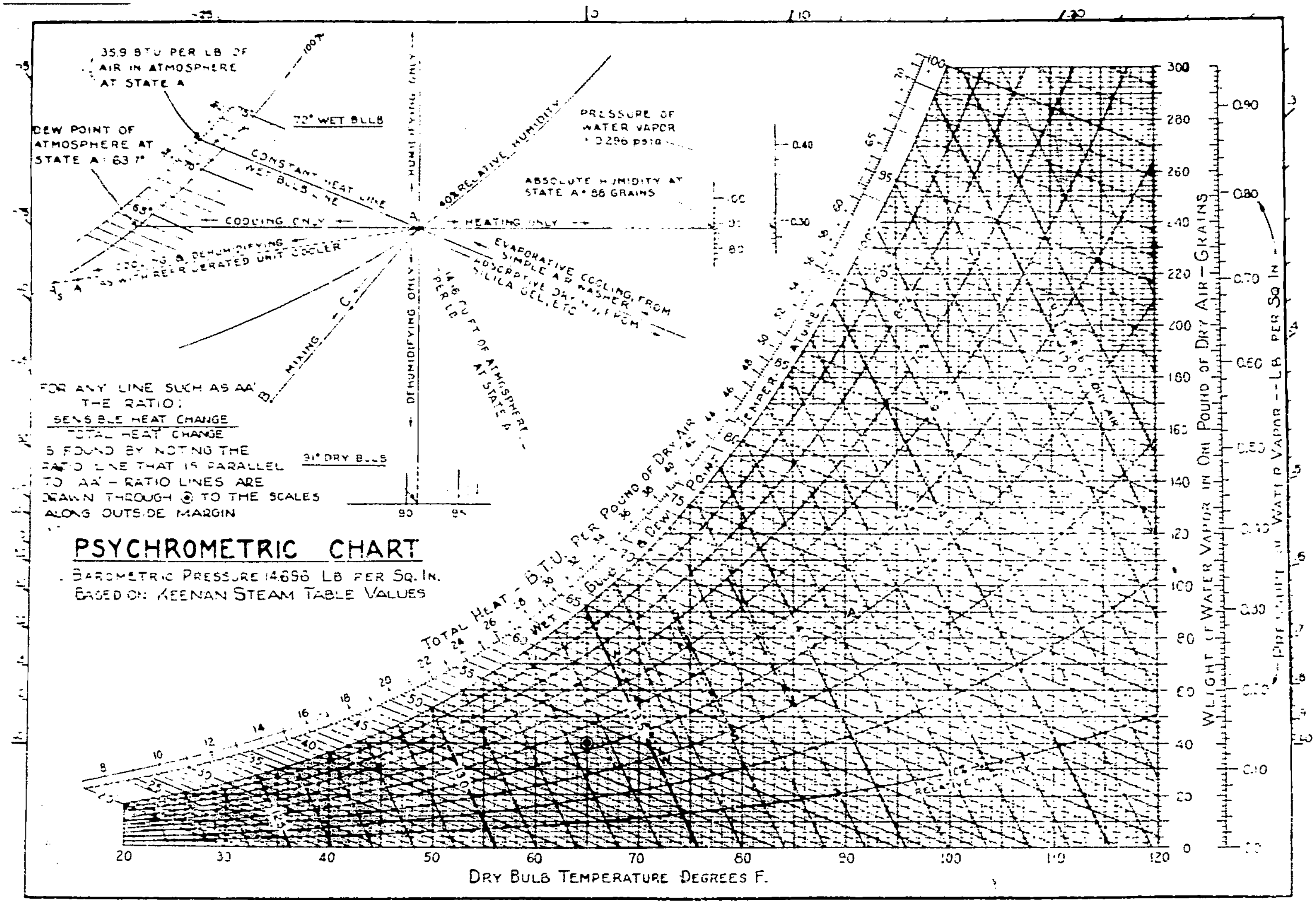
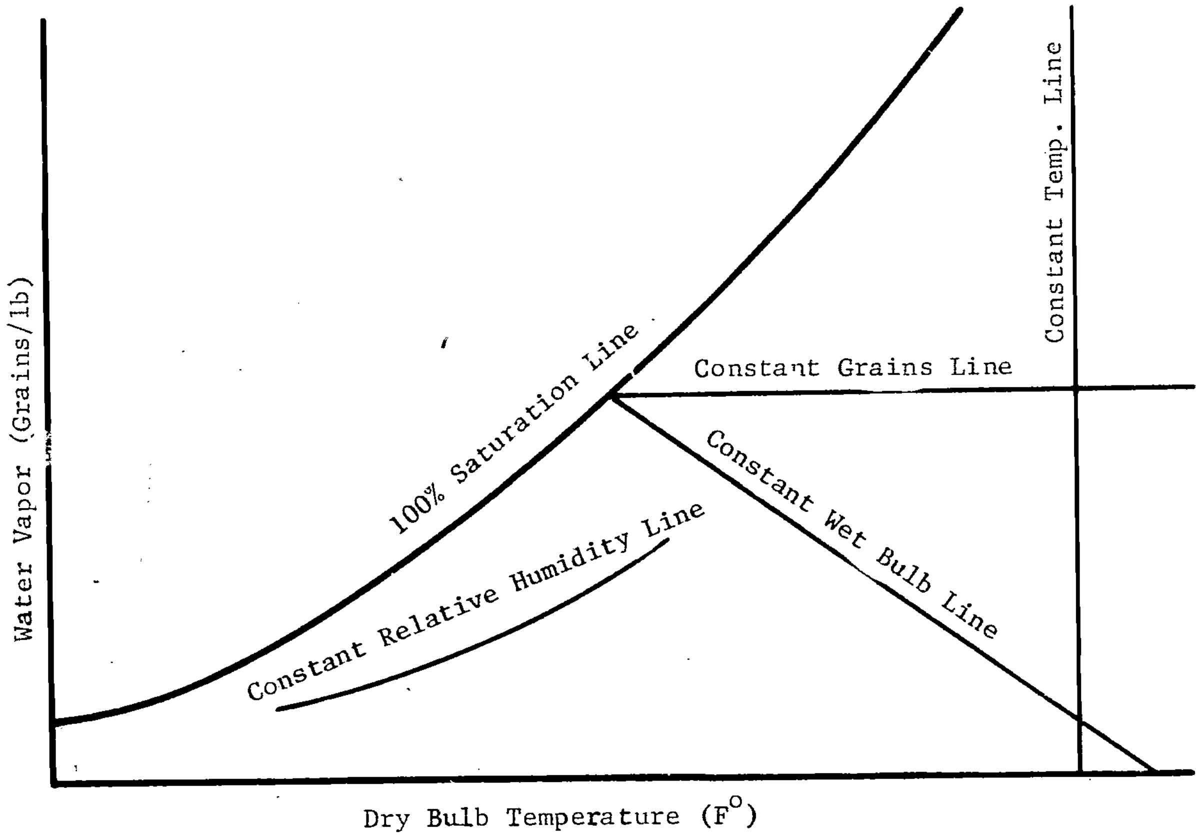


PSYCHROMETRIC CHART FOR TEMPERATURE RANGE 20° TO 120° F
Fig. 4

English tables and charts are based on one pound of dry air (plus the related water vapor) for the climatic condition being evaluated. The psychrometric charts (Figs. 4 and 5) should be studied in order to better understand the formation of particular climatizing conditions.



SIMPLE PSYCHROMETRIC CHART
Fig. 5

Climatizing problems concerning the effects of mixing air of various water vapor contents can be solved by using this psychrometric chart. The chart values along the horizontal base line (x-axis) represent dry bulb temperatures. The values along the vertical line (y-axis) represent grains of moisture per pound of dry air. The 100 per cent humidity line or line of saturation is the larger curved line. The shorter curved line is the constant relative humidity line. A constant wet bulb line and constant grains line are also shown. The wet bulb temperature can be found from the 100% saturation line.

Suppose that you made a dry bulb measurement of 65° F and a wet bulb measurement of 62° F. Find 65° F on the dry bulb temperature scale of Fig. 4 (x-axis scale) and 62° F on the saturation line (wet bulb scale; the large curved line on the left edge of Fig. 4). Extend these two lines until they intersect. This intersection will be above the 40 per cent humidity line (approximately 41 per cent). This intersection has been marked with a large dot and circle.

Now use the chart to find the dew point for a sample of air when the temperature is 80° F and the relative humidity is 50 per cent.

Moisture content of the air also plays an important role in the heating cycle of home climatizing. (See Fig. 6).

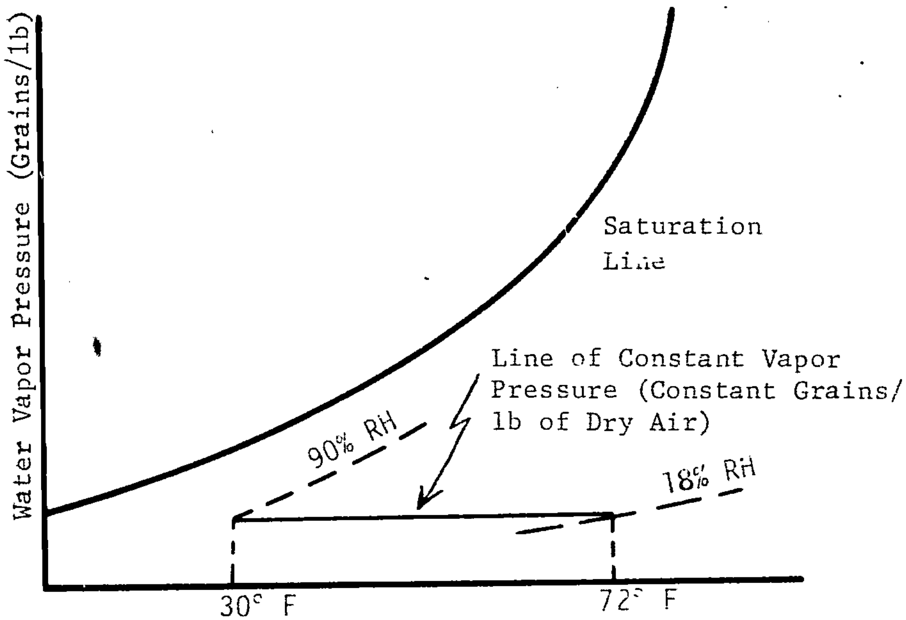


Fig. 6

Heating a living space, say a room, means warming the air to a comfortable condition. Assume that outdoor air conditions are 30° F and 90 per cent relative humidity. As this air comes into the building, it must be heated from 30° F to 72° F (See Fig. 6). At this stage, assume no moisture is added to the air so that the heating is along a line of constant vapor pressure of grains of moisture (i.e., constant vapor pressure implies that the moisture content stays the same per pound of dry air as the temperature increases). The psychrometric chart (Fig. 4) shows that the volume of air increases from 12.4 cu ft to 12.45 cu ft/lb of dry air, and that the amount of total heat energy increases from 10.59 BTU to 20.74 BTU/lb of dry air (an increase of 10.2 BTU).

The heat content of the heated air can be calculated as follows. At 30° F and 72° F the moisture content is the same; that is, 22 grains of water vapor (See Fig. 4). A specific heat chart will reveal that at 30° F the specific heat of dry air is 7.21 BTU/lb, and that the specific heat at 72° F is 17.31 BTU/lb. The total heat energy of our sample is the heat energy of the "dry" air + the heat energy of the water vapor. The heat energy of the "dry" air at both temperatures is known (See the last line of the paragraph above). So we need to calculate the heat energy of the water vapor and then add it to the heat energy of the "dry" air. A heat of vaporization table will show that at 30° F the latent heat due to the <u>vaporization of 1 pound of water</u> is 1074.3 BTU and at 72° F, 1092.6 BTU. But our air sample does not contain 1 pound of moisture (7,000 grains); it contains a constant 22 grains. Therefore,

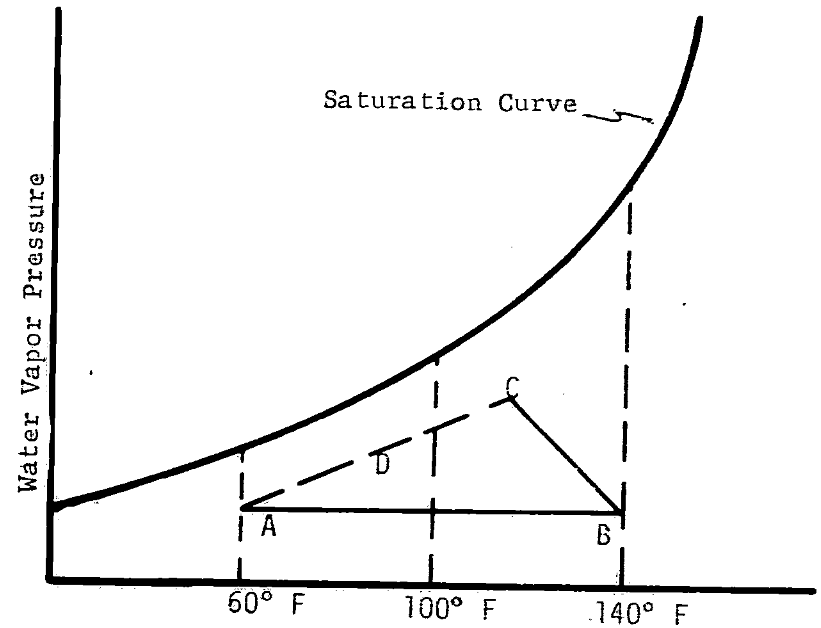
At 30° F, the heat energy of the <u>water vapor</u> $= 1074.3 \text{ BTU} \times \left(\frac{22 \text{ grain}}{7{,}000 \text{ grain}}\right) = 3.38$ BTU/lb of air.

<u>Total heat energy at 30° F</u> = 7.21 BTU/lb + 3.38 BTU/lb = 10.59 BTU/lb of air.

At 72° F, the heat energy of the water vapor $= 1092.6 \text{ BTU/lb} \times \left(\frac{22 \text{ grain}}{7{,}000 \text{ grain}}\right) = 3.43$ BTU/lb of warmed air.

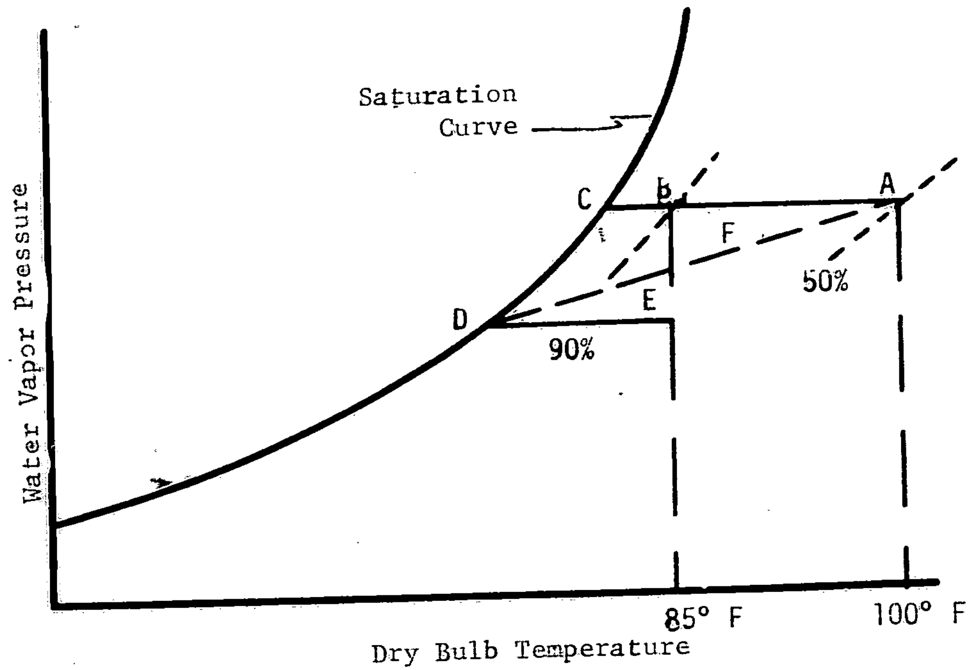
<u>Total heat energy at 72° F</u> = 17.31 BTU/lb + 3.43 BTU/lb = 20.74 BTU/lb of warmed air.

In a typical warm-air heating device the air returns to the furnace at 60° F and at 25 per cent relative humidity (point A, Fig. 7). The furnace then heats this air to 140° F (point B, Fig. 7). A humidifier adds water vapor to this air and, finally, this heated and humidified air is transported to the living space where it is mixed with air in the room. In Fig. 7, the line A to B represents the air being heated; line A to C represents the increase in water vapor and the decrease in temperature as the heated air is passed over the humidifier (where water is vaporized by the hot "dry" air). Point C indicates the final condition of the air as it is delivered to the conditioned living space. The line between the climate condition points C and A represents: (1) the humidified and heated air entering the living space from climate condition point C, (2) the mixing (and consequent cooling) with cooler air already in the living space (line C A), and (3) the eventual rejection of the air which has now cooled to the condition shown at climate point A. Thus, the cycle has been completed, and the air is now ready for re-cycling.



TYPICAL WARM AIR HEATING-HUMIDIFYING CYCLE
Fig. 7

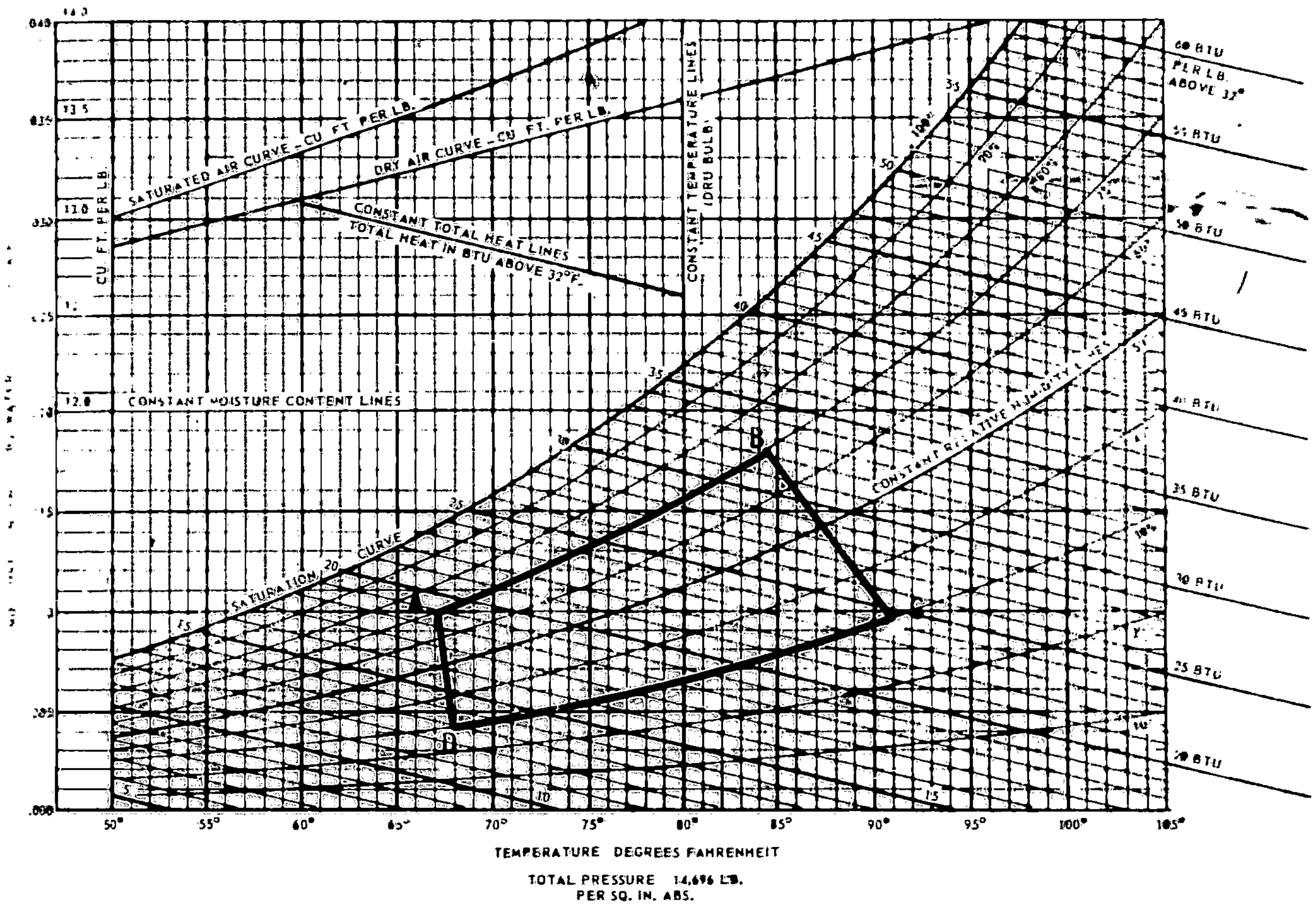
Humidity is also important in the cooling cycle. In this cycle, the dry bulb (db) temperature of the air is lowered. When this happens, the relative humidity increases and some water vapor should be removed to maintain a comfortable humidity. The line from climate condition point A to climate condition point B in Fig. 8 illustrates such a temperature drop. Notice that by cooling the air from 100° F to 85° F, the relative humidity drops from 50% to 90% (Make sure you can follow this on the graph in Fig. 8). Excess vapor can be removed from this "chilled" air by cooling it to some point on its saturation curve, and then passing it over a surface whose temperature is below this saturation point (dew point). This surface is a de-humidifier surface, and the device itself is called a de-humidifier. This portion of the cooling and de-humidifying cycle is the line A to B to C to D in Fig. 8. The line from B to C represents chilling to the saturation or dew point. The line from C to D represents the drop in vapor pressure (equivalent to grains of vapor removed), and point D represents the de-humidifier condenser surface temperature. Re-heating along the horizontal line DE will decrease the humidity. So if the cold "wet" air at climate point D is ejected into the living space it mixes with hotter and "drier" air. The result is an air mixture at a point "well within the comfort zone."



DE-HUMIDIFYING AND COOLING CYCLE
Fig. 8

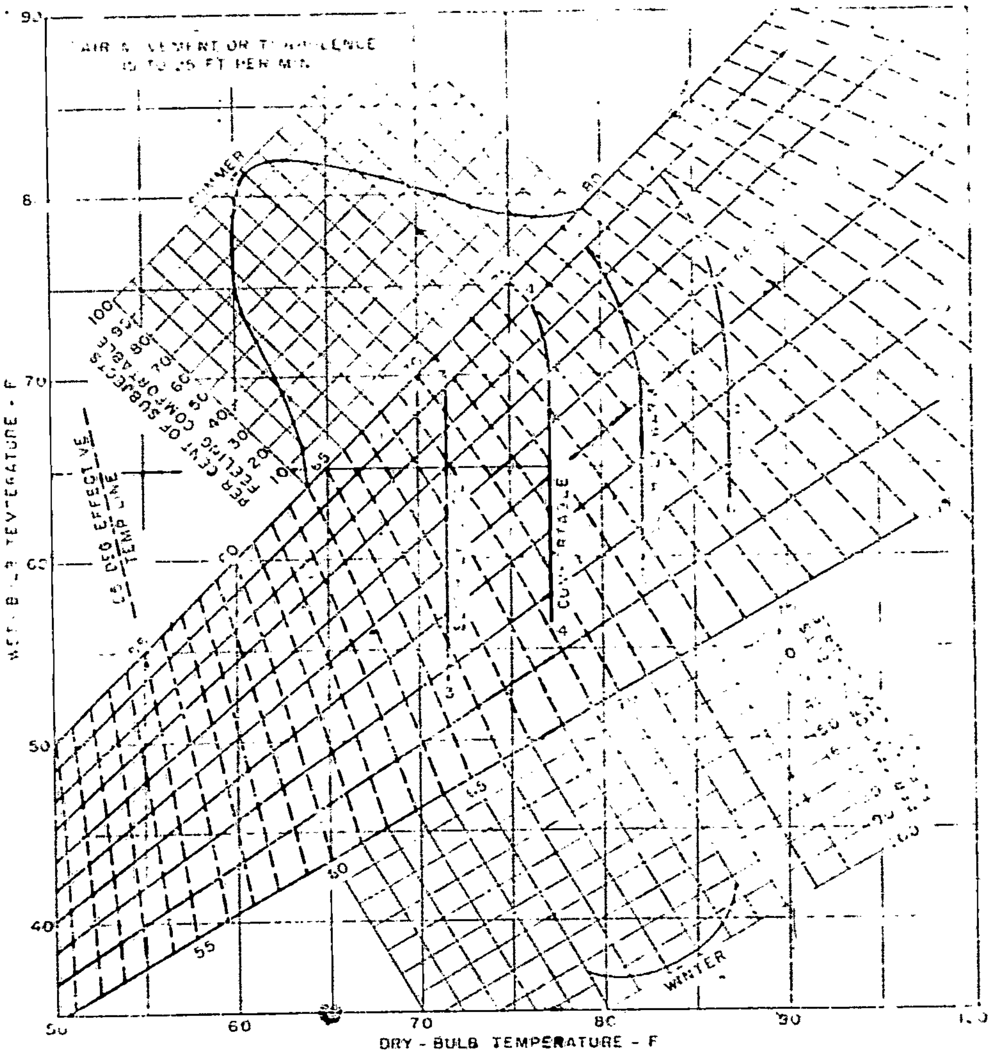
Comfortable conditions during a heating cycle or cooling cycle result from desirable combinations of temperature, humidity, air flow, etc. And different combinations of these same comfort variables can yield a comfortable climate. For instance, high humidity (which tends to be oppressive) may be counteracted by a relative low temperature; and, a low relative humidity can be compensated for by an increased room temperature. In each case, a comfort zone can be satisfactorily maintained.

The area enclosed within the climate condition points ABCD, Fig. 9, illustrates the range of the climate variables for what is commonly accepted as the comfort zone.



Psychrometric chart showing different variables based on one pound of dry air. Space marked A B C D is temperature-humidity range which is most comfortable for majority of people.
(Kelvinator Div., American Motors Corp.)
Figure 9

Figure 10, a more technical graph, distinguishes between preferred comfort zones for summer and winter.



SUMMER AND WINTER
COMFORT ZONES
Fig. 10

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RESOURCE PACKAGE 6-1

INVESTIGATING DEW POINT

How can the dew point be determined?

On a summer day when one feels hot and sticky, it is not much consolidation to have a friend say, "It's not the heat; it's the humidity," but he speaks the truth. Perspiration does not evaporate on such a day because the air is already nearly saturated; perspiration accumulates on body surfaces and you feel sticky and uncomfortable. This is also the type of day climate-wise when small droplets of water condense on the cold sides of a water glass and we say that the glass is "sweating." In this investigation, you will use the temperature at which this "sweating" begins to find the dew point of the air.

Materials needed:

polished metal cup
thermometer
ice
salt

Record the room temperature. Fill the polished cup about half full of tap water. Put a piece of ice in the cup and stir the water gently with the thermometer. Do not breathe on the cup. Moisture from your breath could condense on the cup and give you an inaccurate reading of the dew point. Carefully watch the polished cup for the first trace of a moisture film. If the ice melts before the condensate (moisture) appears, add more ice and keep on stirring.

It is possible for the dew point to be below zero. In this case to obtain the necessary low temperature, place ice in the cup. Then pour out all but a little of the water and gradually add some salt.

When the film of moisture does appear, read the thermometer at once. Look up the calibration correction and record the true temperature in a table such as the one below.

Remove the remaining ice (if any) and allow the water to warm up, while you continually stir with the thermometer. This t... watch for the moisture to disappear (evaporate), and read the thermometer at once when this occurs. Be patient with this one; warming up the cold water takes longer than cooling down the warm water with ice!

Because moisture probably appeared slightly before you noticed it the first time, it would be a good idea to repeat the procedure above. The average of the two readings (falling temperature and rising temperature) will give you a better value of the dew point than just a single reading. Therefore, repeat the entire procedure and take the average of all trials. Report this as your measured dew point.

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	Trial 1	Trial 2
Room Temperature (^{o}F)		
Temperature at Appearance of Moisture (^{o}F)		
Temperature at Disappearance of Moisture (^{o}F)		
Average Temperatures For Trials 1 and 2		
Dew Point		

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RESOURCE PACKAGE 7-1

INVESTIGATING HUMIDITY AND COMFORT

This exercise will help you determine the effect humidity has upon comfort.

You will need a small storage room, a map, some water, and a psychrometer.

Close all doors and vents to stop air movement. Mop the floor; this will increase the humidity as the floor dries. After mopping the floor, start taking dry bulb and wet bulb temperature readings at 1-1/2 minute intervals. Record your readings in a table such as the one below, and describe the comfort conditions concurrent with each reading under the comments column.

After the wet bulb has reached its maximum temperature, open a door and continue taking readings until the room is back to the original dry bulb and wet bulb readings. Determine the relative humidity for each reading.

Make a graph of wet-bulb and dry-bulb temperatures vs time. Label the climate condition points on the graph which you consider to be comfortable, uncomfortable, hot, warm, sticky, clammy, etc. Your graph will resemble Fig. 1 in Resource Package 7-2.

Time	Wet Bulb	Dry Bulb	Comments	R/H

You have likely heard weathercasters say, "The temperature is only _____, but the chill factor is ______."
Find out what is meant by chill factor, how it is determined, whether or not it can be expressed simply in a mathematical way, etc.

RESOURCE PACKAGE 7-2

INVESTIGATING RELATIVE HUMIDITY AND COMFORT

Relative humidity is the per cent ratio of the water vapor present in an air sample to the water vapor the sample could hold if it were saturated at the same temperature and pressure. Mathematically,

$$\text{Relative humidity} = \frac{\text{vapor actually in air}}{\text{vapor air could hold if saturated}} \times 100\%$$

Comfort is quite dependent upon relative humidity. A high relative humidity can result in a climate characterized as sticky, oppressive, muggy, clammy, etc. Low relative humidity is common indoors during cold weather and can cause drying of skin, drying of membranes of the nasal passages and throat, discomfort for persons with respiratory infections, etc.

Using wet bulb and dry bulb temperature readings, and a psychrometric chart, determine and record the following:

1) Relative humidity
2) Weight of water in one pound of air
3) Dew point temperature
4) BTU per pound of air

Locate your relative humidity reading and dry bulb temperature reading on the comfort chart, Fig. 1. Do this for both indoor and outdoor temperature readings. If the coordinates are not located near the point labeled COMFORTABLE, describe how the variables need to be changed to assure a position near the comfort zone locus (point).

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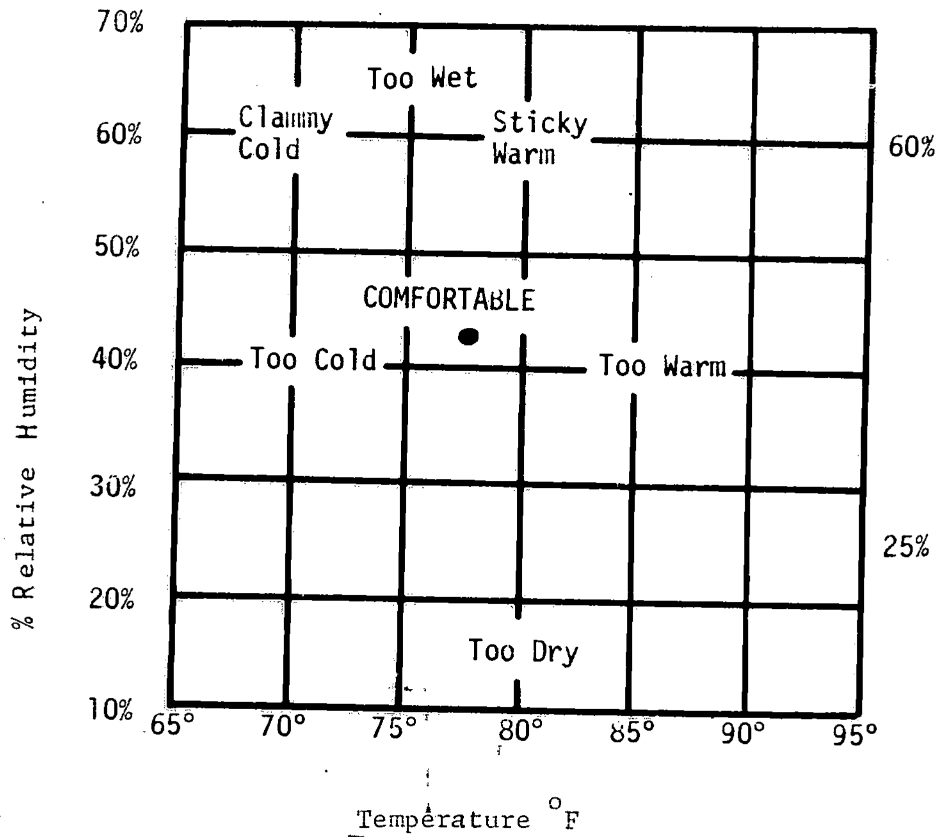


COMFORT CHART
Fig. 1

A <u>discomfort</u> <u>index</u> can be used to indicate discomfort due to humidity. This numerical index is also called the <u>temperature-humidity</u> <u>index</u> (<u>THI</u>). This index number is determined by adding the wet bulb and dry bulb temperatures, multiplying by .4, and then adding 15.

Example: On a certain day the wet bulb (wb) temperature is 70° F and the dry bulb (db) temperature is 80° F. What is the temperature-humidity index?

$$
\begin{aligned}
\text{THI} &= .4 \times (\text{wb} \div \text{db}) \div 15 \\
&= .4 \times (70 + 80) + 15 \\
&= .4 \times 150 + 15 \\
&= 60 \div 15 \\
&= 75
\end{aligned}
$$

The following table indicates the percentage of people who will be <u>uncomfortable</u> at indicated THI numbers: for example, when THI - 75, 50% of a room's occupants can be expected to feel uncomfortable:

THI	% Uncomfortable
70	10
*75	50
80	100

DISCOMFORT TABLE

Consult the psychrometric chart and determine the amount of BTU's needed to change the existing condition to a favorable condition.

Calculate and record the THI number for the dry bulb and wet bulb readings you took indoors and outdoors. Compare the calculated THI values with your comments on the inside and outside conditions in Resource Package 7-1.

RESOURCE PACKAGE 8-1

HEAT LOADS

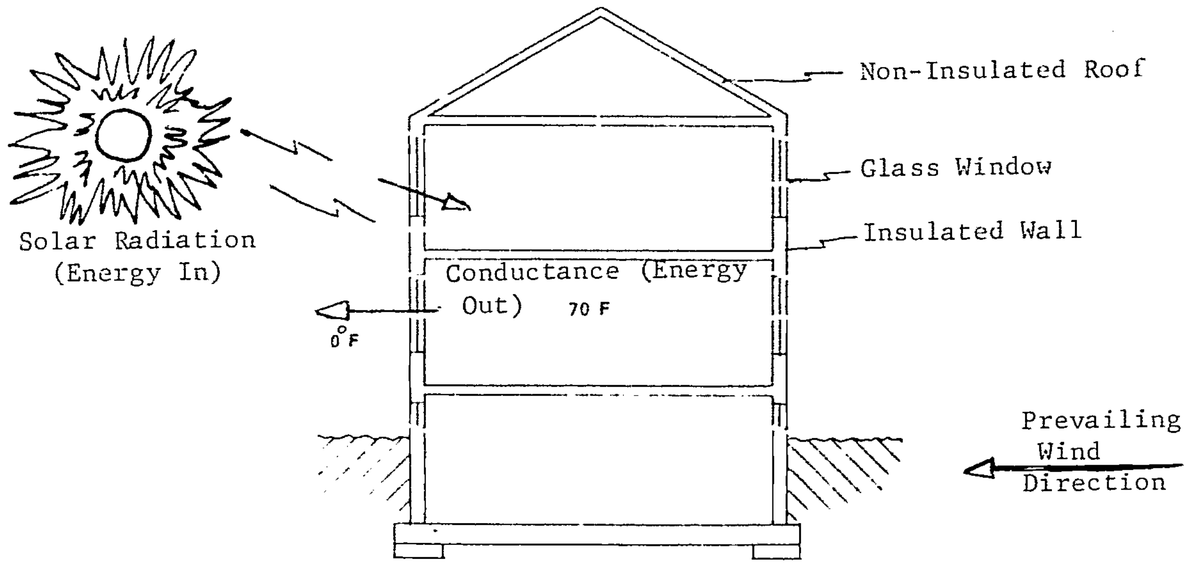
Air-climatizing systems must put enough heat energy into a space to make up for heat losses (when heating) and they must remove as much excess heat energy as a space accumulates to make up for heat gains (when cooling).

Whenever a temperature difference exists between the air inside and outside a space, heat energy will transfer from the air at higher temperature to the air at lower temperature. Since perfect insulating conditions do not exist in buildings and homes, it is important to know the amount of heat energy lost that must be replaced in heating, or the amount of heat energy gained that must be removed in cooling. The total amount of heat gain or heat loss to be compensated for is known as the <u>heat load</u>. Heat load is usually calculated in BTU/hr; these calculations are in terms of <u>sensible heat load</u> (based upon temperature change) and/or <u>latent heat load</u> (based upon water vapor content) depending upon the climatizing problem.

Several factors must be taken into consideration when considering heat loads. Some of these factors are:

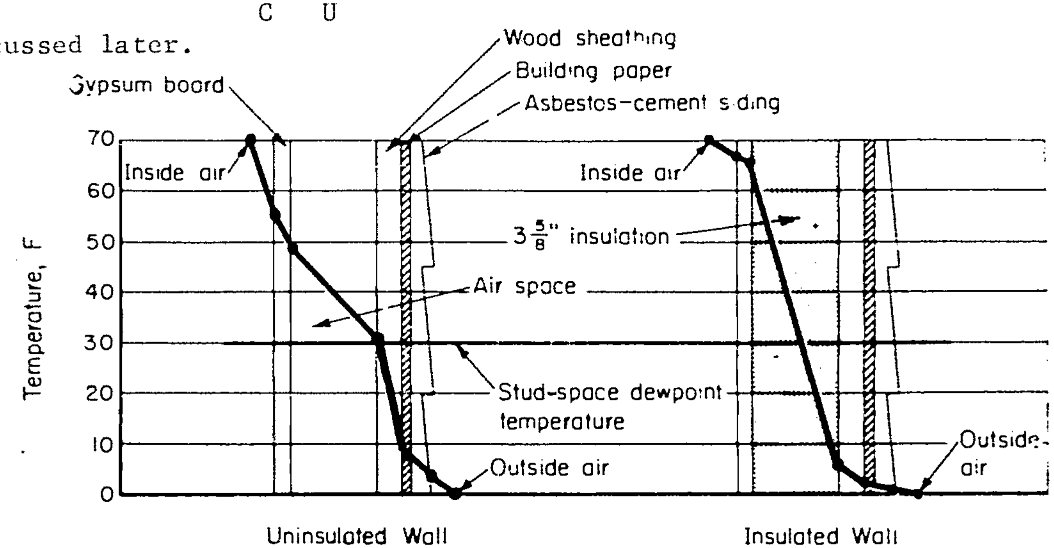
1) Heat energy conducted through walls, ceiling, and floors
2) Heat energy necessary for humidity control
3) Heat energy gained or lost from air leakage and ventilation
4) Heat energy transformed from solar energy absorption
5) Heat energy from other sources (lights, electric motors, stoves, people, etc.).

U, R, and C-Value Calculations. Heat load calculations require almost the same information for both heating and cooling. So if you understand how to calculate one, you automatically are able to calculate the other. Either of these calculations must consider all means by which heat energy is exchanged between the living space and its environment, where this environment includes objects or people inside the space. The means by which this energy is lost from the space is collectively known as heat loss; conversely, the movement of this energy into a space is commonly known as heat gain. Both the heat energy loss and the heat energy gain of a space are sometimes called heat leakage, and this leakage is determined by such physical factors as prevailing winds, solar exposure, type and shape of structure, indoor-outdoor temperature differences, etc. (See Fig. 1). In leakage calculations, the ability of a material to transfer heat energy is termed conductance and is symbolized by the letter C.



SOME LEAKAGE FACTORS
Fig. 1

For example, in Fig. 1, the net amount of heat energy moving from the building through the walls, roof, etc., and out into the air is the heat leakage. This type of calculation is known as <u>heat transfer</u> calculation and is frequently measured in BTU/sq ft - ^{o}F-hr. The common symbol for this net heat transfer is U. Another way of talking about the ability of a structure to transfer heat energy is to consider the <u>conductance</u> (C) of its materials. And yet another method for determining heat leakage of a structure is by the resistance of its materials to heat energy movement. This resistance factor is known as <u>thermal resistance</u> (R). Mathematically, thermal resistance (R) is the reciprocal of conductance (C) or of the overall heat transfer (U): $R = \frac{1}{C} = \frac{1}{U}$. The technical difference between <u>conductance</u> (C) and heat <u>transfer</u> (U) will be discussed later.



TEMPERATURE CHANGES THROUGH WALLS
Fig. 2

Fig. 2 shows temperature changes through different materials for a typical house with wood siding. This type of heat energy movement through structural materials is called <u>conductance</u>.

The general terms used in heat transfer follow:

1) The letter U is used to represent heat leakage <u>from the air</u> on one side of a structural surface <u>to the air</u> on the other side of the structural surface.

2) The letter R is used to represent the thermal resistance of a material to heat transfer (See Fig. 3).

3) The letter K represents the energy transmitted through one square foot of wall or surface in one hour, when a temperature difference of one degree exists and when the material is one inch thick.

4) The letter C is used to represent the heat leakage through <u>structural</u> materials.

The letter U (number 1, above) is almost the same as C. The U-value represents the additional insulating effect of an air film on each side of the surface.

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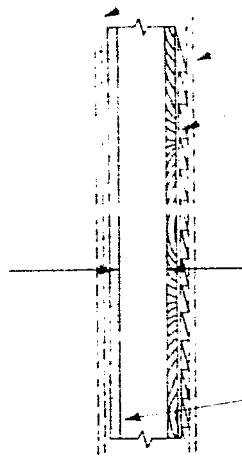

HEAT TRANSFER RESISTANCE (R)
Fig. 3

The U value for almost every construction material can be found in data books published by the American Society of Heating, Refrigerating, and Air Conditioning Engineers. Table 1, presented on the following page, is a simplified U-value table for some common construction materials.

To calculate the heat load (Q) by using a U-factor, you need to know:

1) the area of the transmitting surface

2) the U-factor of the material

3) the indoor and outdoor temperatures.

The equation used is:

Heat Load (Q) = Area (A) X Temperature Difference (ΔT) x U-Factor

Example: The area of a 6-inch thick concrete floor, no finish, is 400 square feet. The temperature conditions are 72° F inside and 42° F outside. What is the heat load?

The U-factor for the floor is shown in Table 1 to be $\frac{.59 \text{ BTU}}{ft^2 - {}^{\circ}F - hr}$.

Using the heat load formula:

$$Q = A\ (\Delta T)\ \text{U-Factor}$$

$$= (400\ ft^2)\ (72-42)\ {}^{\circ}F\ \left(0.59\ \frac{BTU}{ft^2 - {}^{\circ}F - hr}\right)$$

$$= (400)\ (30)\ 0.59\ \frac{BTU}{hr}$$

$$= 7080\ \frac{BTU}{hr}$$

MASONRY CONSTRUCTION

GENERAL WALL CLASSIFICATION	6"	8"	10"	12"	16"
	MASONRY THICKNESS				
K—Plain		50		36	
ster (1/2" Applied Directly to Brick		16		.31	
Plaster on Metal Lath		32		25	
Plaster on 1/2" Rigid Insulation		22		19	
Plaster on 1" Rigid Insulation		16		14	
RETE—Plain	.79		62		48
Plaster Applied Directly to Concrete	70		57		44
Plaster on Metal Lath	.42		.37		31
Plaster on 1/2" Rigid Insulation	26		21		21
Plaster on 1" Rigid Insulation	.19		18		16
Plaster, Lath, 2" Space with Rock Wool Fill	13		13		.12
OW TILE—Plain		40	39		25
Plaster Applied to One Side		.38	37		24
Plaster on Metal Lath		.28	.27		22
Brick Veneer, Hollow Tile, Metal Lath and Plaster (Tile thickness given	25	.25	24	.21	
Brick Veneer, Hollow Tile, 2" Rock Wool Fill, Lath and Plaster (Tile thickness given	.11	11	.11	.10	

FRAME FLOORS AND CEILINGS

Hardwood and Pine Flooring on Joists, no Ceiling	.34
Hardwood and Pine Flooring on Joists, Wood Lath and Plaster Ceiling	.24
Rough Pine Floor, Wood Lath and Plaster Ceiling	28
No Floor, Lath and Plaster Ceiling	62
No Floor, Lath and Plaster Ceiling, 3 5/8" Rock Wool Fill	.079
No Floor, Lath and Plaster Ceiling, 1" Flexible Insulation	.17
Pine Floor, 3 5/8" Rock Wool Fill Lath and Plaster	063

PITCHED ROOF

Wood Shingles on Wood Strips	16
Asbestos Shingles on Wood Sheathing	.56
Tile or Slate Roofing on Wood Sheathing	.56
Wood Shingles, 1" Flexible Insulation between Rafters	.13
Asbestos or Slate Shingles, 1" Flexible Insulation.	.13

FRAME CONSTRUCTION

Wood Siding on 1" Wood Sheathing, Studs, Wood Lath and Plaster	25
Wood Siding, Sheathing, Studs, 1/2" Rigid Insulation and Plaster	.19
Wood Siding, Sheathing, Studs, 1/2" Flexible Insulation, Lath and Plaster	.15
Wood Siding, Sheathing, Studs, Rock Wool Fill, Lath and Plaster	072
Note: Frame Walls with Shingle Exterior Finish same as Walls with Wood Siding.	
Stucco, Wood Siding, Studs, Wood Lath and Plaster	30
Stucco on 1/2" Rigid Insulation, Studs, Wood Lath and Plaster	27
Stucco on 25/32" Rigid Insulation, Studs, 1/2" Rigid Insulation and Plaster	.20
Stucco on 1/2" Rigid Insulation, Studs, Rock Wool Fill, Lath and Plaster	074

CONCRETE FLOORS AND CEILINGS

4" Thick Concrete, No Finish	.65
6" Thick Concrete, No Finish	.59
4" Concrete, Suspended Plaster Ceiling	.37
6" Concrete, Suspended Plaster Ceiling	.35
4" Concrete, Metal Lath and Plaster Ceiling, Hardwood Floor on Pine Sub-flooring	23
6" Thick Concrete, Metal Lath and Plaster Ceiling, Hardwood Floor on Pine Sub-flooring	.21
4" Concrete, Hardwood and Pine Floor, No Ceiling	.31
6" Concrete, Hardwood and Pine Floor No Ceiling	.30

WINDOWS AND SKYLIGHTS

Single glass	1 13
Double glass, intermediate air space	.45
Hollow glass tile wall 6" x 6" x 4" blocks	60

BRICK VENEER ON FRAME CONSTRUCTION

Brick Veneer, 1" Wood Siding, Studs, Lath and Plaster	.27
Brick Veneer, 25/32" Rigid Insulation, Studs, Lath and Plaster	.25
Brick Veneer, 1" Wood Siding, Studs, 1/2" Flexible Insulation, Lath and Plaster	16
Brick Veneer, 1" Wood Siding, Studs, Rock Wool Fill, Lath and Plaster	074

INTERIOR WALLS

Note: In general for Cooling Computations, base the calculations for Heat Gain from adjoining non-conditioned rooms on a differential equal to 1/2 the differential to outside	
Wood Lath and Plaster on Studding Both sides	34
Metal Lath and Plaster on Studding Both sides	39
1/2" Rigid Insulation and Plaster Both sides	18
4" Hollow Clay Tile	45
4" Gypsum Block	30
4" Gypsum Block, Plastered one side	28
4" Gypsum Block, Plastered both sides	27

FLAT ROOFS WITH BUILT-UP ROOFING

Deck Material	No Ceiling	Metal Lath and Plaster Ceiling
Precast Cement Tile	81	.43
Precast Cement Tile, 1" Rigid Insulation	.24	.19
2" Thick Concrete	.82	42
2" Thick Concrete, 1" Rigid Insulation	.24	.19
4" Thick Concrete	.72	.40
4" Thick Concrete, 1" Rigid Insulation	.23	.18
1" Wood	.49	.32
2" Wood	.32	.24
Flat Metal Roofs	.95	46
Flat Metal Roofs, 1" Rigid Insulation	.25	19

HEAT LOADS

Constants For Heat Transmission

Expressed in Btu per hour per square foot per degree temperature difference, based on 15 mph wind velocity

TABLE 1

Now look at an alternate method for calculating heat leakage, using the thermal resistance or R-factor. You recall that $R = \frac{1}{C}$ for structural materials, and, in the case of overall heat transfer from inner air space to outer air space, $R = \frac{1}{U}$. Table 2 presents some typical R-values for some common construction materials.

Material	R Value
Surface (still air)	.68
Air space	.97
Gypsum wallboard 3/8 in	.32
Outside surface (15 mph wind)	.17
Face brick	.39
Concrete blocks, 4 in	1.11
Plaster 1/2 in	.09
Siding (wood) 1/2 in x 8 in	.85
Building paper	.06
Wood sheathing	.98
Wood floor-1 in	.98
Linoleum or tile	.05
Asphalt shingles or plywood	.95

SOME COMMON RESISTANCE VALUES

TABLE 2

Example: Calculate the U-factor for the wall in Fig. 3. All the individual R-values must first be combined to yield a sum, or total of R-values (R_T). These values are listed and summed below:

	R-Value
Outside air film	0.17
$\frac{25}{32}$" fir sheeting, building paper and yellow-pine lap siding	1.85
Air space between studs	0.97
Wood lath and plaster	0.40
Inside film	0.68
R_T =	4.07

Since $R = \frac{1}{U}$, U must equal $\frac{1}{R}$. Substituting the R_T-value calculated above into the reciprocal relationship yields $R_T = \frac{1}{U}$, $U = \frac{1}{4.07} = 0.25$, our desired U-factor.

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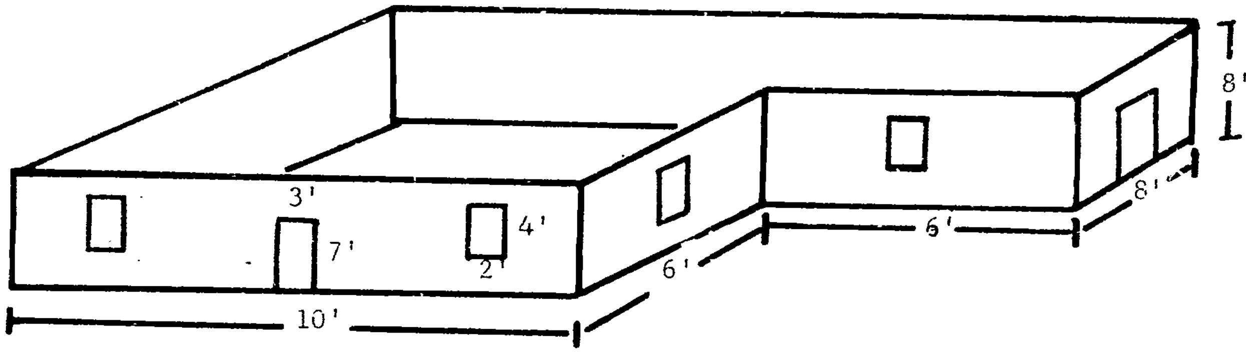
Calculating Wall Area. The gross area of the walls of a living space is the product of the outside wall perimeter and the inside ceiling height; gross wall area = outside wall perimeter x inside ceiling height. For the living space in Fig. 4, the gross wall area is:



A LIVING SPACE
Fig. 4

Outside wall perimeter = 10' + 6' + 8' + 16' + 14' = 60'

Inside ceiling height = 8'

Gross wall area = 60' x 8' = 480 sq ft

For heat load calculations, the effective wall area is used instead of the gross wall area. The effective wall area is found by subtracting the total window and door areas from the gross wall area

(See Table 4 for typical window and door area U-values). Living spaces have both ceiling and floor areas, so these must also be calculated. The effective ceiling <u>and</u> floor areas combined are <u>twice</u> the product of the gross floor length times the gross floor width (In some many cases, the ceiling or floor areas are broken down into small areas for computational purposes). The total effective living space area (A) is the sum of the effective wall, ceiling and floor areas.

<u>Design Temperatures</u>. Design temperatures are the range of temperature differences between the living space and the outside space that the designer expects the climatizing unit to handle for both heating and cooling purposes. In the design state, it is best to set up the total heating load calculations in tabular form. Table 4 illustrates a typical heat load data arrangement for a house.

Surface	Area (ft^2)	U-Value ($BTU/ft^2\ F^o\ hr$)	Temp. Difference (F^o)	Heat Leakage (BTU/hr)
Wall, Gross	480 sq. ft.	.59	70	19824.0
Window	32 sq. ft.	1.13	70	2531.2
Door	42 sq. ft.	.73	70	2146.2
Wall, Net	406 sq. ft.	.25	70	7105.0
Ceiling	188 sq. ft.	.62	35	4079.0
Floor	188 sq. ft.	.34	25	1598.0
			Total	17460.0

TYPICAL HEAT LOAD TABLE
TABLE 4

It is sometimes desirable to calculate the total heat loss for one degree, and t[illegible]n multiply this value

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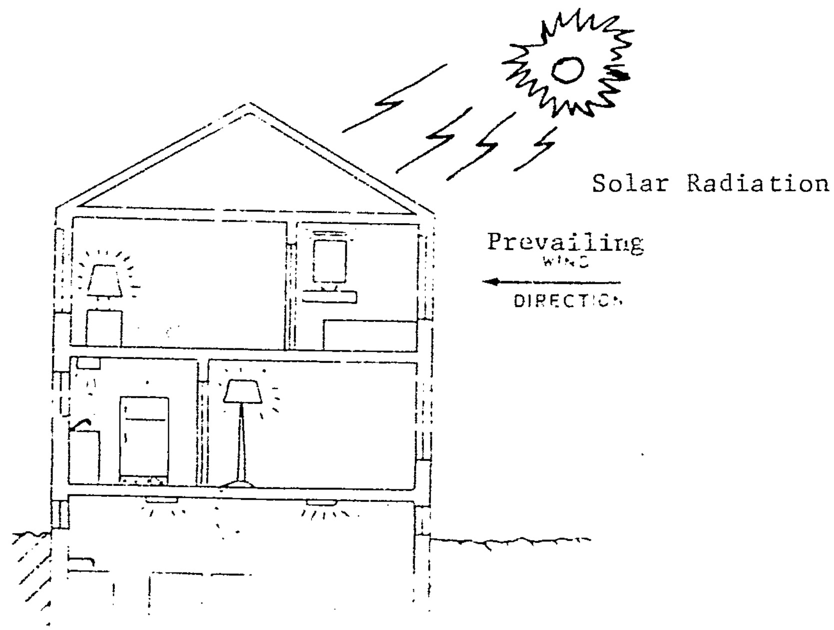
by the design temperature difference to obtain the total heat loss. The design temperature difference is naturally based upon the locality being considered. The indoor temperature is usually designed to be 75° F at 50% relative humidity. Therefore, if the outside space summer design temperature is 100°, the <u>temperature difference</u> used is 25° F.

Miscellaneous sources of heat must be considered in heat loads. Such sources as solar heating, electric load, and occupant load are frequently large enough that they must be taken into consideration. See Fig. 5.



INTERNAL HEAT SOURCES
Fig. 5

Heat Exchange Through Glass. Heat flow through ordinary window glass is approximately four times that of ordinary residential roofs or ceilings. The U-factor value for ordinary glass is 1.13; whereas, the U-factor value for residential roofs is 0.31. Thus, it can be seen that a major problem develops in cooling or heating areas containing large amounts of ordinary window glass. Special types of glass are used to reduce solar heat load and to reduce heat transfer through glassed areas.

Solar Energy Considerations. Solar energy can add considerably to the total heat load during the summer. Solar energy contribution must especially be considered on the east wall in the morning, the south wall all day long, and the west wall in the afternoon. Naturally the amount of solar energy absorbed depends upon such factors as the part of the world in which the building is located, the color and surface condition of the building, the surface material, etc. The varying amounts of heat energy typically gained through windows of different exposures is shown in the example below:

Exposure	Heat Absorption BTU/hr/sq ft
Southwest	110
West	100
South	75
East	55
Single Skylights	110
Double Skylights	60

If windows are not protected by awnings, it is generally agreed that adding about 15° F to the design

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temperature will give correct design results. The solar effect upon outside exposed walls can likewise be generally corrected for by adding 15^{o} F to the outside design temperature.

Of practical interest is the change in position of the sun relative to the surfaces of a building, and the consequent time lag required for solar energy to affect the interior of the building. When a substance is heated on one side, it takes time for the heat to travel through the substance. This interval is called time lag. When the sun heats the outside wall of a building, several hours can elapse before this energy is transmitted to the inner surface of that wall as heat energy. In a typical building, this time lag will be perhaps 3 to 4 hours. If the wall is insulated well enough, or is thick enough, the sun can have set by the time the heat energy "penetrates" or "soaks through" to affect the inner spaces.

Except for windows, heat from the sun on an east wall reaches room spaces approximately as follows:

Time of Sunshine	Time Heat Reaches Room
8 to 9 a.m.	11 to 12 a.m.
9 to 10 a.m.	12 to 1 p.m.
10 to 11 a.m.	1 to 2 p.m.

A south wall is affected from 8 a.m. to 7 p.m., but not as strongly as the east and west walls since for them the sun's rays are from a position more directly overhead.

A west wall receives sun rays of consequence from 4 p.m. to 7 p.m.

Time of Sunshine	Time Heat Reaches Room
4 to 5 p.m.	7 to 8 p.m.
5 to 6 p.m.	8 to 9 p.m.
6 to 7 p.m.	9 to 10 p.m.

It is because of heat lag that rooms can actually receive heat from the solar source (outside source) even after the outdoor temperature has dropped appreciably. Many people complain of uncomfortable temperatures in non-climatized rooms as late as 12 midnight, or even 1 or 2 a.m.

Insulating Materials. It is essential that for efficient economical cooling, the heat/gain loss of a living space be reduced by the use of insulating materials. A large number of insulating materials have been developed. It is important that vapor barriers be included in insulation materials and/or in walls to reduce "moisture travel" and convection currents. Depending upon its location in a structure, insulating material must have sufficient strength to support itself. Further, such material should not shrink or settle, should not deteriorate in the presence of moisture, should be vermin-proof and fire-proof, and should neither have nor develop an unpleasant odor.

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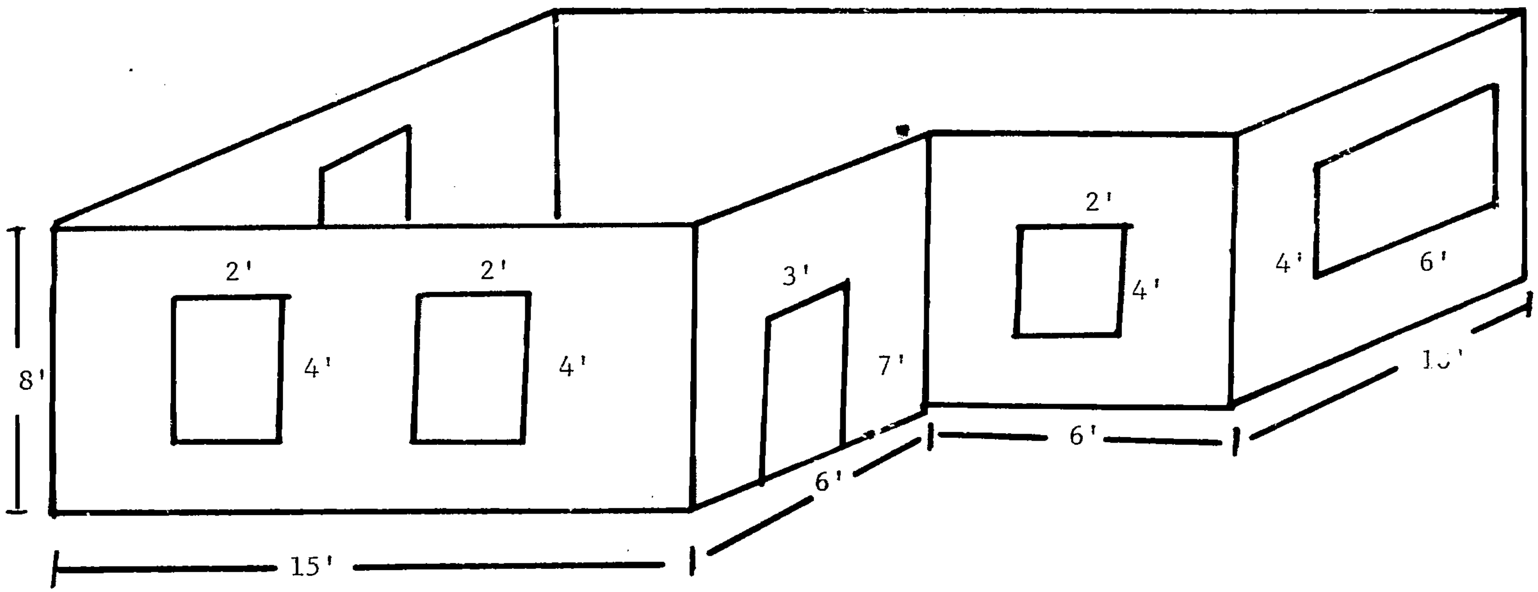
RESOURCE PACKAGE 8-1

CALCULATING HEATING LOADS



MODEL SPACE
Fig. 1

1) Calculate the heat load for Fig. 1 if the outside temperature is 10^{o} F and the inside temperature is 78^{o} F. The building is constructed as follows:

a) Wood siding, sheeting, studs, rockwool fill, lath and plaster.

b) Lath and plaster ceiling, 3-5/8" rockwool fill.

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c) Wood shingle on wood strips.

d) 6" concrete, hardwood and pine floor.

2) Estimate the cooling load of a summer air-conditioning plant for your classroom.

A relatively easy way to calculate the summer heat load per hour is to use this tabular form, filling in the applicable blanks:

Interior room dimensions

Length__________________ Width__________________ Height__________________

Window Load

1) Sun-exposed (interior shades only)

West side___________ sq. ft. x 60 = __________________

2) Sun-exposed (interior shades only)

South side__________ sq. ft. x 40 = __________________

3) East exposure, north exposure, or shaded:

______________ sq. ft. x 15 = __________________

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Wall Load

1) Sun-exposed south and west walls

_______________ sq. ft. x 8 = _______________

2) East or north exposure

_______________ sq. ft. x 5 = _______________

3) All exposures, thin wall

_______________ sq. ft. x 10 = _______________

4) Interior walls

_______________ sq. ft. x 4 = _______________

5) Interior glass partitions

_______________ sq. ft. x 10 = _______________

Floor Load

_______________ sq. ft. x 3 = _______________

Ceiling Load

1) Occupied above

_______________ sq. ft. x 3 = _______________

2) Insulated roof

_______________ sq. ft. x 8 = _______________

3) Uninsulated roof

______________ sq. ft. x 20 = ______________

<u>Occupancy Load</u>

No. of People ______________ x 400 = ______________

<u>Miscellaneous Load*</u>

Electrical watts ______________ x 3.4 = ______________

Other x = ______________

TOTAL BTU PER HOUR = ______________

The multipliers in the above table were obtained by multiplying a typical U-factor by the assumed temperature difference. For example, the windows (no sun) have a U-factor of 1.25; and if the design temperature difference is about 12° F, the multiplier, therefore, becomes 15:

$$12 \times 1.25 = 15$$

Use all of the entries in the above table which apply to your classroom. For example, if the building does not have an insulated roof, omit the ceiling load for an uninsulated roof. Assume a design tempera-

---

* See Fig. 2

ture difference of 12° F, so that you can use the factors in the table just as they appear. Some actual design temperatures appear in Fig. 3.

Device			BTU/hr Sensible	BTU/hr Latent
Electric	Lights/kwhr		3415	
	Motors, electric/hp in room	Up to 1/2 max.	4200	
		Up to 3 max.	3700	
		Up to 20 max.	2950	
	Motors, electric/hp out of room	1/2	1700	
		3	1150	
		20	400	
	Stoves, electric kwhr		3415	
Gas	Natural gas cu ft		1100	300
	Artificial gas cu ft		550	675
General	Heat from meals/meal		36	
	Steam tables/sq ft		400	800
	Humans			140
		Sitting	370	
		Working	700–1500	
		Dancing	2000	

HEAT LOADS
Fig. 2

State	City	Degree days Sept 1 – May 31	Design temp °F	State	City	Degree days Sept 1 – May 31	Design temp °F
[illegible]	[illegible]	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2,780	12	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* Degree days for entire year

NORMAL DEGREE PAYS AND DESIGN OUTSIDE TEMPERATURES
Fig. 3

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