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CONSERVATION OF FUEL

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It would be difficult to conduct a project of this nature without the co-operation of the heating and construction industries. That their assistance was freely given has been most gratifying and the members of the University of Minnesota Engineering Experiment Station staff who participated in conducting this project wish to take this opportunity of acknowledging their cooperation. It would be difficult to mention all the names of the companies and individuals who have aided us in the collection of material for the preparation of this bulletin, but we wish in particular to acknowledge the co-operation extended us by the Insulite Company and the Wood Conversion Company, both of whom have supplied us with much of the material presented in Table VIII. In addition the method of presentation of degree-day data shown in Figures 5 and 6 was patterned after a similar presentation published by the Wood Conversion Company.

Conservation of Fuel

INTRODUCTION

The Office of Price Administration put into effect the rationing of fuel oil in thirty states, including Minnesota, during the winter of 1942-43, and it appears possible that the restrictions may be extended to additional areas in future winters. These measures have forcefully brought to the public mind the necessity for investigating all of the practical methods by which heating plant efficiencies may be increased or heating requirements reduced. Although the principal problem is one of supplying domestic and commercial fuel oil consumers, the conservation of other forms of fuel is also desirable. Such conservation not only helps to reduce the load on our already overtaxed transportation facilities but also results in economies to the consumer.

Because of the smaller population the problem in Minnesota is not nearly as great as it is in some of the more densely populated eastern states. Illustrative of this is the following table showing the relative heating oil consumption in various sections of the country for 1939 (the latest year for which complete figures were available).[1]

TABLE I

1939 HEATING OIL CONSUMPTION FOR VARIOUS SECTIONS OF THE COUNTRY*

Section of Country	States Included	Percentage Total United States Heating Oil Consumption in 1939
Middle Atlantic	Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania	40.0
North Central	Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, Tennessee, Wisconsin	27.0
New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	17.8
Pacific Coast	Arizona, California, Nevada, Oregon, Washington	6.9
South Central	Alabama, Arkansas, Kansas, Louisiana, Mississippi, Missouri, Oklahoma, Texas	5.6
South Atlantic	Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia	2.3
Rocky Mountain	Colorado, Idaho, Montana, New Mexico, Utah, Wyoming	0.4

* H. Stanley Norman, "Higher Fuel Demand May Force Operating Changes," *Oil and Gas Journal,* 40:40, 41. February 27. 1941.

Since the year 1939 there has been a somewhat general increase in the fuel oil consumption for heating purposes, but this increase is not great, and the relative order for the various sections will be about the same.

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[1] H. Stanley Norman, *op. cit.*

The heating plants of the country consume the largest share of fuel oil. Based again on the 1939 figures,[2] 29.8 per cent of all fuel produced during that year was consumed in heating plants. Other major sources of consumption were: ships, 17.3 per cent; mines, smelters, and other manufacturing, 14.7 per cent; railroads, 13.8 per cent; and oil company fuel, 10.7 per cent. Seven per cent of the fuel oil was consumed by gas and electric power plants, 2.7 per cent by the Navy and Coast Guard, and 3.2 per cent for miscellaneous purposes. It is evident that in the past three years many of these minor or comparatively small sources of fuel oil consumption have greatly increased so that the above figures would, of course, be representative only of a prewar year.

The requirements for fuel oil for heating purposes have not changed materially since the start of the war. Figure 1, based on the 1940 United State Census figures,[3] shows the relative distribution of coal-fired, gas-fired, and oil-fired central heating plants throughout the United States. As would be expected, the heating requirements show the maximum demands to be in the centers of greatest population and in the northern parts of the country.

The actual fuel oil consumption for the year 1939 for heating purposes is shown on a percentage basis for the different states in Figure 2. Again it may be seen that maximum fuel oil consumption is to be found in the northerly states having the densest population. This figure shows that over 50 per cent of the entire fuel oil consumption of the United States for heating purposes is in the five states, New York, Pennsylvania, Massachusetts, New Jersey, and Connecticut.

That dense population is not the only reason for the high consumption of fuel oil in the North Atlantic states is shown by Figure 3, which presents the relative consumption of fuel oil in the United States based upon barrels per 100 persons. This figure, again based on the 1939 fuel oil heating consumption figures, indicates that oil is a somewhat more common type of fuel in the North Atlantic states than in other sections of the country.

According to the 1940 *United States Census,* 52 per cent of the homes reporting in Minnesota were heated with central heating plants. The classification of central heating plants included central steam or hot water heating systems, piped warm air systems, and pipeless warm air systems. The remaining 48 per cent without central heating were heated by stoves, fireplaces, or similar means. The types of fuel burned by the 52 per cent with central heating systems were distributed as follows: coal or coke 67.2 per cent, wood 8.7, gas 5.2, fuel oil 16.5, and other fuel 1.4 per cent. The 48 per cent of the homes in Minnesota that were without central heating were heated with the following kinds of fuel: wood 48.5 per cent, coal or coke 33.4, fuel oil 16.1, gas 0.7, kerosene or gasoline 0.3, and other fuel or no heating 0.7 per cent.

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[2] H. Stanley Norman, *op. cit.*

[3] United States Department of Commerce, Bureau of the Census, *Sixteenth Census of the United States, 1940,* Series H-13, No. 5.

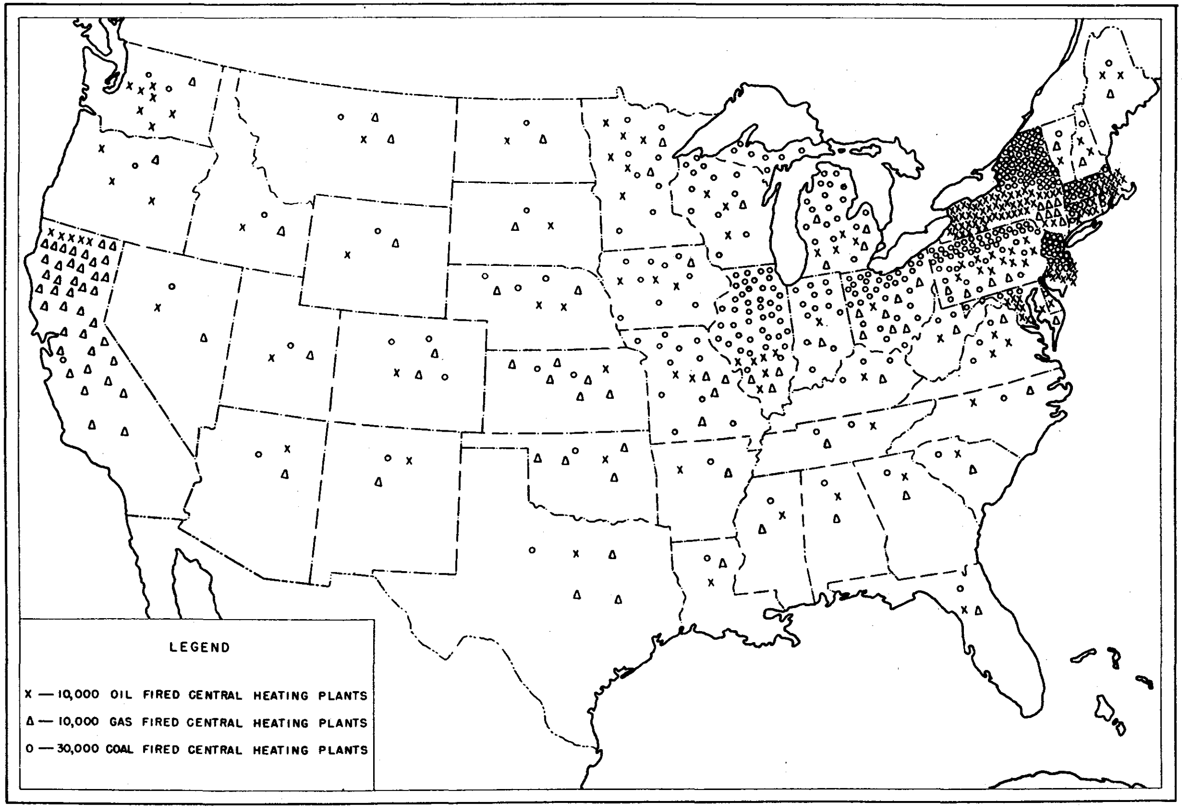

FIGURE 1. DISTRIBUTION OF COAL-, OIL-, AND GAS-FIRED HEATING PLANTS THROUGHOUT THE UNITED STATES

FIGURE 2. PERCENTAGE DISTRIBUTION OF FUEL OIL CONSUMED FOR HEATING PURPOSES BY THE DIFFERENT STATES (YEAR 1939)

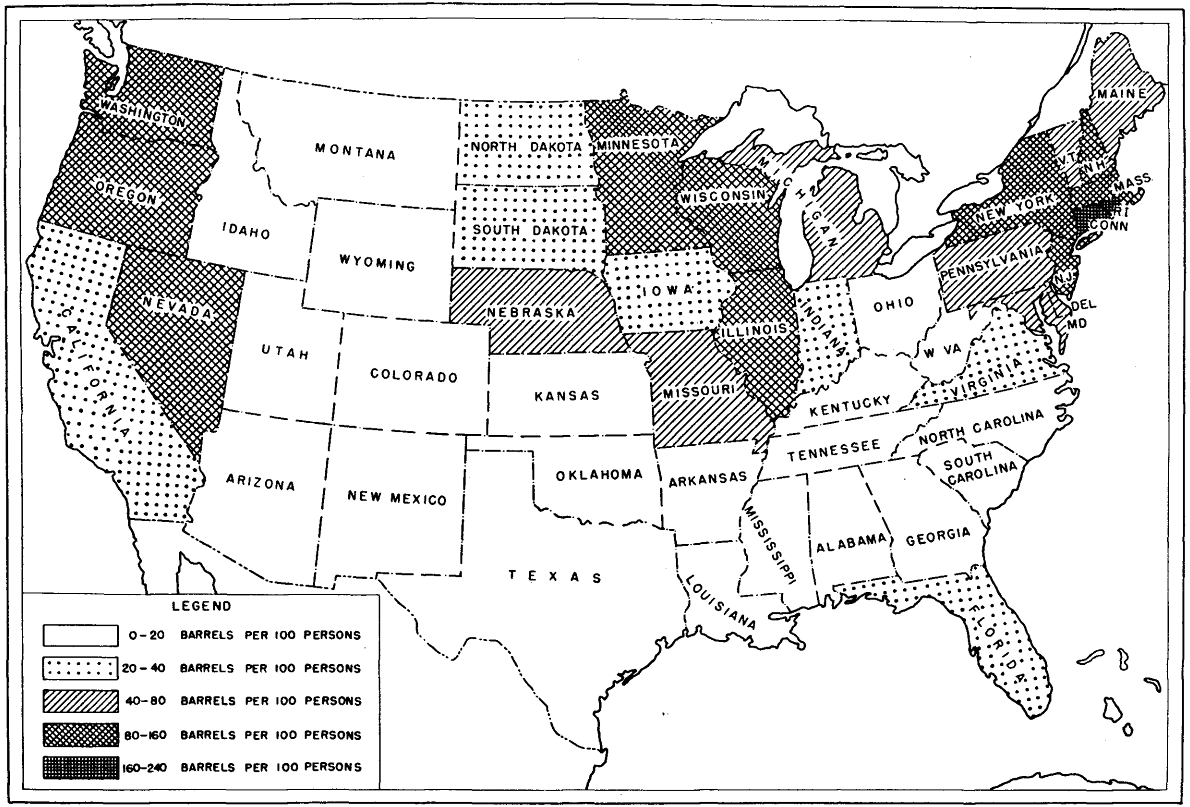

FIGURE 3. RELATIVE PER CAPITA FUEL OIL CONSUMPTION FOR THE VARIOUS STATES (YEAR 1939)

CLIMATIC CONDITIONS IN MINNESOTA RELATIVE TO OTHER SECTIONS OF THE COUNTRY

The state of Minnesota is subjected to some of the most rigorous cold weather conditions in the United States. This is indicated by Table II which presents the average outdoor temperatures for various sections of the country during the heating season, October 1 to May 1. Minnesota winter temperatures vary from an average heating season outdoor temperature of approximately 30° F. in the southern part to 20° F. in the most northerly part. Minneapolis and St. Paul have an average outdoor winter heating season temperature of 29.7° F. In contrast, the winter average temperature for Chicago, Illinois, is 36.4° F.; for Washington, D.C., 43.4° F.; New York, New York, 40.7° F.; Denver, Colorado, 38.9° F.; Detroit, Michigan, 35.8° F.; Salt Lake City, Utah, 40.0° F.; and Seattle, Washington, 44.8° F. Figure 4 shows the average winter temperature isotherms for the state of Minnesota. The more rigorous climatic conditions to which structures and heating plants in Minnesota are subjected in turn mean more substantial savings than for other sections of the country when various economy measures are enacted. In the year 1939, 4,620,000 barrels of heating oil was consumed in Minnesota. If, through economy measures, such oil consumption could be reduced 25 per cent, this would amount to a saving of 1,155,000 barrels or 48,510,000 gallons of fuel oil per year.

FIGURE 4. AVERAGE HEATING SEASON TEMPERATURE FOR MINNESOTA, OCTOBER 1 TO MAY 1

DEGREE-DAYS AND THE ESTIMATION OF HEATING REQUIREMENTS

The degree-day is a unit used by the heating engineers to express the average heating load for a specific locality during an average winter. It is a measure of the relative heating requirements for various sections of the country as, theoretically, it is proportional to the difference between the outdoor and indoor temperatures. For any one day, there are as many degree-days as there are degrees Fahrenheit difference in temperature between 65° F. and the mean outdoor temperature for the day. If the number of degree-days is summed up over an entire heating season, it is, therefore, a measure of the amount of heat required by a building in that locality during an average winter. Theoretically, the indoor base temperature should be taken as 70° F. but, because the heating load is actually reduced somewhat over a winter's period by the amount of heat supplied by the sun's radiation and either passing through the windows to the interior of the building or absorbed by the walls of the building, this has been modified. It has been found in practice that fuel consumption varies directly as the difference between a 65° F. base temperature and the outdoor average temperature. Because of the close agreement between actual fuel consumption and this method of calculating degree-days, this procedure is almost universally used throughout the country for estimating heating requirements.

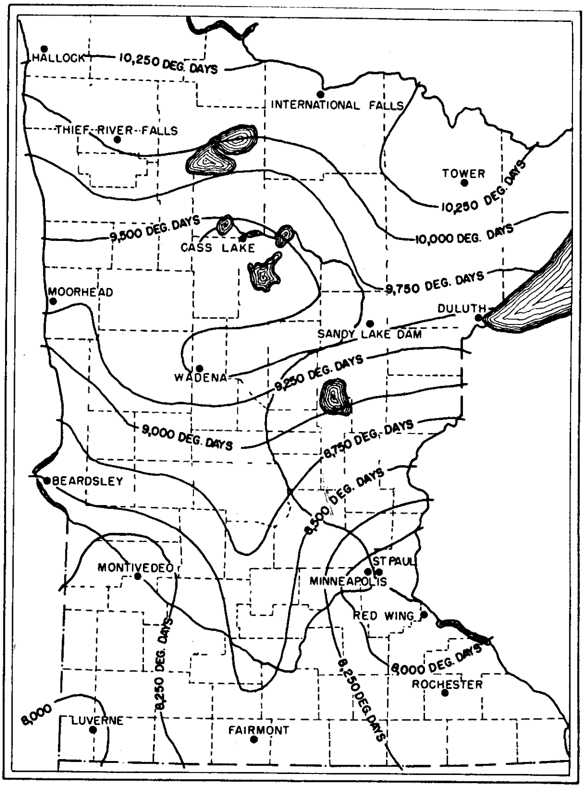

FIGURE 5. DEGREE-DAYS FOR VARIOUS SECTIONS OF MINNESOTA

The number of degree-days for an entire heating season for typical cities in the United States and Canada are presented in Table II and the degree-days for various sections of the state of Minnesota are indicated graphically in Figure 5.

TABLE II

TOTAL HEATING SEASON DEGREE-DAYS* FOR TYPICAL NORTH AMERICAN CITIES

City	Average Heating Requirements in Degree-Days	City	Average Heating Requirements in Degree-Days
Birmingham, Alabama	2,410	Havre, Montana	8,635
Los Angeles, California	1,472	New York, New York	5,290
Denver, Colorado	5,894	Bismarck, North Dakota	9,127
Washington, D.C.	4,631	Cincinnati, Ohio	5,127
Jacksonville, Florida	928	Philadelphia, Pennsylvania	4,784
Boise, Idaho	5,614	Fort Worth, Texas	2,178
Chicago, Illinois	6,027	Salt Lake City, Utah	5,601
Indianapolis, Indiana	5,321	Spokane, Washington	6,312
Des Moines, Iowa	6,409	Green Bay, Wisconsin	7,896
Louisville, Kentucky	4,185	Cheyenne, Wyoming	7,503
New Orleans, Louisiana	1,017	Edmonton, Alberta	10,289
Boston, Massachusetts	6,003	Winnipeg, Manitoba	11,130
Detroit, Michigan	6,460	Port Arthur, Ontario	10,588
Duluth, Minnesota	9,797	Montreal, Quebec	8,341
Minneapolis, Minnesota	7,883	Saskatoon, Saskatchewan	11,493
Kansas City, Missouri	5,002		

* *Heating, Ventilating, Air Conditioning Guide, 1942,* Chapter 11. American Society of Heating and Ventilating Engineers, New York.

Figure 6, based on an average heating season in Minneapolis, Minnesota, shows the degree-days normally elapsed at every point during the heating season and the percentage of heating demand elapsed for each day during the season. Thus, in an average year on January 31, 4,600 degree-days have elapsed and 58.6 per cent of the seasonal heating requirements are completed. Figure 7 presents the same information for sections having heating loads of 8,000, 9,000, and 10,000 degree-days and may be used in conjunction with Figure 5 to determine the average remaining heating requirements during any time of the year for any location within the state.

If the heating requirements for a structure are known along with the type and cost of fuel and the overall efficiency of the heating plant, it is then possible to estimate in advance the fuel cost during an average season. This is done by substituting the correct values in the equation

$$\text{Cost of fuel, dollars per season} = \frac{\left\{\begin{matrix}\text{Heat loss of structure, Btu}\\ \text{per hr. per deg. temp. diff.}\end{matrix}\right\} \times 24 \times \left\{\begin{matrix}\text{deg.-days}\\ \text{per season}\end{matrix}\right\} \times \left\{\begin{matrix}\text{fuel cost, dol-}\\ \text{lars per gallon}\end{matrix}\right\}}{(\text{Overall efficiency of heating plant, \%}) \times (\text{heating value of fuel, Btu per gallon})}$$

Thus, if it is known that the design heating requirements, based on a 90° F. design temperature difference between the inside and outside, for a structure located in Minneapolis are 100,000 Btu per hour, that the overall efficiency of the heating plant is 75 per cent, and that a No. 2 fuel oil with a

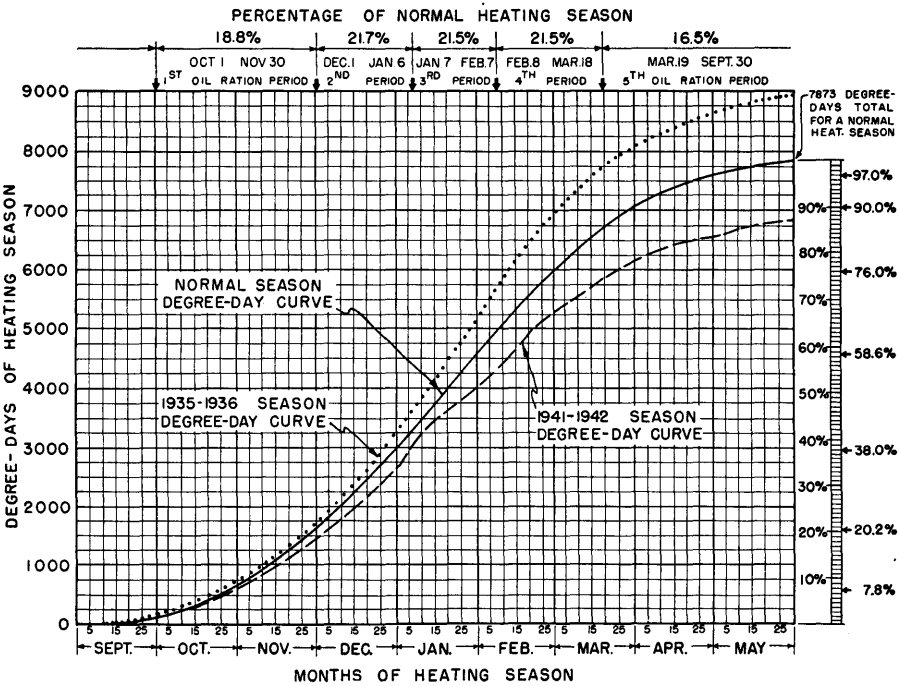

FIGURE 6. DEGREE-DAYS AND PERCENTAGE HEATING DEMAND ELASPED AT VARIOUS POINTS DURING NORMAL HEATING SEASON, MINNEAPOLIS, MINNESOTA

heating value of 139,700 Btu per gallon and a cost of 8.1 cents per gallon is to be used, the cost during an average heating season would be

$$\text{Cost of fuel in dollars per season} = \frac{100{,}000 \times 24 \times 7{,}883 \times .081}{90 \times .75 \times 139{,}700} = \$163$$

Similarly the cost of heating for any other type of fuel can be computed. The range of efficiencies normally found in domestic heating plants and the heating valves for different types of fuels are presented in Tables III and IV.

Table III gives figures only for gas-fired, oil-fired, and stoker-fired domestic heating plants. For hand firing the range of efficiencies is so wide, dependent upon the methods used in firing, that it is practically impossible to estimate this factor. The efficiencies of oil-fired, stoker-fired, and coal-fired boilers will, of course, depend upon the design of the heating plant, and the above efficiencies are for well-designed plants with properly installed and adjusted automatic firing units.

TABLE III

DOMESTIC CENTRAL HEATING PLANT EFFICIENCIES

Type of Fuel	Design of Heating Unit	
	Converted from coal	Design specifically for fuel burned
Coal (stoker fired)	50% to 60%	50% to 65%
Oil	50% to 75%	65% to 80%
Gas	60% to 80%	70% to 85%

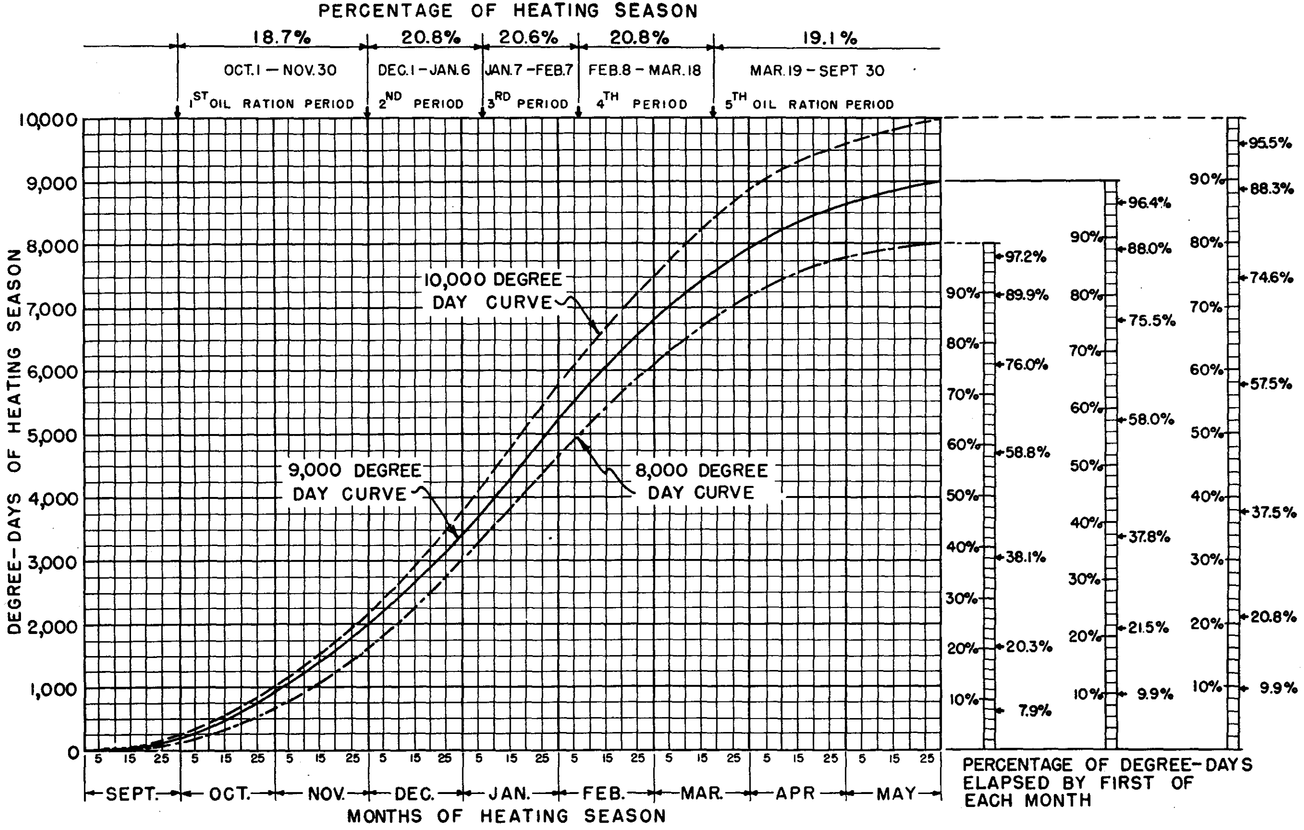

FIGURE 7. DEGREE-DAYS AND PERCENTAGE HEATING DEMAND ELAPSED AT VARIOUS POINTS DURING HEATING SEASON FOR LOCALITIES HAVING HEATING DEMANDS OF 8,000, 9,000 AND 10,000 DEGREE-DAYS

TABLE IV

HEATING VALUES FOR DIFFERENT TYPES OF FUELS

Type of Fuel	Grade of Fuel	Heating Value
Coal	Anthracite	13,950 Btu per lb.
	Semi-bituminous	13,509
	Eastern bituminous	12,417
	Western bituminous	10,064
	Sub-bituminous	9,734
	Lignite	7,002
Oil	No. 1	137,500 Btu per gal.
	No. 2	139,700
	No. 3	142,200
	No. 4	144,500
	No. 5	146,000
	No. 6	150,000
Gas	Duluth, Minnesota (manufactured gas)	530 Btu per cu. ft.
	Minneapolis, Minnesota (natural and manufactured gas mixed)	807
	St. Paul, Minnesota (manufactured gas)	550
	Southern Minnesota (natural gas)	1,014

HEATING FOR COMFORT AND HEALTH

TEMPERATURE CONTROL OF HUMAN BODY

The normal temperature of the human body is 98.6° F. For persons in good health this temperature does not vary more than a fraction of a degree regardless of the exterior temperatures of the air and the surroundings. This body temperature must be maintained by a delicate balance between the rate of heat production and the rate of heat loss for the human body. The human body is often likened to a furnace or boiler in which fuel is taken in and burned and heat given off in the form of usable energy and losses. In the case of the human system the food eaten by the individual is the fuel which when consumed is utilized as useful energy or lost as waste heat.

In order that the human body may be maintained at a constant temperature at all times, it is necessary that heat be lost from the body. This heat is lost either by radiation, convection, or evaporation. If the surface of the human body is at a higher temperature than the surrounding walls and objects, heat will be lost to them by radiation. If the surrounding objects are, conversely, at a higher temperature than the body, heat will be gained by the body by radiation. The surface temperature of the body is somewhat lower than the true body temperature of 98.6° F. and normally ranges somewhere between 80° and 90° F. If a person is in a room surrounded by cold wall and window surfaces, heat will be lost from the body to these walls and windows by radiation. With most buildings, the lower the outdoor air temperatures, the lower the inside surface wall and window temperatures will be, and at these times, the greater will be the heat lost by radiation from the occupants of a room to these cold wall surfaces. This explains why most structures seem colder to the occupants when the outdoor temperatures decrease although the inside air temperature is maintained the same.

If the surface of the body is at a higher temperature than the surrounding air, heat will be conducted from the body's surface to the air directly next to the skin. This air, in turn, will become heated by contact with the body and will then rise because of its reduced density. This will allow new air to come in contact with the body and the process will be repeated. In this manner heat is lost from the body by convection. The more rapidly the air is circulated past the body, the more rapidly heat will be lost by convection. Thus, if we force the air over the surface of the body with a fan or by other mechanical means, the body will lose heat more rapidly and feel cooler. The portions of the human body covered by clothing have to conduct the heat through the clothing and hence to the air. Thus, one effect of clothing is to reduce the rate at which the heat can flow from the body to the air and thereby reduce the rate of heat lost by convection.

Heat is required to evaporate water and change it from water into water vapor. The amount of heat required is roughly 1,000 Btu or heat units per pound of water evaporated. When such a change takes place, this heat of vaporization will be absorbed either from the water itself or the other surfaces in contact with the water. There is always a certain amount of moisture on the surface of the body and when this moisture is evaporated, the majority of the latent heat of vaporization comes from the body itself. This, therefore, is a third means by which heat is lost from the human body. The rate of this evaporation and the resulting heat loss will depend upon the amount of moisture secreted, the area of the exposed surface, and the temperature and relative humidity of the surrounding air. If we wet the surface of the skin and then circulate air past this surface by either natural or mechanical means, the rate of evaporation from the surface of the body becomes abnormally great and the resulting loss of heat tends to chill the wetted body surface. It is for this reason that "the water feels warmer than the air" when we first emerge from a swim during the summer months.

Although practically all the heat is lost from the human body by radiation, convection, and evaporation, and practically all of this heat loss is dependent upon the conditions of air, relative humidity, and surrounding object temperatures, there must still be considerable control over the rate of these losses if the body temperature is to be maintained constant. The exact mechanism by which the human system is maintained almost thermostatically at a definite temperature is not fully known, but the means by which this is accomplished are to a great extent understood. The action itself is entirely automatic and involuntary, similar to the beating of our hearts and the functions of our digestive tract.

Within small limits the rate of heat production or chemical action within the body is under control. Thus, during the hot summer months there is an intercorrelation between our general desire for inactivity and the attempts of the body to maintain the desired temperature.

The human body has some control over the rate of heat lost by constricting or expanding the blood vessels near the surface of the skin. This prevents or allows the blood to come closer to the surface of the body and thus lowers or raises the surface temperature. This, in turn, controls to a certain extent the rate of heat lost by convection and by radiation.

By stimulating the action of the sweat glands as the temperature rises, the body is able to increase, within limits, the heat lost by evaporation. This, in fact, is the only means by which the body can lose heat when the temperature of the air and the temperature of the surrounding surfaces are higher than the surface temperature of the body. Under such conditions the body will actually gain heat by radiation and convection, and this additional heat, along with the heat formed by assimilation of the foods consumed, must all be lost by evaporation if the body temperature is to be kept down to 98.6° F. Thus, the sweat glands act as a safety valve for the release of heat when the body temperature can be maintained at the desired level by no other means.

It may be seen that when the outdoor temperature rises above normal, the rate of metabolism or heat production of the body will first slow down. The blood capillaries near the surface of the skin will tend to expand and thus allow the blood to come closer to the surface, and thereby increase the losses by convection and radiation. In addition, there will be increased activity of the sweat glands as the temperature rises, thereby allowing the body to lose any excess heat by evaporation. In converse, when the weather becomes cold, the sweat glands will close and there will be only a very small amount of heat lost by evaporation. The rate of metabolism will increase and the blood vessels will constrict in order to prevent the blood from getting close to the surface of the skin. During a prolonged period of cold, there apparently is an additional thickening of the blood which will also aid in preventing its reaching close to the skin's surface. If the body becomes extremely cold, involuntary shivering will take place, such action automatically speeding up the rate of heat production.

EFFECTIVE TEMPERATURES

It is apparent from the discussion of heat control of the human body that an ordinary thermometer reading is not a true index of how warm or how cold the space will feel to the body. For example, a room with a dry bulb thermometer reading of 70° F. and a relative humidity of 50 per cent will present the same feeling of warmth to the human body as a room at a dry bulb temperature of 73.5° F. and a relative humidity of 15 per cent. In addition, if the air in the room is set in circulation or if the surface temperatures of the walls and windows are lower than the surrounding air temperature, there will be an even greater feeling of coolness. All of these factors actually affect the feeling of warmth experienced by the human body, and it is necessary to consider them all in determining the conditions which must be maintained for comfort and health.

It was for these reasons that the American Society of Heating and Ventilating Engineers took what they believed to be the three most important factors affecting the feeling of warmth experienced by an individual and combined these into a composite temperature reading which is termed "effective temperature." Thus, effective temperature may be defined as an index of

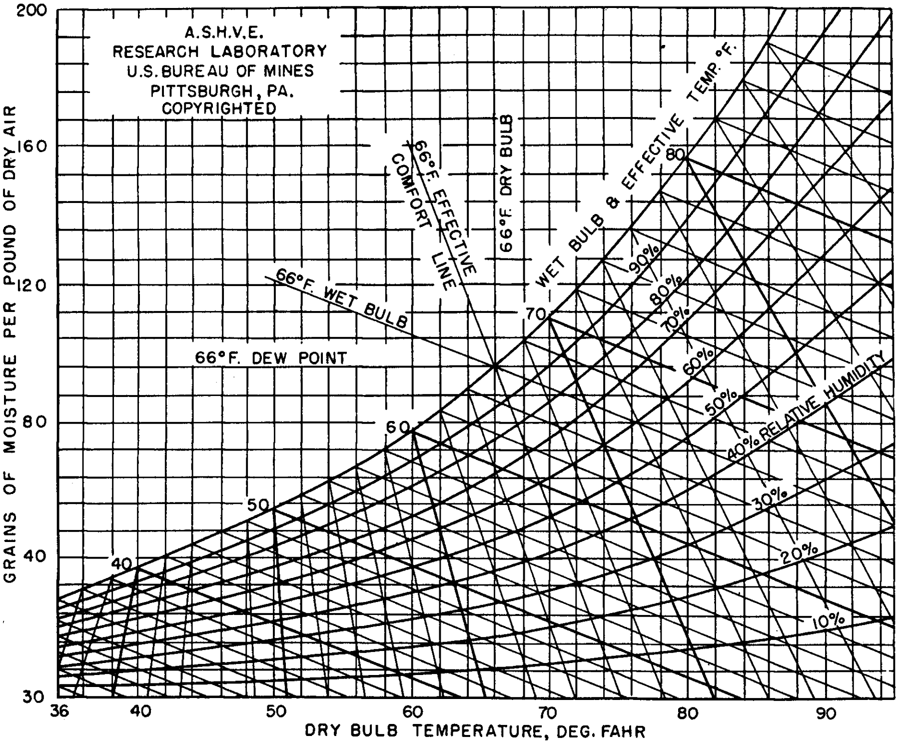

FIGURE 8. EFFECTIVE TEMPERATURE CHART OF PERSONS AT REST, NORMALLY CLOTHED, IN STILL AIR

the degree of warmth or cold experienced by the human body in response to temperature, humidity, and movement of air. Any effect of cold surrounding wall and object temperatures must be considered separately as it is not considered in this composite index of warmth.

Figure 8 presents an effective temperature chart[4] showing the relationship between dry bulb temperature, wet bulb temperature, dew point temperature, relative humidity, and effective temperature. The dry bulb temperature is represented by the vertical lines and the scale at the bottom of the chart. The dew point temperatures are represented by the horizontal lines and the wet bulb and effective temperatures by the diagonal lines. The relative humidities are shown as curved lines contained in the body of the chart. This chart is for still air conditions and for persons normally clothed and at rest. Any modifications as to degree of activity, clothing, or air circulation would change the relationships of the lines on the chart. If any two of the five conditions of the air are known, the remaining conditions can be found. For example, if the dry bulb temperature is 70° F. and the wet bulb temperature is 60°, the dew point temperature will be 54° F., the relative humidity 56 per cent, and

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[4] *Heating, Ventilating, Air Conditioning Guide, 1942,* Chapter 2. New York: American Society of Heating and Ventilating Engineers.

the effective temperature 66.5° F. Any other conditions in the air which have the same effective temperatures will also provide the occupants of a room with the same feeling of warmth as the conditions of this example. Thus, if the dry bulb temperature is raised to 74° F., the relative humidity may be lowered to approximately 19 per cent and the effective temperature will still be approximately 66.5° F., indicating that persons exposed to this air will experience the same feeling of warmth.

There are certain ranges of effective temperatures and relative humidities within which the average person will feel comfortable in either summer or winter months. When these ranges of effective temperatures and humidities are blocked out on an effective temperature chart, they are termed the comfort zones. If the air conditions of the room are maintained within the limits of these comfort zones, then such an environment will be comfortable to the majority of persons. Figure 9 presents such a comfort chart[5] and is merely another form of the effective temperature chart presented in Figure 8. In this chart the dry bulb lines are the vertical lines, the wet bulb lines are the horizontal lines, the relative humidity lines are the diagonal lines running from the lower left hand to the upper right hand corner of the chart, and the effective temperature lines are the slightly curved lines running diagonally from upper left to lower right on the chart. Two overlapping zones have been blocked out and cross-hatched on the main body of the chart. One of these is the winter comfort zone ranging from 63° to 71° F. effective temperature, and the other is the summer comfort zone ranging from 66° to 75° F. effective temperature. Further limitations are placed on the relative humidities within the comfort zones with 30 per cent the minimum allowable relative humidity and 70 per cent the maximum. These limitations are to a great extent arbitrary, and it is well known that in climates associated with states as northerly as Minnesota, it is very difficult to maintain relative humidities as high as 30 per cent without condensation difficulties arising in cold weather. (See Condensation of Moisture within Building Structures, page 50.)

The significance of the winter comfort zone is that 50 per cent or more of the individuals in average good health will feel comfortable when the effective temperature is between 63° and 71° F. In summer months 50 per cent or more of the persons will feel comfortable when the effective temperature is between 66° and 75° F. In addition to these two comfort zones heavy dashed lines called comfort lines are also indicated on the chart, one for summer and one for winter. The winter comfort line is 66° F. effective temperature and the summer comfort line is 71° F. effective temperature. These are the lines representing the effective temperatures at which the greatest number of persons are comfortable during these seasons. Thus, for the winter comfort line of 66° F. effective temperature, it is found that 97 per cent or more persons are comfortable under air conditions represented by this line. Approximately 98 per cent or more persons find the conditions comfortable in the summer months if the effective temperature is 71° F.

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[5] Copyright American Society of Heating and Ventilating Engineers, from *A.S.H.V.E. Transaction*, Vol. 38, 1932.

It should be noted that the summer comfort zones and lines presented in Figure 9 apply only to homes, offices, and similar structures where the period of occupancy is sufficiently long to allow individuals to become fully adapted to the artificial air conditions there maintained. If exposure to these conditions is less than three hours' duration such as would be the case in theaters, restaurants, department stores, etc., these comfort zones no longer hold. For example, it may be found that a person exposed to high outdoor temperatures during the summer months is freely perspiring in order to lose heat from the body with sufficient rapidity to maintain body temperature down at the desired level. If this person enters a theater which is cooled to the conditions represented by the summer comfort line on the chart, his sweat glands will immediately close in order to compensate for the sudden change in environment. However, the perspiration remaining on the surface of the skin must still be evaporated. During this process the latent heat of vaporization will be absorbed from the body resulting in excessive heat loss and a sensation that the environment is too cold. It would probably require anywhere from one-half hour to one hour before the air conditions surrounding the individual would seem comfortable to him.

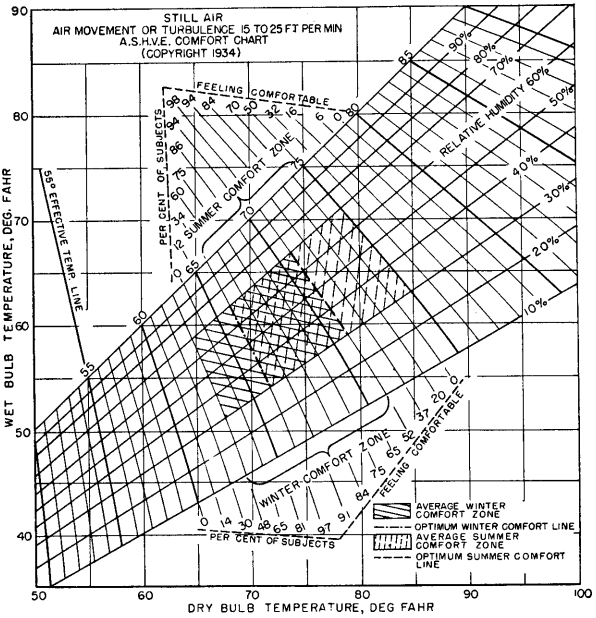

FIGURE 9. COMFORT CHART FOR STILL AIR

EFFECT OF COLD WALLS ON COMFORT AND FUEL REQUIREMENTS

The effective temperature and comfort charts presented in Figures 8 and 9 do not take into consideration the effects of cold wall and window surfaces on the feeling of warmth experienced by the human body. It is well known that if one stands near an open fire, he receives additional radiant heat from the hot flames and surfaces and that the resulting increased feeling of warmth is due to radiant heat and not to any conditions of the air surrounding the body. The opposite is true when a person stands in front of a window on a cold day. As the temperature of the glass window is considerably below that of the surrounding air, radiant heat will be lost from the body to the cold window surfaces. Persons near these cold surfaces will, therefore, experience a feeling of cold greater than that indicated by the conditions of the air surrounding the body. It is for this reason that during the cold winter months air conditions normally comfortable during the spring and fall months may no longer feel comfortable. The cold wall and window surfaces surrounding the body lower the effective temperature below that indicated by the conditions of the air alone.

Figure 10 shows a typical large living room with three walls exposed and with four windows and two french doors. The chilling effect of the cold wall and window surfaces during the winter months for an occupant of this room is analyzed in the following paragraphs. It should be noted that this analysis applies only to the specific conditions for this particular room and that any changes in construction, outdoor temperatures, or amounts of exposed cold surfaces will vary these figures somewhat.

The room shown in Figure 10 has an outside cold wall area of 433 square feet and an uncovered window area—assuming the shades in the room to be half drawn—of 47 square feet. It is assumed that all windows and french doors are equipped with storm windows and doors. This analysis has been based upon three different typical wall constructions. Construction C is an ordinary frame wall with wood lath and plaster on the inside surface, 4-inch face brick on the exterior, and no insulation. Construction B is the same as Construction C, but with one inch of flexible wood fiber insulation flanged midway in the stud space. Construction A is the same as Construction C, but with a 3⅝-inch insulation fill in the stud space.

With the maximum amount of insulation placed in the stud spaces, the inside surface temperatures of the wall will be the warmest, and, therefore,

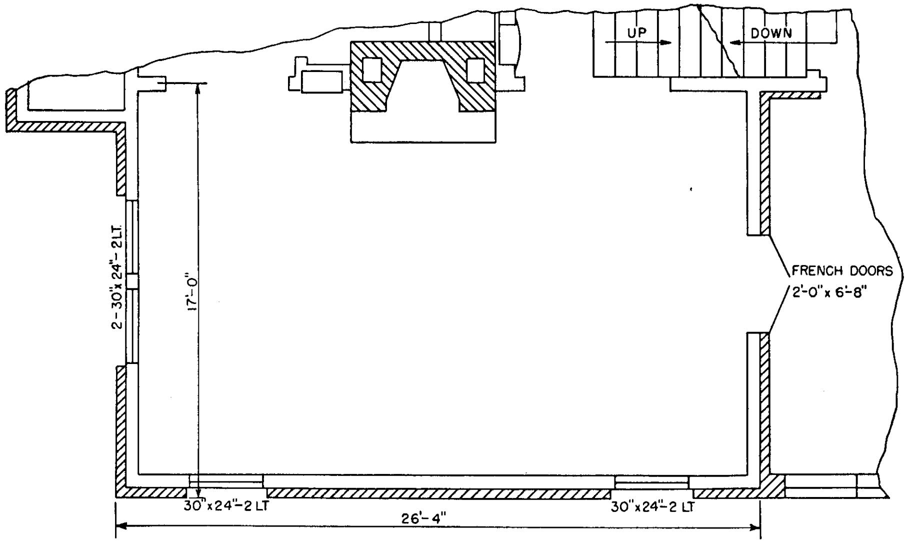

FIGURE 10. TYPICAL LIVING ROOM USED IN ANALYSIS OF CHILLING EFFECT RESULTING FROM COLD OUTSIDE WALLS AND WINDOWS

the wall surfaces will have the least effect upon the feeling of warmth experienced by the occupants of the room. With no insulation in the walls the wall surface temperatures will be the coldest and will, therefore, have the greatest chilling effect upon the room occupants.

If the wall surface temperatures and the room air temperatures are the same, then the wall surfaces will have no effect upon the feeling of warmth experienced by the room occupants. This condition, however, would be experienced only when the outdoor temperature is approximately equal to the indoor temperature. As the outdoor temperature drops, the inside wall surface temperatures will also drop, and there will be a chilling effect experienced by the individuals in the room. Figure 11 presents the relationship between outdoor temperature and the inside room temperature which must be maintained in order that a room occupant will experience the same feeling of warmth as when both the wall and the air temperatures are at 70° F. Three curves are presented, one for Construction A, one for Construction B, and one for Construction C. If, for example, no insulation is placed in the wall, it will be found necessary to keep the room air temperature at 74.2° F. when the outdoor temperature is —20° F., in order that the occupants may experience the same feeling of warmth as when the room is kept at 70° F. in mild weather. If the insulation corresponding to Construction B is installed, it will be necessary to keep the air temperature of the room at only 72.2° F., and if the insulation corresponding to construction A is installed, the room air temperature may be 71.5° F.

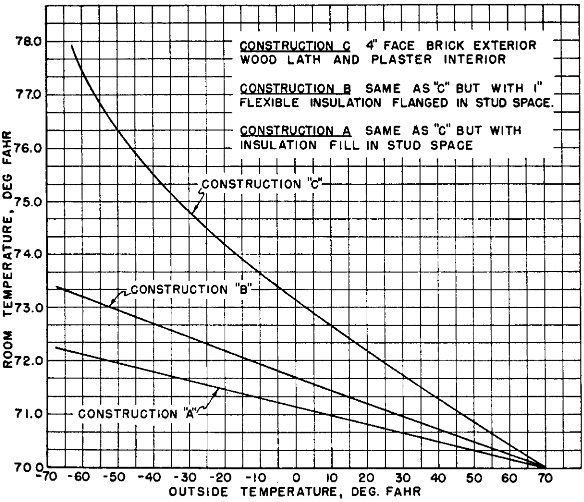

FIGURE 11. INDOOR TEMPERATURES REQUIRED TO COMPENSATE FOR COLD WALL AND WINDOW SURFACES IN ORDER TO MAINTAIN EQUIVALENT WARMTH

It may, therefore, be seen that in cold weather there are two alternatives, either a heating plant may be operated so that the room air temperatures are the same as in mild weather, thereby causing some discomfort to the room occupants during cold weather, or the room air temperatures may be boosted to the higher values indicated in Figure 11. Such operation results in more comfortable living conditions but has the disadvantage of greater fuel consumption. The additional fuel requirements over an entire heating season depend, of course, upon the actual construction of the house and upon the outdoor temperatures. Table V presents the percentage increase in fuel consumption required during an average winter based upon Constructions A, B, and C, for southern, central, and northern Minnesota. Thus, in central Minnesota, it will be necessary to burn, 4.8 per cent more fuel for Construction C with no insulation and 1.9 per cent more fuel for Construction A with wall thick insulation if conditions of comfort corresponding to a 70° F. air temperature in mild weather are to be maintained.

Thus, it may be seen that the advantages of the application of insulation to a structure are greater than would be indicated by first analysis. With an insulated building, the air temperatures may be kept lower with the same resultant feeling of warmth as in an uninsulated structure with higher air temperatures. The resulting fuel savings are in addition to those normally credited to insulation when comparing buildings maintained at a constant base temperature.

TABLE V

ADDITIONAL FUEL REQUIRED TO COMPENSATE FOR COLD WALL AND WINDOW SURFACES FOR ROOM ILLUSTRATED BY FIGURE 10

Section of State	Average Winter Temperature (October 1 to May 1)	Wall Construction (See text)	Percentage Increase in Fuel Requirements to Compensate for Cold Wall and Window Surfaces
Southern Minnesota	30° F.	A	1.8
		B	2.5
		C	4.4
Central Minnesota	25° F.	A	1.9
		B	2.7
		C	4.8
Northern Minnesota	20° F.	A	2.1
		B	3.0
		C	5.5

INCREASING THE EFFICIENCY OF THE HEATING PLANT

There are a great many heating installations which are wasting fuel through either improper installation and adjustment or improper operation. This is especially true of automatically fired installations originally designed to burn coal and later converted to oil or gas by the removal of the grates and the installation of an oil or gas burner. It is, of course, impossible to utilize all of the heat contained in the fuel for heating purposes, as there must, of necessity, be some waste in the gases discharged from the chimney. These losses, however, should not amount to more than 30 per cent of the heat in the case of oil or gas and not more than 40 per cent in the case of stoker-fired coal; yet it is not uncommon to find these losses appreciably higher than these figures. Such losses can often be reduced by having a competent serviceman check and adjust the plant. Some of the more important factors which should be investigated in considering possible methods of increasing the efficiency of an automatically fired heating plant are as follows:

FUEL INPUT

Theoretically the amount of fuel burned in the furnace should be just sufficient to supply all of the heat required to maintain temperature in the structure, plus any unavoidable waste heat losses from the heating plant. As practically all oil and gas burners are designed to burn fuel at the same rate, regardless of the outdoor temperatures and the heating requirements, such installations run practically continuously in the coldest weather and operate with decreasing frequency as the weather becomes milder and the heating requirements are not as great. The most practical adjustment of input for proper operation is to supply the fuel at a somewhat greater rate than that required theoretically. If this is not done, it will be found that when the thermostat is turned back to a lower temperature for a few hours, it will take too long a period of time to again warm the structure to its original temperature upon resetting the thermostat. There are, however, countless burners which have been adjusted to supply the fuel at a much greater rate than is necessary or desirable from an economical standpoint. The amount of heating surface available in the heating unit for the purpose of extracting the heat from the flame and hot combustion gases is the same regardless of how the fuel input is adjusted. Therefore, if this fuel input can be kept as low as practical, there will be less likelihood of overloading the heating surfaces of the plant and this, in turn, will result in a reduction of the waste heat loss to the chimney by excessive stack gas temperatures. However, in any case care should be taken that the fuel input is not so low as to cause an excessively low stack temperature resulting in the condensation of moisture from the stack gases on to the flue and stack surfaces. The advisability of changing the rate of fuel input in a heating plant should be left to the judgment of a competent serviceman.

FLUE GAS ANALYSIS

The correct combustion of fuel requires that a definite amount of air be supplied and properly mixed with the fuel during the burning processes. If too little air is supplied, the fuel will be incompletely burned and this results in a loss of some of the available heat. If too much air is supplied, the excess air will pass through the heating plant, will be heated to the temperature of the chimney gases and discharged as waste heat from the chimney. In either case the losses may be considerable, and correct adjustment of the plant with a consequent reduction of this loss can be carried out properly only by analyzing samples taken of the flue gases.

Such an analysis is accomplished by means of an Orsat apparatus which, among other things, enables determinations to be made of the amount of carbon dioxide (CO_2) contained in these flue gases. In the case of fuel oil, if just a sufficient amount of air is supplied to burn the oil, about 15 per cent of the volume of the flue gases consists of carbon dioxide. In the case of the average stoker-fired coal, the percentage carbon dioxide is approximately 17 per cent, and in the case of a mixture of natural and manufactured gas such as used in the city of Minneapolis, the percentage carbon dioxide is approximately 12.6 per cent. If some excess air is supplied to the combustion chamber, this will dilute the carbon dioxide of the flue gases and the Orsat analysis will show a correspondingly lower percentage of carbon dioxide. If too little air is supplied to the combustion chamber, the fuel oil will not be completely burned and again an Orsat analysis will indicate this, along with showing a reduction in the percentage of carbon dioxide. Because in practice it is difficult to get a complete and proper mixing of the air with the fuel, it is usually necessary to operate with 25 to 60 per cent more air in the case of oil and gas and somewhat higher in the case of stoker-fired coal than that required theoretically for perfect combustion. Under these conditions of operation, an Orsat analysis will show the flue gases to contain 8 to 12 per cent carbon dioxide in the case of fuel oil and 7.5 to 10 per cent in the case of gas. In the case of stoker-fired coal and hand-fired coal, an Orsat analysis will vary continuously because of the variations in conditions under which the coal is burning.

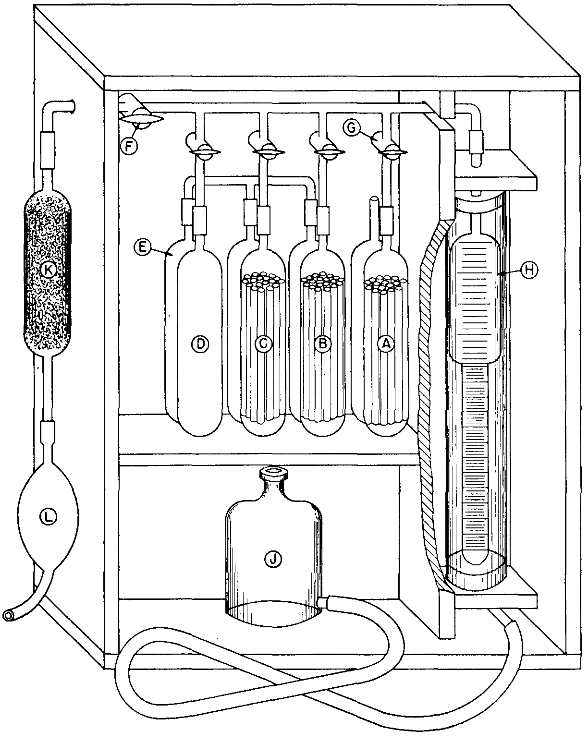

FIGURE 12. DIAGRAMMATIC VIEW OF ORSAT APPARATUS FOR ANALYSIS OF FLUE GASES

A complete Orsat apparatus is shown in Figure 12. In its operation the sample of gas to be analyzed is first drawn into chamber H where its volume is measured and from there pumped successively into the absorption pipettes A, B, and C. The solutions in these, in turn, absorb the carbon dioxide (CO_2), the oxygen (O_2), and the carbon monoxide (CO), respectively. Between each absorption the remaining gases are returned to chamber H where their volume is measured and the percentage of the gas absorbed in the pipette determined. The first pipette contains potassium or sodium hydroxide for the absorption of carbon dioxide; the second pipette, potassium pyrogallate for the absorption of oyxgen, and the third pipette cuprous chloride for the absorption of carbon monoxide. In this way the three principal constituents of the flue gases, which it is necessary to know in order to analyze the heat losses up the stack, are determined. Pipette 4, shown in the drawing, is a water seal, while J indicates the water leveling bottle, L a rubber bulb pump, K a filter, and F and G valves.

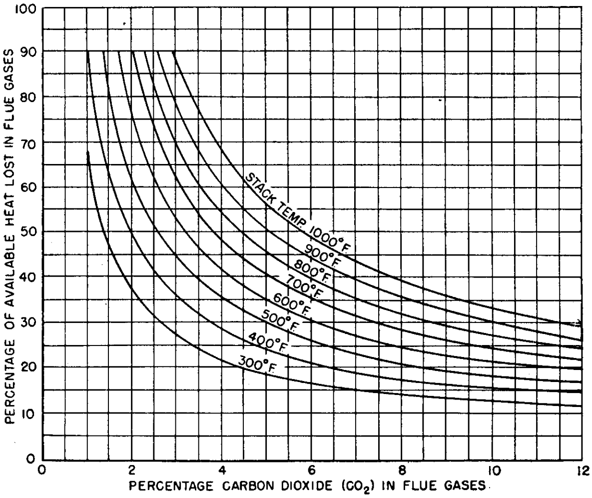

FIGURE 13. PERCENTAGES OF AVAILABLE HEAT IN FUEL OIL LOST TO FLUE GASES FOR VARIOUS STACK TEMPERATURES AND PERCENTAGES CARBON DIOXIDE

There are several simplified methods on the market for determining the percentage carbon dioxide in the stack gases and which exclude the measurement of the oxygen and carbon monoxide. Since the most important constituent of the flue gases from the standpoint of determining heat losses is carbon dioxide, such equipment is usually satisfactory for most practical work.

Figure 13 shows the percentage of the available heat contained in fuel oil which is lost to the flue gases under different conditions of stack temperature and carbon dioxide content. For example if an Orsat analysis shows 10 per cent carbon dioxide and the stack temperature is 600° F., then approximately 22 per cent of the available heat is being lost in the flue gases. However, if the carbon dioxide is only 4 per cent and the stack temperature is still 600° F., these losses will amount to 42 per cent. Further examination of these curves shows that the flue gas losses increase both as the percentage carbon dioxide in the flue gases decreases and as the stack temperature increases.

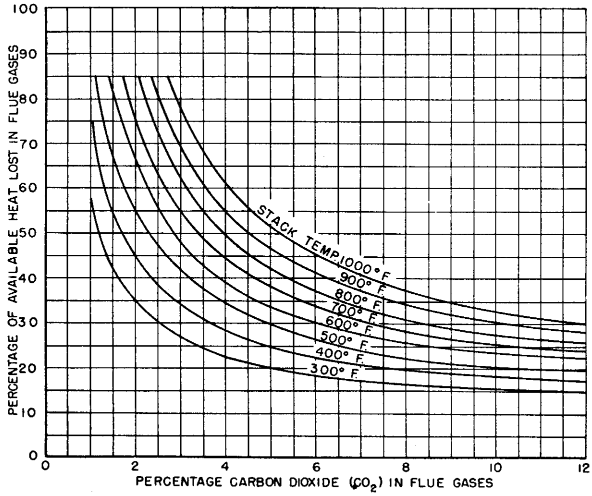

FIGURE 14. PERCENTAGES OF AVAILABLE HEAT IN MINNEAPOLIS CITY GAS LOST TO FLUE GASES FOR VARIOUS STACK TEMPERATURES AND PERCENTAGES CARBON DIOXIDE

Figures 14 and 15 show similar relationships between flue gas heat losses, percentage carbon dioxide in flue gases, and stack temperature for the mixture of manufactured and natural gas used in Minneapolis and for coal for stoker use.

All automatically fired heating installations should be given a periodic checkup in order to make certain that the plant is in proper adjustment. Such adjustments should be done by a competent, properly equipped serviceman. It should be realized that, regardless of the amount of a person's experience in heating plants, it is very difficult to get a plant in proper adjustment without the aid of some form of flue gas analyzer.

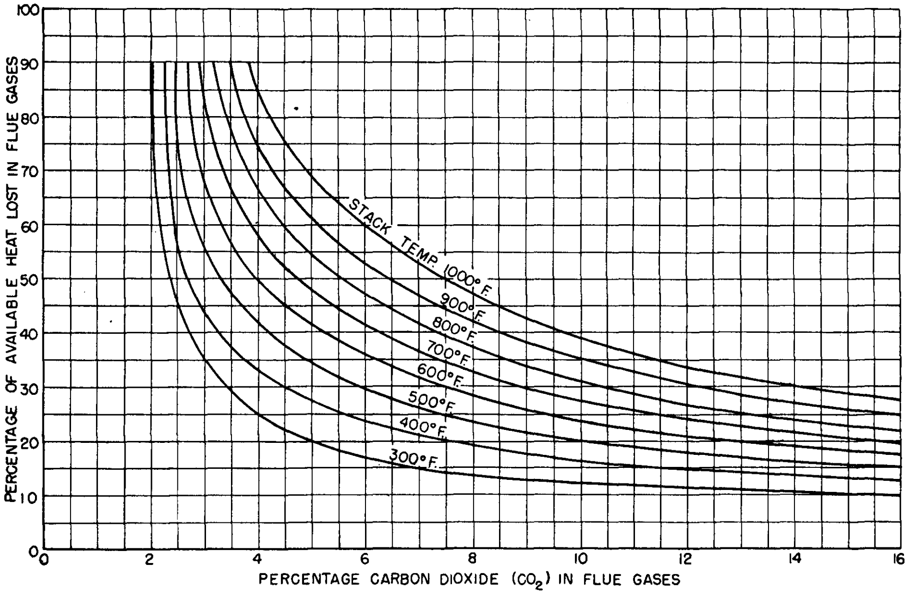

FIGURE 15. PERCENTAGES OF AVAILABLE HEAT IN STOKER COAL LOST TO FLUE GASES FOR VARIOUS STACK TEMPERATURES AND PERCENTAGES CARBON DIOXIDE

AUTOMATIC DRAFT REGULATORS

An automatic draft regulator is any device which will automatically maintain constant draft at the heating plant regardless of the outside atmospheric conditions. Such devices are attached to the stack and either automatically adjust a damper located in the stack or operate to admit a varying amount of room air to the stack as the chimney draft varies. It is thus possible to have the same amount of air passing through the combustion chamber at all times during operation of the heating plant regardless of the outside wind velocity and other atmospheric conditions. Such a device is usually necessary for the efficient operation of an oil-fired or a stoker-fired heating plant, since without draft control, a burner adjusted for the best efficiency under one condition of chimney draft may not give good efficiency when the draft is altered by a change of weather conditions. With gas-fired heating equipment it is usually required that a downdraft diverter be located in the stack. This equipment serves the double purpose of maintaining a constant flow of air through the combustion chamber and also of preventing any back drafts down the chimney from blowing out the gas flames.

With draft diverters and the types of draft regulators which operate to admit a varying amount of room air to the stack with variations in chimney draft, there is some loss of heat because of the warmed room air discharged from the stack. However, this additional loss is more than compensated for by the gains in operating efficiency through the use of such equipment. Draft regulators which automatically adjust the damper located in the stack and do not admit room air to the stack have the additional advantage of eliminating this source of heat waste. Satisfactory automatic draft regulators can be purchased through and installed by any reputable dealer in heating supplies and equipment.

FUEL SAVERS

Many devices have been designed for installation in the stack between the boiler and the chimney for the purpose of recovering some of the heat normally wasted in the flue gases. Such devices are usually termed "fuel savers" and are designed so as to permit recovery of some of the heat in the flue gases by transferring it to either circulating air or water. The heat recovered in this manner may then be utilized either through the installation of an additional radiator or register, the heating of basement areas, or for the heating of domestic hot water. Fuel savers of this type should be used only in those cases where the stack temperatures are abnormally high and where there is sufficient chimney draft to handle the additional resistance to the flow of stack gases imposed by such a device. Essentially, a device of this type consists of additional heating surface, and its use is warranted only in those cases where high stack temperatures are the result of lack of heating surface and not due to improper installation or adjustment of the burner. In systems sized and designed for automatic fuel burning the amount of heating surface is usually great enough so that such auxiliary devices are neither warranted nor advisable. However, in some systems originally designed for coal firing and later converted to oil or gas, it may be found that the amount of heating surface of the plant is insufficient for economical operation and, therefore, the use of such a fuel saver may be advisable. In any case it should be realized that such a device should not lower the stack temperature below approximately 350° F. as there then may result some condensation of the moisture contained in the flue gases on the chimney and stack walls, thereby causing harm to the chimney and to the heating system.

INSULATION OF PIPING, HEATING UNITS, AND HOT WATER TANKS

Where it has not already been done, it is sometimes possible to effect fuel economies in heating systems by the insulation of the piping or the heating unit itself. In general, there is a waste of fuel where pipes and ducts conveying heat run through unheated spaces. The greater the difference in temperature between the heating medium and the cold space through which the pipes and ducts are run or in which the heating unit is located, the greater will be the waste of fuel from this source. All piping on hot water heating systems and all of the steam supply piping on steam heating systems should be insulated unless the system has been designed to use the uncovered pipe as actual heating surface. With gravity warm air and with forced air heating systems, it is advisable to insulate all of the supply pipes and ducts which pass through very cold areas or through outside walls. It is not general practice to insulate such ducts and pipes merely passing through basement areas because of the large amount of insulation which would be required. However, it should be realized that heat loss to the basement area is not entirely wasted as it tends to warm the floors above and to reduce heat losses from the first floor into the basement. The advisability of the further use of insulation on ducts, pipes, or the heating unit itself should be left to the judgment of a reputable heating contractor.

All hot water storage tanks should be well insulated in order to reduce heat waste from this source. In addition, any leaky hot water faucets should be repaired as this continuous loss may be considerable over a period of weeks.

CLEANING OF BOILERS AND RADIATORS

For greatest operating efficiency any deposits of soot on the flue surfaces or heating surfaces of a boiler or furnace should be removed periodically. Such soot deposits may become heavy enough to reduce the rate of heat transmission to the heating surfaces enough so that the over-all efficiency of the heating plant is reduced as much as 6 per cent. If, in addition, there are any heavy deposits of soot in the smoke pipe connection between the furnace or boiler and the chimney, this connection should also be removed and cleaned.

With hot water heating systems the radiator efficiencies can be increased by periodic removal of any dirt collections between the radiator tubes or sections. This can be done by the home owner with the aid of a long handled brush. If convection units are used in conjuction with a steam or hot water plant, the cabinets or fronts of these convectors should be removed periodically and the heating elements cleaned. Such cleaning of radiators and convectors will not appreciably increase the efficiency of the heating plant from the standpoint of saving fuel but will permit more rapid passage of the heat through the radiator into the room being heated. This will aid in the proper distribution of the heat within the space being heated.

FIRING OF COAL

The efficiency with which a hand-fired coal heating plant is operated will vary greatly dependent upon the skill of the fireman. There will, of course, be many variations in the correct methods of firing dependent upon the types of coal being used, but there are some generalities which apply to practically all hand-fired heating plants. For example, it may be said that the deeper the fuel bed, the more complete will be the combustion and, therefore, the higher the efficiency.

Care should be taken that as few small particles of coal as possible be allowed to enter the ashpit and from there be removed with the ashes. The grates should be shaken gently at night until the ashpit shows a glow indicating that some combustibles have entered the ashpit, but beyond this additional shaking is unnecessary. After this the firepot should then be filled to take care of the fuel required for the night hours.

If bituminous coal is used, the entire burning coal bed should never be completely covered with fresh coal. If the entire bed is covered, the hot gases driven off from the fresh coal will not be ignited and the heating value of these volatiles will be lost in the chimney discharge. When coal contains such volatile matter, a portion of the coal bed should be left uncovered when fresh coal is added in order that ignition of these gases will take place.

In the morning the preferable procedure is to add a thin layer of coal to the fire and then fill the firepot only after the fire has obtained a good start. After the fire is burning vigorously and has been checked, then the grate should be shaken lightly to rid the combustion chamber of excess ashes.

With stoker-fired heating boilers and furnaces the firing of the fuel is automatically controlled, but some improvement of the firing efficiency may be obtained by manual means. A hooked poker may be used to pull the clinkers to the surface of the fuel bed from which they may be removed by means of clinker tongs. If fly-ash has caked or banked up around the sides of the fire box or combustion chamber, this should be broken down by agitating such portions of the fuel bed with a hooked poker, then with the back of the hook, the center of the fuel bed may be hollowed out by scraping all coal, clinkers, and ashes to the sides of the firebox. Such a procedure will generally improve the efficiency somewhat of a stoker-fired heating unit.

FUEL SAVINGS THROUGH MAINTENANCE OF LOWER TEMPERATURES

In addition to fuel savings which may be realized by increasing the operating efficiency of a heating plant and by reducing the heat loss from a structure by insulation and weatherstripping, substantial savings may also be accomplished by modifying the conditions under which a residence or building is operated. Such savings are practically all the direct result of reducing the heat requirements of a structure by various means. Those most easily accomplished are the following:

INSIDE AIR TEMPERATURES

Substantial fuel savings can be realized either through carrying inside air temperatures lower than 70° F. continuously or by carrying these lower temperatures during the night hours and periods of physical activity. The amount of saving, of course, is dependent both upon the inside temperature and the number of hours per day during which it is maintained as well as the average outside temperature during the heating season. The percentage saving which will result from the maintenance of a lower temperature is greater in a mild climate than it is in a severe climate. Thus, a somewhat greater percentage saving would be experienced by this means in southern Minnesota than in northern Minnesota. In either case, however, the saving would be sufficient to warrant the carrying of substantially lowered temperatures if the individuals exposed to these conditions are able to withstand them without harm to health.

TABLE VI

PERCENTAGE FUEL SAVINGS OBTAINED BY CONTINUOUSLY MAINTAINING THE INSIDE AIR TEMPERATURE BELOW 70° F.

	District		
	Southern Minnesota	Central Minnesota	Northern Minnesota
Average winter temperature (October 1-May 1)	30° F.	25° F.	20° F.
Percentage savings: 65° F. air temperature	12.5%	11.0%	10.0%
Percentage savings: 60° F. air temperature	25.0%	22.0%	20.0%
Percentage savings: 55° F. air temperature	37.5%	33.0%	30.0%

Table VI indicates the approximate fuel savings which may be expected for southern, central, and northern Minnesota when the base temperature maintained throughout the entire day is lowered from 70° F. to either 65°, 60°, or 55° F. A temperature of 65° F. may be assumed to be approximately the lowest base temperature to which the average individual may be exposed continuously without undue discomfort or harm to health. The saving to be obtained by maintaining this temperature would range normally from approximately 12½ per cent in the southern part of the state to 10 per cent in the northern part.

TABLE VII

PERCENTAGE FUEL SAVINGS OBTAINED BY MAINTAINING THE INSIDE AIR TEMPERATURE BELOW 70° F. FOR EIGHT HOURS

	District		
	Southern Minnesota	Central Minnesota	Northern Minnesota
Average winter temperature (October 1-May 1)	30° F.	25° F.	20° F.
Percentage savings: 65°F. air temperature	4.2%	3.7%	3.3%
Percentage savings: 60° F. air temperature	8.3%	7.3%	6.7%
Percentage savings: 55° F. air temperature	12.5%	11.0%	10.0%
Percentage savings: 50° F. air temperature	16.7%	14.7%	13.3%

Table VII shows the approximate savings which may be expected in the southern, central, and northern parts of the state when the temperature is lowered from 70° F. to either 65°, 60°, 55°, or 50° F., for an eight-hour period during the night. Savings of this magnitude may be expected only in case the heating plants were originally properly sized and installed. The exact extent to which night temperatures can be lowered depends upon the adaptability of the heating plant to raising the air temperatures within a reasonable length of time.

When a house is to be left unoccupied for several or more days, it is advisable to lower the thermostat setting to approximately 50° F. Such a temperature will result in substantial fuel savings yet be sufficiently high to prevent any possible damage through freezing.

CLOSING OFF OF UNUSED ROOMS

Many homes have rooms which are rarely used and which may be left unheated without undue discomfort or inconvenience. Garages, sunrooms, and amusement rooms generally fall within this classification, and all usually require abnormally large amounts of heat. In addition, many homes have spare bedrooms and other spaces which are not frequently occupied.

If rooms normally heated by hot water radiators are to be unheated, there are certain precautions which should be taken. Complete closing of radiator valves may not be advisable as the temperature may be lowered below the freezing point and thereby result in damage to the heating system. Radiator risers to such rooms may be disconnected in the basement and drained, but a much simpler expedient is to make coverings for the radiators. Such coverings (Fig. 16) should completely surround the radiators on all sides and the top, and may be made of any heavy blanketing material such as rug padding or may be made of any rigid material such as insulation board, plywood, etc. These coverings will keep the radiators well above the freezing temperatures and yet prevent most of the heat from escaping into the room.

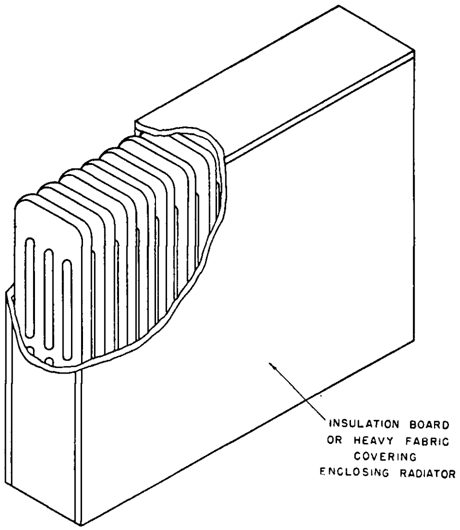

FIGURE 16. RADIATOR COVERING TO REDUCE HEAT SUPPLY TO ROOMS NOT IN USE

Doors leading from heated portions of the house to unheated rooms or attic spaces should be well sealed to prevent any leakage of cold air.

From the standpoint of ventilation, it is unnecessary to open bedroom windows at night, as there is sufficient leakage of air into the house from the outside to more than take care of all health requirements. Some people, however, find it uncomfortable to sleep in a heated room and therefore prefer to open bedroom windows. If such is the case, radiators should be turned off or preferably blanketed if the house is heated by hot water or steam, and if heated by warm air or forced air, all supply and return registers should be closed or blanked off.

REDUCING THE HEAT LOSS FROM THE STRUCTURE

When the temperature within a building is higher than the outside air temperature there is a flow of heat from the inside to the outside. If the building is to be maintained at the desired temperature, there must be a continuous supply of replacement heat to compensate for this loss. In addition there is also a leakage of air through the cracks around the windows and doors and even through the walls which results in an exchange of outdoor air for inside air. Heat, of course, is required for bringing this outdoor air up to the desired room temperature. Although it is impossible to eliminate entirely these two major sources of heat loss from a building, they may be greatly reduced by the proper application of insulation, storm windows, and weatherstripping.

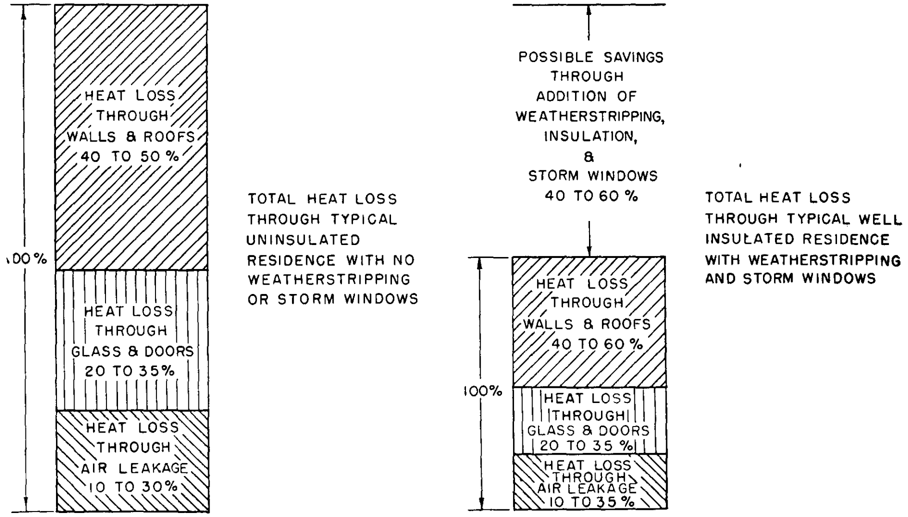

FIGURE 17. POSSIBLE HEAT SAVINGS THROUGH THE ADDITION OF INSULATION, STORM WINDOWS, AND WEATHERSTRIPPING TO TYPICAL RESIDENCES

Figure 17 shows the range of savings possible through the proper application of insulation, storm windows, and weatherstripping. The heat loss from an average uninsulated residence with neither storm windows nor weatherstripping will show approximately 40 to 65 per cent of this loss occuring through the walls and roof. Heat lost by air leakage will constitute 10 to 30 per cent of the total, and heat loss through windows and doors, 20 to 35 per cent. The actual percentage values will, of course, depend upon the design and construction of the residence. When such an average residence is well insulated and equipped with both storm windows and weatherstripping, the savings in heat will amount to from 40 to 60 per cent. The remaining heat losses will be redistributed with approximately 40 to 60 per cent through the walls and roof, 20 to 35 per cent through the glass and doors, and 10 to 35 per cent lost through air leakage. Figures 18 and 19 show the results of actual analyses made of the heating requirements for (1) a two-story, six-room residence with three bedrooms on the second floor and (2) a single-story, four-room bungalow with two bedrooms. These residences have been analyzed from the standpoint of heating requirements for seven different variations in construction ranging from a construction with no insulation, weatherstripping, or storm sash to a construction with four inches of insulation in the ceiling and walls and with complete weatherstripping and storm sash. The distribution of heat losses through the various parts of the buildings and the savings resulting from the addition of various degrees of insulation, weatherstripping, and storm sash, hold true, of course, only for these particular cases. Nevertheless, they are indicative of the general savings which will result in other cases.

WEATHERSTRIPPING

Weatherstripping may be applied satisfactorily to either new or old construction with a resultant fuel saving of from 5 to 10 per cent. There are several different styles of weatherstripping, but, in general, it may be said that any good quality metal weatherstripping properly applied will give satisfactory results. Felt weatherstripping is satisfactory as a temporary measure but does not usually give as good a seal as most metal weatherstripping and may, over a long period of time, cause some rotting of the adjacent wood through the collection of moisture.

STORM WINDOWS

The application of storm windows and storm doors will result in fuel savings ranging from 10 to 25 per cent. In order to be effective such storm sash should be well constructed and tight fitting. The application of storm doors will not only reduce the heat loss of the building but will also increase the inside surface temperature of the glass and thus aid in decreasing the feeling of cold experienced by occupants upon approaching windows on cold days. (See Effect of Cold Walls on Comfort and Fuel Requirements, page 16.) There will also be a decrease in the downdrafts of cold air originating at windows.

CALKING

Over a period of years there may be a separation of the window and door frames from the exterior building materials because of the continual expansion and contraction of these frames and materials when subjected to the varying temperature and moisture content of the air. Air leakage may result through these cracks and is usually evident by dust streaks on the wall adjacent to the framing. Such leakage may be largely eliminated by filling or as is com-

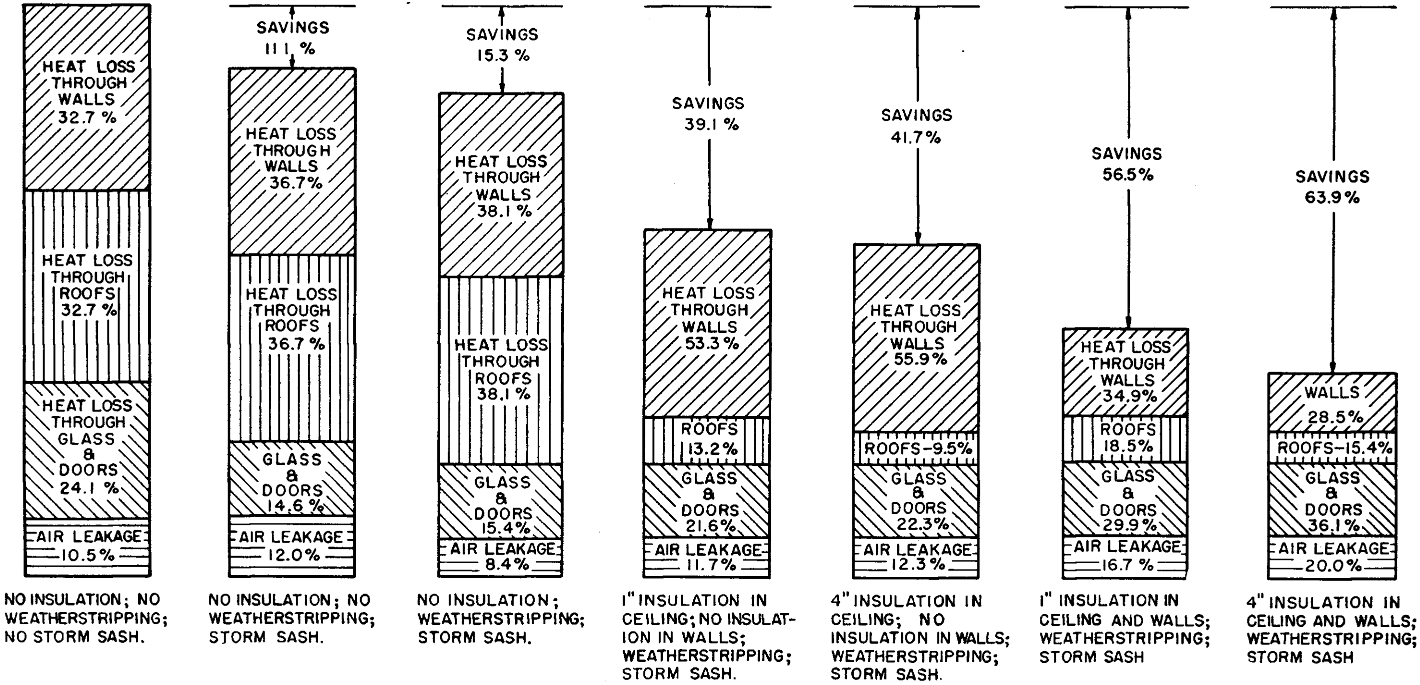

FIGURE 18. DISTRIBUTION OF HEAT AND PERCENTAGE SAVINGS OBTAINED THROUGH VARIOUS COMBINATIONS OF INSULATION, WEATHERSTRIPPING, AND STORM SASH APPLIED TO A TWO-STORY, SIX-ROOM RESIDENCE. (PERCENTAGE SAVINGS SHOWN ARE COMPARISONS WITH CONSTRUCTION HAVING NO INSULATION, NO WEATHERSTRIPPING, AND NO STORM SASH)

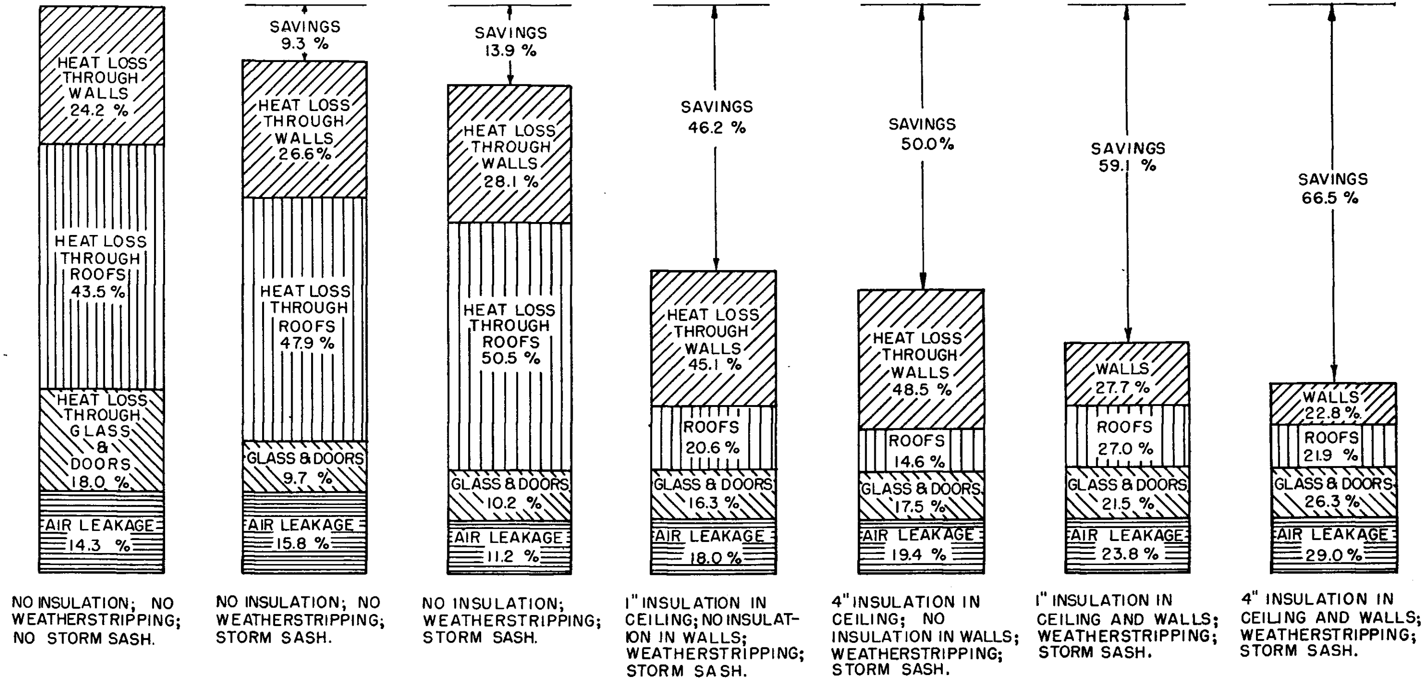

FIGURE 19. DISTRIBUTION OF HEAT AND PERCENTAGE SAVINGS OBTAINED THROUGH VARIOUS COMBINATIONS OF INSULATION, WEATHERSTRIPPING, AND STORM SASH APPLIED TO A ONE-STORY, FOUR-ROOM BUNGALOW (PERCENTAGE SAVINGS SHOWN ARE COMPARISONS WITH CONSTRUCTION HAVING NO INSULATION, NO WEATHERSTRIPPING, AND NO STORM SASH)

monly termed "calking" these cracks and crevices. Such calking should be done by a reputable and experienced contractor.

REFLECTIVE RADIATOR SHIELDS

There are very definite savings to be obtained through the use of shields made of reflective materials placed between radiators and outside walls. Radiators which are placed next to outside walls will tend to overheat the adjacent wall surfaces by radiant heat and thereby increase the heat losses through such wall sections. These losses may be reduced by placing reflector shields between the radiators and the walls so that this radiant heat will be reflected back into the room before it can be absorbed by the wall. Such shields should be made of metallic reflective materials such as tin plated iron or aluminum or of any nonmetallic material surfaced with a reflective foil. There are several standard products which have recently been placed on the market for this purpose and have proved to be satisfactory. In general, those materials surfaced or made of an actual metallic material or foil are preferable to those painted with a reflective paint. The exact degree of saving which will result from the use of such shields is not fully known because of the limited tests which have, at yet, been made. In general, it appears that those shields when satisfactorily constructed of proper materials and costing approximately $1 per radiator are well worth the expenditure.

CURTAINS AND BLINDS

The amount of heat lost through glass windows is approximately 20 to 30 per cent of the total in the average residence, and for this reason an appreciable fuel saving may be obtained during the winter months by the judicious pulling of curtains and blinds. With blinds, an additional air space is formed between the window and the blind which aids in retarding the flow of heat. Therefore it is recommended that all blinds and curtains be fully pulled during the night hours and that they be half pulled during the daytime hours. In those rooms that are not used during the daytime, blinds and curtains should be fully pulled at all times. These simple expedients may result in fuel savings of as much as 10 per cent.

FIREPLACES

Fireplaces are frequently used as an auxiliary means of supplying heat to residences, but from the standpoint of fuel conservation, the measure is questionable. In order to operate a fireplace satisfactorily, large volumes of heated air must be drawn from the heated rooms in order to maintain proper chimney draft and to supply the necessary oxygen for the combustion of the fuel burning in the fireplace. Although there is a radiant heating effect originating from the fireplace and noticeable to the occupants of the room, the remaining rooms of the house may become somewhat cooler because of the air drawn from them. Actual tests indicate that in some cases more heat in the form of heated air discharged from the chimney is lost than there is heat gained by virtue of the operation of the fireplace.

INSULATION

Insulating materials in general may be classed as either rigid, flexible, or fill. The rigid or "board" insulations are usually manufactured in panels and are used not only because of their heat insulating value but also because they possess structural strength. They may be used either as sheathing, plaster base, or as an inside wall finishing material. They usually range from one-half to an inch in thickness.

The flexible insulating materials, commonly called "quilt," "blanket," or "batt" insulations are used primarily because of their heat insulating properties. These materials are usually fibrous in nature and may be covered on one or both sides with a retaining material such as paper. These materials are usually placed between the studs in walls or between the joists in ceilings and generally range in thickness between one-half and four inches.

The fill insulations are also used primarily because of their heat insulating properties and are placed in the wall stud spaces and the ceiling joist spaces. Such materials are usually sold in bulk and are either fibrous, granulated, or shredded. When fill insulations are applied to walls, the entire stud space is usually filled with the insulating material. When applied to ceiling joists or roof rafters, it is usually applied in a two-inch to a four-inch thickness.

In the application of insulation to existing buildings the starting point is usually the attic floor. Because of its greater accessibility, insulation is more easily applied here. Therefore, when a limited amount of money is available, much can be gained through the insulation of attic areas only. From the standpoint of fuel economy, it is, of course, advisable to insulate both the walls and the attic floor, but the application of insulation to the walls of an existing building is a more difficult problem.

In determining those portions of a structure which it is advisable to insulate in order to conserve fuel, it should be remembered that heat always flows from a higher temperature to a lower temperature. If, for example, in a residence no portion of the attic space is used for living quarters, the insulation and vapor barrier (see Condensation of Moisture within Building Structures, page 50) should be located as shown to the right of Figure 20. In this case the insulation is placed in the attic flooring and in the walls of the structure. There would be no advantage in placing insulation between the rafters of the attic roof as there would be no additional heat saving and it would require considerably more insulation than when located in the attic floor. However, in case a portion of the attic is to be heated and used for living quarters, the insulation and vapor seal should be installed as shown to the left of Figure 20. In addition the flow of heat from the heated structure into any cold area over an unexcavated portion of the building should be retarded by the use of insulation. However, even though the ground temperature adjacent to the basement is at a somewhat lower temperature than the basement itself, actual basement areas usually are not insulated. This is because the ground itself acts to a certain extent as an insulating material,

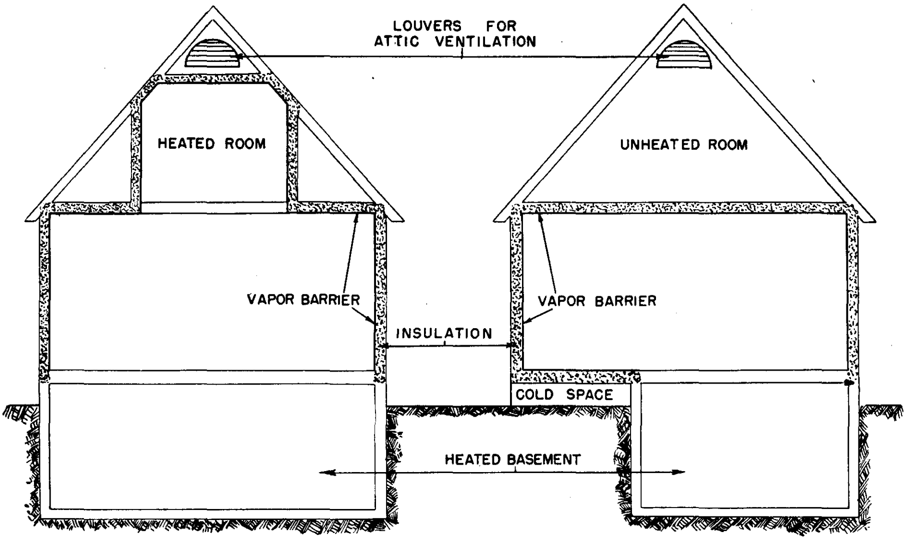

FIGURE 20. PROPER LOCATION OF INSULATION AND VAPOR BARRIER

and it is usually considered that the small savings resulting from the insulating of basement areas would not warrant the original expenditure.

Practically any type of fill, batt, or blanket insulation may be used for the insulation of floors and roofs. One satisfactory method by which the walls of an existing structure may be insulated is to have the insulation blown into the wall stud spaces. There are many reputable contractors who are properly equipped to apply insulation by this method. In some cases the walls may be partially insulated without this procedure by pouring fill insulation into the stud spaces from the attic. Only those portions of the wall above the top framing members of windows and doors and above any headers or cross members in the walls may be insulated in this manner.

It should be kept in mind that in the remodeling of rooms or other portions of an existing structure it is frequently possible to apply insulation. In certain cases either the fill, batt, or blanket type of insulation may be applied satisfactorily or the rigid board insulations may be used as either a plaster base, sheathing, exterior wall covering, or as an interior room finish.

The first inch of insulating material applied to a wall or attic floor will result in a greater saving in heat and fuel than will the second inch, the second inch will result in a greater saving than the third inch, etc. This decreasing economic return makes it practical to limit the thickness of an insulating material to approximately four inches. However, it must be kept in mind that two inches of insulation will save more fuel than one inch and that three inches will save more than two, etc., so that the actual thickness of the insulating material purchased should be kept in mind as well as the price of the material.

COST OF APPLICATION OF INSULATION

The cost of applying insulation to either a new or an old structure will vary greatly depending upon the type of insulation chosen, local labor conditions, and the periodic fluctuations in the cost of the materials themselves. Furthermore, these prices and rates vary not only from time to time but also between different sections of the country and between rural and urban communities. For these reasons it is virtually impossible to set up definite numerical values which will fairly present the costs of insulating either new or old structures. However, the amounts of material required and the hours of labor necessary remain practically constant throughout the country and it is, therefore, possible to determine comparative costs between different types of walls and ceiling when information as to the labor and materials necessary is available. Such information is presented in Table VIII for both new and old constructions, and combinations of the various materials shown will enable the prospective builder or contractor to determine the cost of practically all types of ordinary wall and ceiling constructions. The second and third columns in this table present a description of the construction covered and its point of application. The fourth column itemizes the various materials and labor needed for such construction, and the fifth column presents figures as to the actual quantities of material and hours of labor needed for each of these items. The sixth and seventh columns are left blank so that the local, current values covering these materials may be filled in and the cost of construction thus determined.

Tables IX through XVI are presented to show how typical cost figures may be developed for various types of noninsulated and insulated walls for comparison purposes. In these tables two values have been tabulated. The lower value in each square represents the overall coefficient of heat transmission in Btu per hour per square foot per degree temperature difference and the upper value represents the cost of construction of such a wall per thousand square foot of area based on the prevailing material costs and labor rates in Minneapolis during the first part of the year 1943. The labor rates are based upon union scales and the material costs are approximately ceiling prices at the time calculated. There were considerable variations between the various dealers and material installers even within the comparatively small area involving Minneapolis and St. Paul and these figures, therefore, approximated the average encountered at that time. However, in comparing these figures it should be remembered that they applied only to a specific area at a specific time.

Table XVII presents typical cost figures for ceilings and was developed in the same manner as Tables IX through XVI dealing with walls. Again the overall coefficients of heat transmission and the construction costs per thousand square feet of area are compared as based upon prevailing material costs and labor rates in Minneapolis during the first part of the year 1943. In interpreting these results it should be remembered that they applied only to a specific area at specific time.

TABLE VIII

LABOR AND MATERIALS REQUIRED IN WALL AND CEILING CONSTRUCTION

Item No.	Description of Construction	Point of Application	Components	Amount Required per 1,000 Square Feet	Rate	Total
			Wall Exterior Finish			
1.	*Beveled wood siding;* ½" x 8"—6½ inches exposed to weather; 3 coats exterior paint	Wall	Wood siding	1,230 bd. ft.	______	______
			Nails (6 d)	8 lbs.	______	______
			Carpenter	16.4 hrs.	______	______
			Labor	6.2 hrs.	______	______
			Paint	8.5 gal.	______	______
			Painter	20.0 hrs.	______	______
2.	*Wood shingles;* laid 6" to weather — one coat stain	Wall	Wood shingles	30 bdl's.	______	______
			Nails (3 d)	25 lbs.	______	______
			Carpenter	33 hrs.	______	______
			Stain	6⅔ gal.	______	______
			Painter	6⅔ hrs.	______	______
3.	*Face brick (veneer);* 8" x 2¼" x 3¾"	Wall	Brick veneer	6,000 + 2%	______	______
			Mason	81 hrs.	______	______
			Brick mortar	1.36 cu. yd.	______	______
			Labor	69 hrs.	______	______
4.	*Two coat stucco;* applied on metal lath	Wall	Portland cement	7 bbls.	______	______
			Sand	33 cu. ft.	______	______
			Hair	2 bu.	______	______
			Fiber	1 bu.	______	______
			Plasterer	17½ hrs.	______	______
			Helper	11 hrs.	______	______
			Building Paper			
5.	*15 lbs. asphalt felt paper*	Wall	Building paper	1,100 sq. ft.	______	______
			Carpenter	4 hrs.	______	______
			Sheathing Materials			
6.	*Shiplap wood sheathing;* 25/32" x 12", laid horizontally	Wall	1" wood sheathing	1,150 bd. ft.	______	______
			Nails (8 d)	23 lbs.	______	______
			Carpenter	11.5 hrs.	______	______
			Labor	4.9 hrs.	______	______
7.	*Rigid insulation sheathing;* 25/32" x 2' x 8" pieces	Wall	25/32" rigid insulation sheathing	1,100 sq. ft.	______	______
			Nails (8 d)	38 lbs.	______	______
			Carpenter	8.0 hrs.	______	______
8.	½" *plasterboard sheathing*	Wall	½" plasterboard sheathing	1,100 sq. ft.	______	______
			Nails (3 d)	22 lbs.	______	______
			Carpenter	10 hrs.	______	______
			Supporting Members			
9.	2" x 4" *wood studs;* spaced 16" on center	Wall	2" x 4" studs	755 bd. ft.	______	______
			Nails (16 d)	18 lbs.	______	______
			Carpenter	13.6 hrs.	______	______
			Labor	3.4 hrs.	______	______

TABLE VIII—*Continued*

Item No.	Description of Construction	Point of Application	Components	Amount Required per 1,000 Square Feet	Rate	Total
10.	2" x 6" *joists;* spaced 16" on center	Ceilings	2" x 6" joists	760 bd. ft.	______	______
			Nails (16 d)	18 lbs.	______	______
			Carpenter	7.2 hrs.	______	______
			Helper	3.0 hrs.	______	______
	Insulation Between Framing Members					
11.	1" *blanket insulation;* applied between studs with staples	Wall or Ceiling	1" flexible insulation (k = .27)*	937 sq. ft.	______	______
			Staples	1 box	______	______
			Carpenter	13 hrs.	______	______
12.	2" *blanket insulation;* applied between studs with staples	Wall or Ceiling	2" flexible insulation (k = .27)*	937 sq. ft.	______	______
			Staples	1 box	______	______
			Carpenter	13 hrs.	______	______
13.	3⅝" *blanket insulation;* applied between studs with staples	Wall or Ceiling	3⅝" flexible insulation (k = .27)*	937 sq. ft.	______	______
			Staples	1 box	______	______
			Carpenter	13 hrs.	______	______
14.	4" *mineral wool batt;* applied between studs or joists	Wall or Ceiling	4" mineral wool batts (k = .27)*	937 sq. ft.	______	______
			Carpenter	8.9 hrs.	______	______
15.	2" *mineral wool batt;* applied between studs or joists	Wall or Ceiling	2" mineral wool batts (k = .27)*	937 sq. ft.	______	______
			Carpenter	8.9 hrs.	______	______
16.	3⅝" *granulated mineral wool;* poured between studs	Wall	3⅝" granulated mineral wool (Density 10 lbs./cu. ft.) (k = .27)*	2,720 lbs.	______	______
			Labor	10 hrs.	______	______
17.	4" *granulated mineral wool;* poured between joists	Ceiling	4" granulated mineral wool (Density 10 lbs./cu. ft.) (k = .27)*	3,000 lbs.	______	______
			Labor	10 hrs.	______	______
18.	3⅝" *redwood bark;* applied between studs	Wall	3⅝" redwood bark (Density 3 lbs./cu. ft.) (k = .31)*	816 lbs.	______	______
			Labor	10 hrs.	______	______

* "k" represents the heat conductivity in Btu passing between the surfaces of one square foot of material in an hour's time when there is a difference in temperature of one degree Fahrenheit and the material is one inch thick.

TABLE VIII—*Continued*

Item No.	Description of Construction	Point of Application	Components	Amount Required per 1,000 Square Feet	Rate	Total
19.	3⅝″ *redwood bark;* applied between studs	Wall	3⅝″ redwood bark (Density 5 lbs./ cu. ft.) (k = .26)*	1,360 lbs.	____	____
			Labor	10 hrs.	____	____
20.	4″ *redwood bark;* applied between joists	Ceiling	4″ redwood bark (Density 3 lbs./ cu. ft.) (k = .31)*	900 lbs.	____	____
			Labor	10 hrs.	____	____
21.	4″*redwood bark;* applied between joists	Ceiling	4″ redwood bark (Density 5 lbs./ cu. ft.) (k = .26)*	1,500 lbs.	____	____
			Labor	10 hrs.	____	____
22.	3⅝″ *expanded vermiculite;* applied between studs	Wall	3⅝″ vermiculite (Density 5.2 lbs./ cu. ft.) (k = .41)*	1,415 lbs.	____	____
			Labor	10 hrs.	____	____
23.	3⅝″ *expanded vermiculite;* applied between studs	Wall	3⅝″ vermiculite (Density 6.3 lbs./ cu. ft.) (k = .29)*	1,720 lbs.	____	____
			Labor	10 hrs.	____	____
24.	4″ *expanded vermiculite;* applied between joists	Ceiling	4″ vermiculite (Density 5.2 lbs./ cu. ft.) (k = .41)*	1,560 lbs.	____	____
			Labor	10 hrs.	____	____
25.	4″ *expanded vermiculite;* applied between joists	Ceiling	4″ vermiculite (Density 6.3 lbs./ cu. ft.) (k = .29)*	1,890 lbs.	____	____
			Labor	10 hrs.	____	____
26.	*Blown insulation;* applied between the studs or joists of ready built structure	Wall or Ceiling	Blown insulation (k varies with material)	Depends upon type of material and construction	____ ____ ____ ____	____ ____ ____ ____
			Vapor Barriers			
27.	*Asphalt coated and saturated paper;* applied over the inner side of studs	Wall or Ceiling	Vapor barrier	1,100 sq. ft.	____	____
			Nails	5 lbs.	____	____
			Carpenter	4 hrs.	____	____

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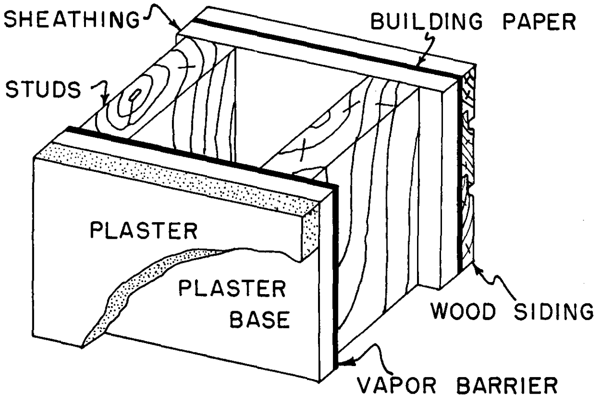
* "k" represents the heat conductivity in Btu passing between the surfaces of one square foot of material in an hour's time when there is a difference in temperature of one degree Fahrenheit and the material is one inch thick.

TABLE VIII—*Continued*

Item No.	Description of Construction	Point of Application	Components	Amount Required per 1,000 Square Feet	Rate	Total
			Interior Finishes			
28.	*Neat gypsum plaster;* (½") applied to wood lath	Wall and Ceiling	Plaster—½"	0.67 ton		
			Sand	1.17 ton		
			Plasterer	8.9 hrs.		
			Helper	8.9 hrs.		
			Wood lath	1,610 pcs.		
			Nails (3 d)	10 lbs.		
			Lather	8.9 hrs.		
29.	*Neat gypsum plaster;* (⅝") applied to metal lath	Wall and Ceiling	Plaster—⅝"	1.0 ton		
			Sand	2.1 ton		
			Plasterer	13.4 hrs.		
			Helper	13.4 hrs.		
			Metal lath	1,050 sq. ft.		
			Staples	17 lbs.		
			Lather	10 hrs.		
30.	*Neat gypsum plaster;* (½") applied to ⅜" plasterboard	Wall and Ceiling	Plaster—½"	0.56 ton		
			Sand	1.17 ton		
			Plasterer	8.9 hrs.		
			Helper	8.9 hrs.		
			Plasterboard—⅜"	1,100 sq. ft.		
			Nails (3 d)	9 lbs.		
			Lather	8.0 hrs.		
31.	*Neat gypsum plaster;* (½") applied to ½" rigid insulation plaster base	Wall and Ceiling	Plaster—½"	.58 ton		
			Sand	1.17 ton		
			Plasterer	8.9 hrs.		
			Helper	8.9 hrs.		
			Insulation Lath—½"	1,100 sq. ft.		
			Nails (4 d)	7 lbs.		
			Lather	8.0 hrs.		
32.	½" *rigid insulation;* used as interior finish	Wall and Ceiling	Rigid insulation—½" interior	1,050 sq. ft.		
			Nails (4 d)	8 lbs.		
			Carpenter	20.0 hrs.		
33.	½" *tile insulation board;* applied to 1" x 2" furring strips	Wall and Ceiling	Tile—12" x 12"	1,100 sq. ft.		
			Nails (4 d)	10 lbs.		
			Carpenter	18.2 hrs.		
			Labor	18.2 hrs.		
			Wood furring, 1" x 2"	785 lineal ft.		
			Nails (6 d)	11 lbs.		
			Carpenter	11.7 hrs.		
			Attic Flooring			
34.	1" x 6" *yellow pine flooring;* nailed to upper side of joists	Ceiling	1" x 6" flooring	650 bd. ft.		
			Nails (10 d)	23 lbs.		
			Carpenter	5.2 hrs.		
			Helper	3.3 hrs.		

TABLE IX

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH WOOD SIDING AS EXTERIOR FINISH (NO INSULATION BETWEEN STUDS)

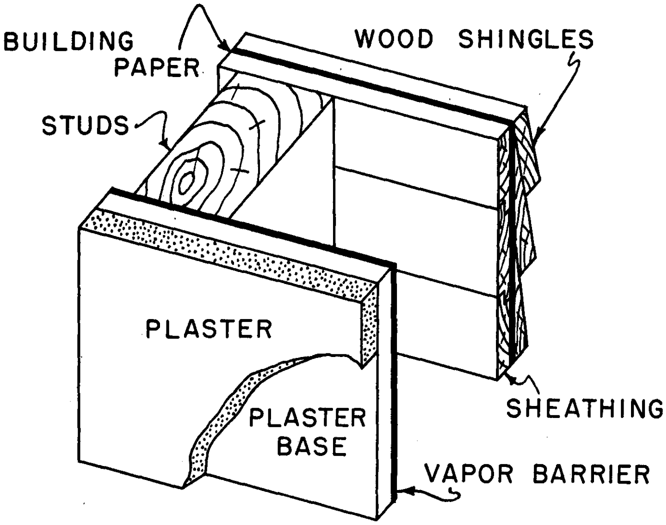


TYPE OF SHEATHING		INTERIOR FINISH							
		PLASTER ON WOOD LATH	PLASTER ON METAL LATH	PLASTER ON $\frac{3}{8}$" PLASTERBOARD	PLASTER ON $\frac{1}{2}$" RIGID INSULATION	PLASTER ON $\frac{3}{4}$" RIGID INSULATION	PLASTER ON 1" RIGID INSULATION	NO PLASTER, $\frac{1}{2}$" DECORATIVE INSULATION ON FURRING STRIPS	1" WOOD SHEATHING, FURRING STRIPS, PLASTER ON WOOD LATH
1" WOOD	$/THOUS. SQ. FT.	429	469	454	465	476	504	503	538
	"U"	0.25	0.26	0.25	0.19	0.17	0.15	0.19	0.17
$\frac{25}{32}$" RIGID INSULATION	$/THOUS. SQ. FT.	432	472	457	468	479	507	506	541
	"U"	0.19	0.20	0.19	0.15	0.14	0.13	0.16	0.14
$\frac{1}{2}$" PLASTER-BOARD	$/THOUS. SQ. FT.	413	453	438	449	460	488	487	522
	"U"	0.31	0.33	0.31	0.22	0.20	0.17	0.23	0.19

TABLE X

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH WOOD SHINGLES AS EXTERIOR FINISH

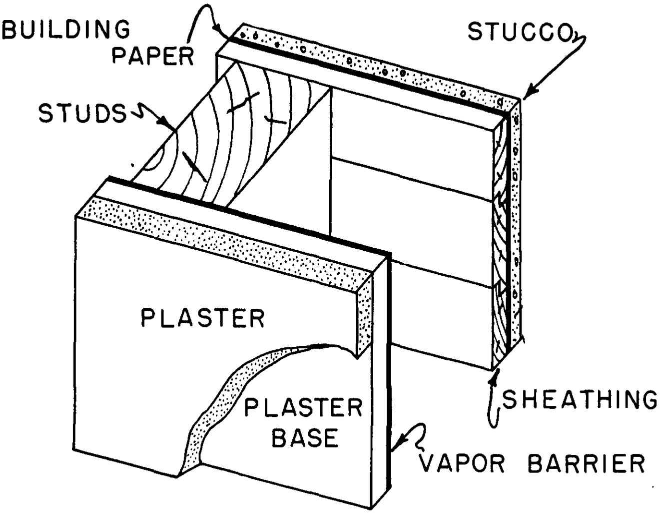
(NO INSULATION BETWEEN STUDS)



TYPE OF SHEATHING		INTERIOR FINISH							
		PLASTER ON WOOD LATH	PLASTER ON METAL LATH	PLASTER ON 3/8" PLASTERBOARD	PLASTER ON 1/2" RIGID INSULATION	PLASTER ON 3/4" RIGID INSULATION	PLASTER ON 1" RIGID INSULATION	1/2" DECORATIVE INSULATION	1" WOOD SHEATHING, FURRING STRIPS, PLASTER ON WOOD LATH
1" WOOD	$/THOUS. SQ. FT.	367	408	393	403	415	442	441	476
	"U"	0.25	0.26	0.25	0.19	0.17	0.15	0.19	0.17
25/32" RIGID INSULATION	$/THOUS. SQ. FT.	370	411	396	407	418	445	444	479
	"U"	0.17	0.17	0.17	0.14	0.13	0.11	0.14	0.14
1/2" PLASTER-BOARD	$/THOUS. SQ. FT.	351	392	377	388	399	426	425	460
	"U"	0.24	0.25	0.24	0.19	0.17	0.15	0.19	0.14

TABLE XI

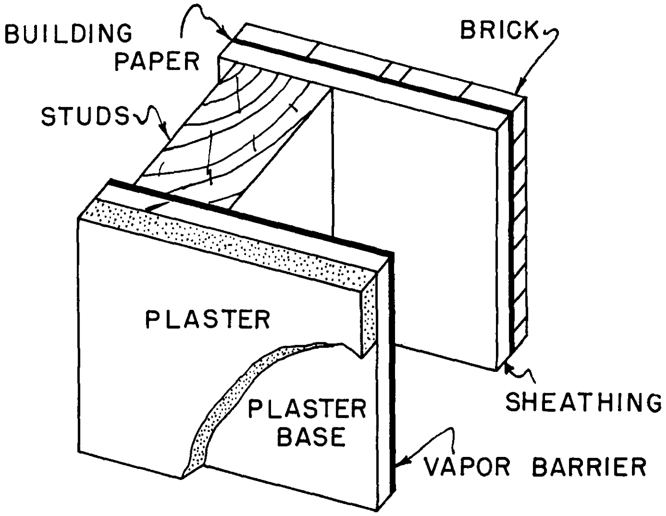
CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH STUCCO AS EXTERIOR FINISH (NO INSULATION BETWEEN STUDS)



TYPE OF SHEATHING		INTERIOR FINISH							
		PLASTER ON WOOD LATH	PLASTER ON METAL LATH	PLASTER ON 3/8" PLASTERBOARD	PLASTER ON 1/2" RIGID INSULATION	PLASTER ON 3/4" RIGID INSULATION	PLASTER ON 1" RIGID INSULATION	1/2" DECORATIVE INSULATION	1" WOOD SHEATHING FURRING STRIPS, PLASTER ON WOOD LATH
1" WOOD	$/THOUS. SQ. FT.	425	465	450	461	472	500	499	534
	"U"	0.30	0.32	0.30	0.22	0.19	0.16	0.22	0.19
25/32" RIGID INSULATION	$/THOUS. SQ. FT.	428	472	453	464	475	503	502	537
	"U"	0.22	0.23	0.22	0.17	0.16	0.14	0.19	0.15
1/2" PLASTER-BOARD	$/THOUS. SQ. FT.	409	449	434	445	456	484	483	518
	"U"	0.40	0.43	0.40	0.26	0.23	0.19	0.28	0.22

TABLE XII

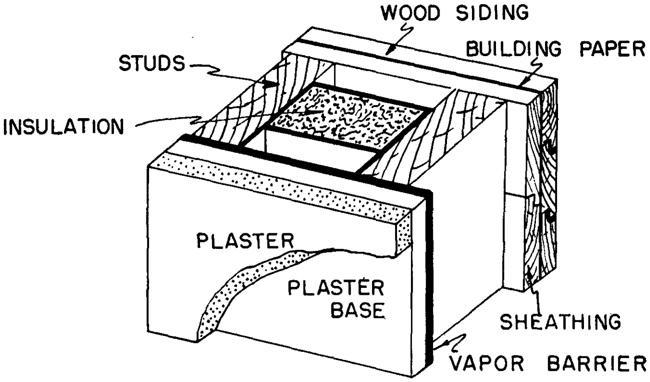
CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH BRICK VENEER AS EXTERIOR FINISH (NO INSULATION BETWEEN STUDS)



TYPE OF SHEATHING		INTERIOR FINISH							
		PLASTER ON WOOD LATH	PLASTER ON METAL LATH	PLASTER ON 3/8" PLASTERBOARD	PLASTER ON 1/2" RIGID INSULATION	PLASTER ON 3/4" RIGID INSULATION	PLASTER ON 1" RIGID INSULATION	1/2" DECORATIVE INSULATION	1" WOOD SHEATHING FURRING STRIPS, PLASTER ON WOOD LATH
1" WOOD	$/THOUS. SQ. FT.	660	700	685	696	707	735	734	769
	"U"	0.27	0.28	0.27	0.20	0.18	0.15	0.21	0.17
25/32" RIGID INSULATION	$/THOUS. SQ. FT.	663	703	688	699	710	738	737	772
	"U"	0.21	0.21	0.21	0.16	0.15	0.14	0.17	0.15
1/2" PLASTER-BOARD	$/THOUS. SQ. FT.	644	684	669	680	691	719	718	753
	"U"	0.35	0.37	0.35	0.24	0.21	0.18	0 25	0.21

TABLE XIII

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH WOOD SIDING AS EXTERIOR FINISH (INSULATION BETWEEN STUDS)

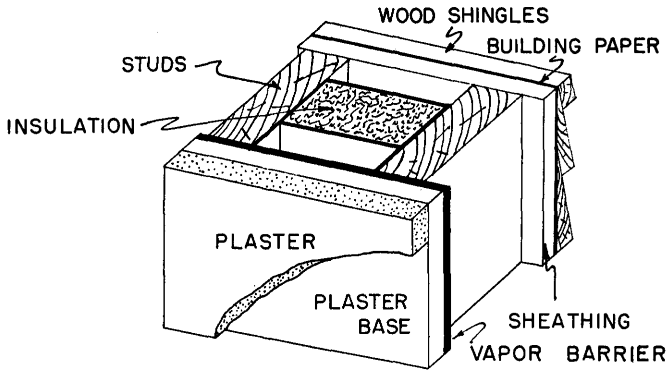


TYPE OF SHEATHING		INTERIOR FINISH AND INSULATION											
		PLASTER ON $\frac{3}{8}$" PLASTERBOARD.			PLASTER ON METAL LATH			PLASTER ON $\frac{1}{2}$" RIGID INSULATION			$\frac{1}{2}$" DECORATIVE INSULATION		
		1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3$\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3$\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3$\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3$\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.
1" WOOD	\$/THOUS. SQ. FT.	522	538	559	537	553	574	533	549	570	571	587	608
	"U"	0.120	0.092	0.074	0.120	0.093	0.072	0.110	0.082	0.068	0.110	0.083	0.066
$\frac{25}{32}$" RIGID INSULATION	\$/THOUS. SQ. FT.	525	541	562	540	556	577	536	552	573	574	590	611
	"U"	0.100	0.081	0.067	0.100	0.089	0.068	0.092	0.074	0.062	0.093	0.074	0.062
$\frac{1}{2}$" PLASTER-BOARD	\$/THOUS. SQ. FT.	506	522	543	521	537	558	517	533	554	555	571	592
	"U"	0.130	0.097	0.078	0.130	0.098	0.076	0.110	0.087	0.071	0.110	0.087	0.071

[a] FLEXIBLE INSULATION COSTS ASSUMED AT \$45, \$60 AND \$80 PER 1000 SQ.FT. FOR 1", 2" AND 3$\frac{5}{8}$" THICKNESSES RESPECTIVELY.

TABLE XIV

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH WOOD SHINGLES AS EXTERIOR FINISH (INSULATION BETWEEN STUDS)

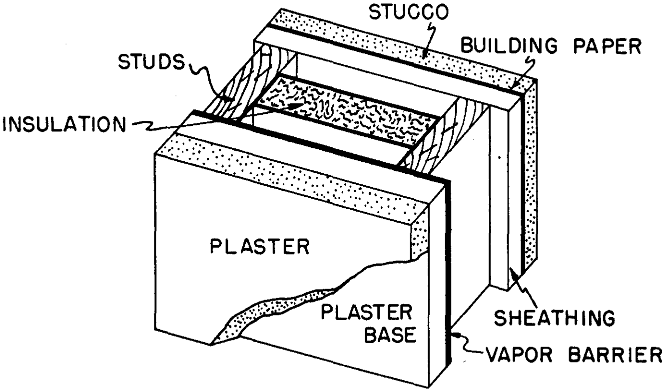


TYPE OF SHEATHING		INTERIOR FINISH AND INSULATION											
		PLASTER ON 3/8" PLASTERBOARD			PLASTER ON METAL LATH			PLASTER ON 1/2" RIGID INSULATION			1/2" DECORATIVE INSULATION		
		1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.
1" WOOD	$/THOUS. SQ. FT.	461	477	498	476	491	512	472	488	509	509	525	546
	"U"	0.120	0.092	0.075	0.120	0.091	0.072	0.110	0.083	0.068	0.110	0.082	0.067
25/32" RIGID INSULATION	$/THOUS. SQ. FT.	464	480	501	479	494	515	475	491	512	512	528	549
	"U"	0.110	0.082	0.068	0.094	0.081	0.064	0.092	0.074	0.062	0.092	0.073	0.062
1/2" PLASTER-BOARD	$/THOUS. SQ. FT.	445	461	482	460	475	496	456	472	493	493	509	530
	"U"	0.130	0.098	0.078	0.120	0.097	0.071	0.110	0.087	0.071	0.110	0.086	0.070

[a] FLEXIBLE INSULATION COSTS ASSUMED AT $45, $60, AND $80 PER 1000 SQ. FT. FOR 1", 2" AND 3 5/8" THICKNESSES RESPECTIVELY.

TABLE XV

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH STUCCO AS EXTERIOR FINISH (INSULATION BETWEEN STUDS)

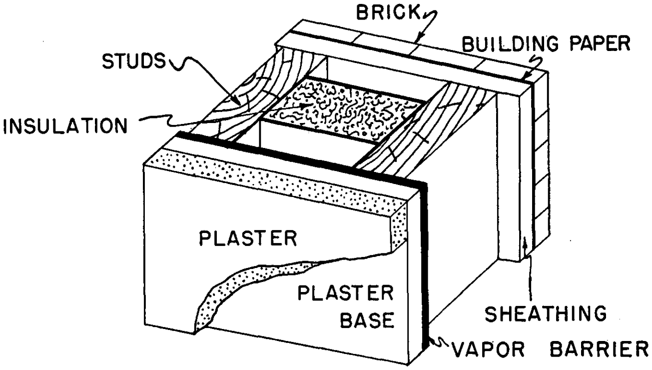


TYPE OF SHEATHING		INTERIOR FINISH AND INSULATION											
		PLASTER ON $\frac{3}{8}$" PLASTERBOARD			PLASTER ON METAL LATH			PLASTER ON $\frac{1}{2}$" RIGID INSULATION			$\frac{1}{2}$" DECORATIVE INSULATION		
		1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	$3\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	$3\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	$3\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	$3\frac{5}{8}$" FLEXIBLE INSULATION BETWEEN STUDS.
1" WOOD	$/THOUS. SQ. FT.	518	534	555	533	549	570	529	545	566	567	583	604
	"U"	0.140	0.099	0.079	0.130	0.099	0.076	0.120	0.088	0.072	0.120	0.088	0.072
$\frac{25}{32}$" RIGID INSULATION	$/THOUS. SQ. FT.	521	537	558	536	552	573	532	548	569	570	586	607
	"U"	0.110	0.087	0.071	0.110	0.087	0.071	0.100	0.078	0.065	0.100	0.078	0.071
$\frac{1}{2}$" PLASTER-BOARD	$/THOUS. SQ. FT.	502	518	539	517	533	554	513	529	550	551	567	588
	"U"	0.150	0.110	0.083	0.140	0.110	0.081	0.120	0.093	0.075	0.130	0.093	0.075

[a] FLEXIBLE INSULATION COSTS ASSUMED AT $45, $60, AND $80 PER 1000 SQ. FT. FOR 1", 2" AND $3\frac{5}{8}$" THICKNESSES RESPECTIVELY.

TABLE XVI

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR WALLS WITH BRICK VENEER AS EXTERIOR FINISH (INSULATION BETWEEN STUDS).

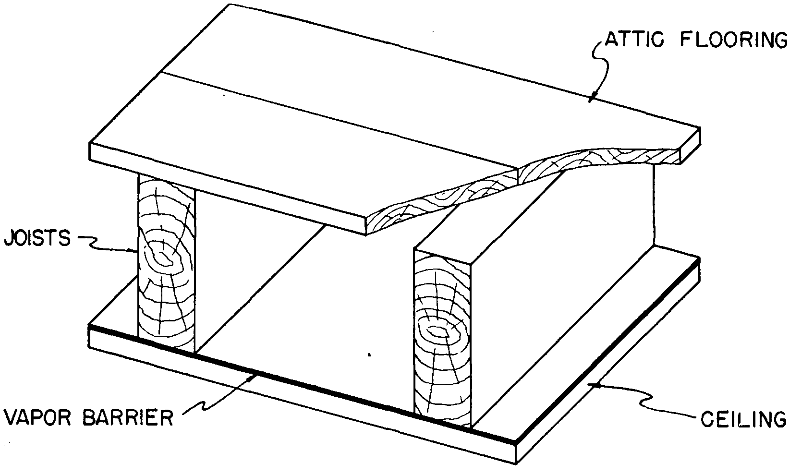


TYPE OF SHEATHING		INTERIOR FINISH AND INSULATION											
		PLASTER ON 3/8" PLASTERBOARD			PLASTER ON METAL LATH			PLASTER ON 1/2" RIGID INSULATION			1/2" DECORATIVE INSULATION		
		1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.	1" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	2" FLEXIBLE INSULATION BETWEEN STUDS. 2 AIR SPACES.	3 5/8" FLEXIBLE INSULATION BETWEEN STUDS.
1" WOOD	$/THOUS. SQ. FT.	753	769	790	768	784	805	764	780	801	802	818	839
	"U"	0.130	0.094	0.075	0.120	0.095	0.074	0.110	0.083	0.069	0.110	0.085	0.070
25/32" RIGID INSULATION	$/THOUS. SQ. FT.	756	772	793	771	787	808	767	783	804	805	821	842
	"U"	0.110	0.083	0.068	0.110	0.084	0.068	0.094	0.075	0.063	0.095	0.076	0.063
1/2" PLASTER-BOARD	$/THOUS. SQ. FT.	737	753	774	752	768	789	748	764	785	786	802	823
	"U"	0.140	0.100	0.080	0.140	0.100	0.079	0.12	0.088	0.072	0.120	0.089	0.073

a FLEXIBLE INSULATION COSTS ASSUMED AT $45, $60, AND $80 PER 1000 SQ. FT. FOR 1", 2" AND 3 5/8" THICKNESSES RESPECTIVELY.

TABLE XVII

CONSTRUCTION COSTS AND OVERALL HEAT TRANSMISSION COEFFICIENTS FOR CEILING CONSTRUCTIONS



TYPE OF CEILING	INSULATION[a] BETWEEN JOISTS	TYPE OF FLOORING			
		NO FLOORING		1" YELLOW PINE	
		"U"	$/THOUS. SQ. FT.	"U"	$/THOUS. SQ. FT.
WOOD LATH AND PLASTER	NONE	0.62	142	0.28	197
	1" FLEXIBLE[b]	0.16	210	0.13	265
	2" FLEXIBLE[b]	0.10	226	0.086	281
	3⅝" FLEXIBLE[c]	0.079	239	0.069	293
METAL LATH AND PLASTER	NONE	0.69	182	0.30	237
	1" FLEXIBLE[b]	0.17	224	0.13	306
	2" FLEXIBLE[b]	0.10	266	0.086	321
	3⅝" FLEXIBLE[c]	0.079	279	0.068	333
⅜" PLASTERBOARD AND PLASTER	NONE	0.61	168	0.28	222
	1" FLEXIBLE[b]	0.17	236	0.13	290
	2" FLEXIBLE[b]	0.10	252	0.086	306
	3⅝" FLEXIBLE[c]	0.079	264	0.069	318
½" RIGID INSULATION LATH AND PLASTER	NONE	0.35	179	0.21	233
	1" FLEXIBLE[b]	0.14	247	0.11	301
	2" FLEXIBLE[b]	0.091	262	0.078	317
	3⅝" FLEXIBLE[c]	0.072	275	0.064	329
½" DECORATIVE INSULATION BOARD	NONE	0.37	167	0.27	221
	1" FLEXIBLE[b]	0.14	235	0.11	289
	2" FLEXIBLE[b]	0.092	251	0.078	305
	3⅝" FLEXIBLE[c]	0.072	263	0.064	318

[a] FLEXIBLE INSULATION COSTS ASSUMED AT $45, $60, AND $80 PER 1000 SQ. FT FOR 1", 2" AND 3⅝" THICKNESSES RESPECTIVELY

[b] BASED ON ONE AIR SPACE WITHOUT FLOORING AND TWO AIR SPACES WITH FLOORING.

[c] BASED ON NO AIR SPACE WITHOUT FLOORING AND ONE AIR SPACE WITH FLOORING.

CONDENSATION OF MOISTURE WITHIN BUILDING STRUCTURES

THEORY OF CONDENSATION

In recent years the subject of moisture accumulation within building structures has attracted considerable attention from the general public. With the more recent types of building construction much attention has been concentrated upon proper insulation and weatherstripping, and many of the latest heating installations incorporate artificial humidification. As a result, higher humidities are being maintained inside structures, less heat is being lost through the walls, and there is less movement of the air from the outside to the inside. Under extreme climatic conditions, these factors, in turn, tend to promote condensation on the window surfaces and within the walls. However, no one factor is solely responsible for the existence of condensation within walls, and it is possible to arrive at satisfactory solutions to the problem without sacrificing either insulation, weatherstripping, or humidification.

To understand thoroughly the problems of building condensation it is first necessary to have a clear understanding of the mechanics involved. Under ordinary conditions condensation is found on the inside surfaces of windows, doors, or the interior construction of walls, and under extreme conditions on the interior surfaces of walls. Probably one of the most harmful forms of condensation, principally because it is not apparent, is that which takes place within the walls themselves, such as on the inside surfaces of the sheathing. This type of condensation is sometimes termed interstitial or structural condensation because of its location. Structural condensation may also appear in attic spaces beneath the roof boards and sometimes below the flooring where attic flooring is used.

The extent to which condensation takes place is dependent upon many factors, the more important being:

1. *The temperature drop across the wall.* This is dependent upon the inside and the outside air temperatures.

2. *The vapor pressure drop across the wall.* This is dependent upon both the inside and outside air temperatures and the inside and outside relative humidities.

3. *The resistance of the wall or ceiling construction to the passage of vapor or moisture.* This is dependent upon the materials used in construction.

For a constant outdoor and indoor air temperature, the temperature gradient across a wall is dependent upon the insulating properties of the materials used in the construction of the wall. For example, a wall consisting of ⅜-inch plaster and wood lath, 2x4-inch studs, wood sheathing, building paper and siding, and without any insulation in the air space will transmit approximately three and one-half times as much heat as a similar wall in which the stud space is filled with an efficient type of insulation. For an outdoor temperature of —10° F. and an inside temperature of 70° F. the inside surface temperature of the sheathing for the uninsulated wall would be 35° F. as compared with 4° F. at the same location for the insulated wall. It is apparent that it will be easier to condense moisture on the cold sheathing surface of the insulated wall than it will on the comparatively warm sheathing surface of the noninsulated wall.

The quantity of moisture which exists in air at a certain temperature and pressure is usually termed the relative humidity. For a definite temperature saturated air can hold a specific quantity of moisture, and the addition of any more moisture beyond this point will cause condensation in the form of water. Under these conditions of maximum moisture content the air has a relative humidity of 100 per cent and is termed "saturated." If the air were 50 per cent saturated, the relative humidity would be 50 per cent, indicating that the air contained only 50 per cent of the moisture it could hold if it were saturated. The higher the temperature of the air, the greater the quantity of moisture required before saturation is reached. For example, air at 70° F. can hold 110 grains of moisture at saturation. (7,000 grains = one pound.)

Illustrative of the conditions under which condensation can occur, consider air which is 50 per cent saturated and at a dry bulb temperature of 70° F. This air may be changed to the saturated condition by lowering the temperature to 51° F. At this new temperature, the same amount of moisture which resulted in a 50 per cent relative humidity at the higher temperature now is sufficient to give a 100 per cent relative humidity. As any further cooling of the air below this temperature of 51° F. will cause condensation of moisture, this 51° F. temperature is termed the dew point temperature of the air. Thus, if a glass of water at a temperature of 51° F. is placed in this air, condensation will take place on the outside surface of the glass. A similar action takes place within building walls when moisture in the form of vapor diffuses through the walls from the inside of the structure and strikes any cold surfaces which are below the dew point temperature.

Water vapor associated with the air is moisture in a gaseous state and is invisible when below 100 per cent relative humidity. If the relative humidity rises to a maximum of 100 per cent, any additional moisture condenses out of the air in the form of a mist or fog. The water vapor associated with the air may be classified as a gas and as such exerts a definite pressure which depends upon the amount or concentration of the vapor and the temperature. The water vapor exerts its pressure independent of any pressure of the associated air and tends to diffuse from one point to another if there is a difference in vapor pressures between two such points. The vapor will tend to diffuse from the high pressure area to the low pressure area until equilibrium has been established, and the rate of the diffusion will be dependent upon the difference in vapor pressures and the resistance of the materials in its path. This action is similar to that of a gas confined under a pressure greater than atmospheric, such as air in an automobile tire. If the valve is open, the gas will diffuse until the pressure within the tire is equal to the pressure on the outside. In this case, the valve is the resistance set up between the two pressures and is similar to the resistance to the transmission of vapor set up by a wall section.

For most conditions existing within building structures during the winter months the vapor pressure within the heated space is considerably greater than that of the outdoor air. Therefore, the vapor will tend to move from the indoor air toward the outdoor air at a rate which depends upon the resistance of the intervening materials. If the material on the warm side of the wall has a very low resistance to vapor transmission and the materials on the outside of the wall have a high resistance to vapor transmission, the vapor will tend to flow from the inside air to the inner surfaces of the outside portion of the wall at a greater rate than it will be transmitted through the outside wall sections. Under such conditions, and with the surface temperature of the sheathing lower than the dew point temperature of the inside air, condensation will tend to occur at the sheathing. However, if the resistance of the inner section of the wall is greater than the resistance of the outer section of the wall, the vapor will then be retarded at the inner wall section and, therefore, will not allow a building up of the moisture within the wall. This will prevent the formation of any condensation in the interior of the wall and thereby eliminate the condensation difficulty. A more rapid drop in temperatures occurs through an insulated wall than through a noninsulated wall, and for this reason a lower dew point temperature is reached more readily in an insulated wall. Therefore, the possibilities of condensation are much greater for an insulated wall than for a noninsulated wall unless some type of vapor barrier is used on the interior construction.

PREVENTION OF CONDENSATION BY CONTROL OF HUMIDITY

The prevention of moisture condensation within walls and attic spaces and upon windows may be accomplished by several methods dependent upon the type of construction. The methods to be used may be outlined briefly as follows:

1. Control of the relative humidity of the inside air.
2. Application of a vapor barrier directly beneath the plaster of all outside exposed walls and ceilings. (To be used in new construction.)
3. Treatment of the inside surface of the plaster of all outside exposed walls and ceilings. (To be used in completed construction where vapor barrier has been omitted.)
4. Installation of louvres in attic spaces to provide adequate ventilation for the removal of moisture from such areas. (To be used in all completed construction where insulation has been applied to the attic floor and no vapor barrier has been installed.)

The simplest method of controlling condensation within walls and attic spaces and on the surfaces of windows is to reduce the humidity within the structure itself. If the relative humidity of the inside air has been raised through use of artificial humidification such as is commonly provided in forced air heating systems and warm air gravity plants, the relative humidity may be controlled by simply adjusting the humidity controller or humidistat to the desired level. However, in some cases the humidity may be greater than desired because of uncontrolled humidity sources such as cooking, laundry, excessive baths, etc. If the family laundry is done in the home, during the winter the clothes are usually hung in the basement to dry and during the drying process large quantities of water will be evaporated into the air and will diffuse to other parts of the structure. Another common source of moisture is damp basement walls and floors brought about by moisture travel through these areas from the outside. Such factors tend to give rise to condensation difficulties in the upper part of the structure by raising the humidity of the inside air. If a structure is tightly constructed and well weatherstripped, this moisture will build up in concentration and result in condensation even though no artificial humidification is provided.

If certain precautions are taken, it is possible to reduce the effects of uncontrolled humidity sources to a minimum. For example, when laundry is dried in the basement, it is recommended that a basement window be opened slightly in order to allow the greater part of this moisture to escape directly to the outside air. Slightly opened windows will also reduce the moisture effects of cooking and bathing. With respect to basement walls proper drainage should be provided around the structure so that the excessive surface water may drain off freely during the fall and the early winter months. If this is not done, the concrete blocks of the foundation, having considerable moisture storage capacity, may tend to absorb and give off this moisture to the basement areas during the winter.

From the standpoint of fuel conservation, it has been found advantageous in modern construction to reduce the air leakage around the cracks of doors and windows to a minmum by the use of weatherstripping. This results in a minimum quantity of outdoor air passing through these openings and during the winter months, when condensation is most apt to occur, the outside air is relatively dry in comparison with the inside air. In a well weatherstripped structure where air leakage has thus been reduced to a minmium, it is difficult for the vapor to escape from the structure and to be replaced by relatively dry outside air and this in turn tends toward the maintenance of higher inside relative humidities. When the relative humidity of a well-weatherstripped and well-constructed building cannot be reduced below the point of condensation by any other means, it is sometimes necessary to provide some type of ventilation such as the opening of windows or of a fireplace damper. Although this is contrary to good heat conservation practice, it sometimes may be necessary and desirable to prevent damage to the structure. Where this is the case, it is recommended that a centrally located window or a fireplace damper be opened partially during the night hours when the thermostat is at a lower setting. This will tend to obtain the maximum quantity of ventilation with a minimum of heat loss and eliminate undue drafts during the daytime hours.

The maximum inside relative humidity which may be maintained with different inside air temperatures in combination with different outside air temperatures without danger of excessive condensation within a frame wall, insulated with 3⅝ inches of mineral wool and with the vapor barrier omitted, is shown in Figure 21. This figure is based upon tests made at the University of Minnesota[6] and illustrates the relationship between outside air temperature, inside air temperature, and relative humidity. For example, at —20° F. outdoor air temperature and 70° F. inside air temperature, the maximum

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[6] F. B. Rowley, C. E. Lund, and A. B. Algren. *Condensation of Moisture and Its Relation to Building Construction and Operation.* University of Minnesota Engineering Experiment Station. Bulletin No. 18, September, 1941.

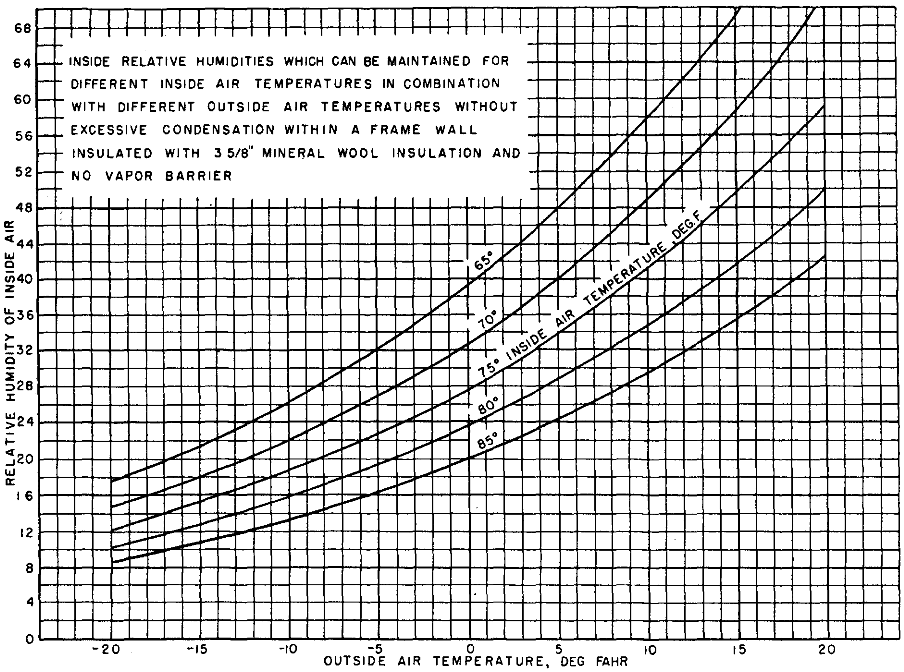

FIGURE 21. LIMITING RELATIVE HUMIDITIES WHICH CAN BE MAINTAINED WITHOUT EXCESSIVE WALL CONDENSATION (WALLS FULLY INSULATED BUT WITH NO VAPOR BARRIER)

relative humidity that may be maintained without excessive condensation is 15 per cent. When the outdoor air temperature is raised to 5° F. and the inside temperature is maintained the same, the interior relative humidity may be 40 per cent without excessive condensation. These figures are based upon a plain wall with the stud space filled with insulation. However, if less insulation is used, somewhat higher relative humidities may be maintained without encountering condensation.

The accumulation of moisture on the inside surfaces of windows during extreme cold weather is caused by the maintenance of excessive humidities within the structure. Such condensation in the form of frost or free moisture will tend to damage the window frames and the woodwork around the windows together with the decorations below the window sills. Such condensation is similar in principle to that occuring in walls, as in either case the surfaces are lowered below the dew point temperatures corresponding to the moisture content of the surrounding air.

Window condensation may be reduced either by raising the surface temperature of the glass or by reducing the relative humidity of the inside air. The temperature of the glass may be increased best by the application of storm windows, as such application will not only aid in the prevention of condensation but also tend to reduce materially the heat loss through the windows.

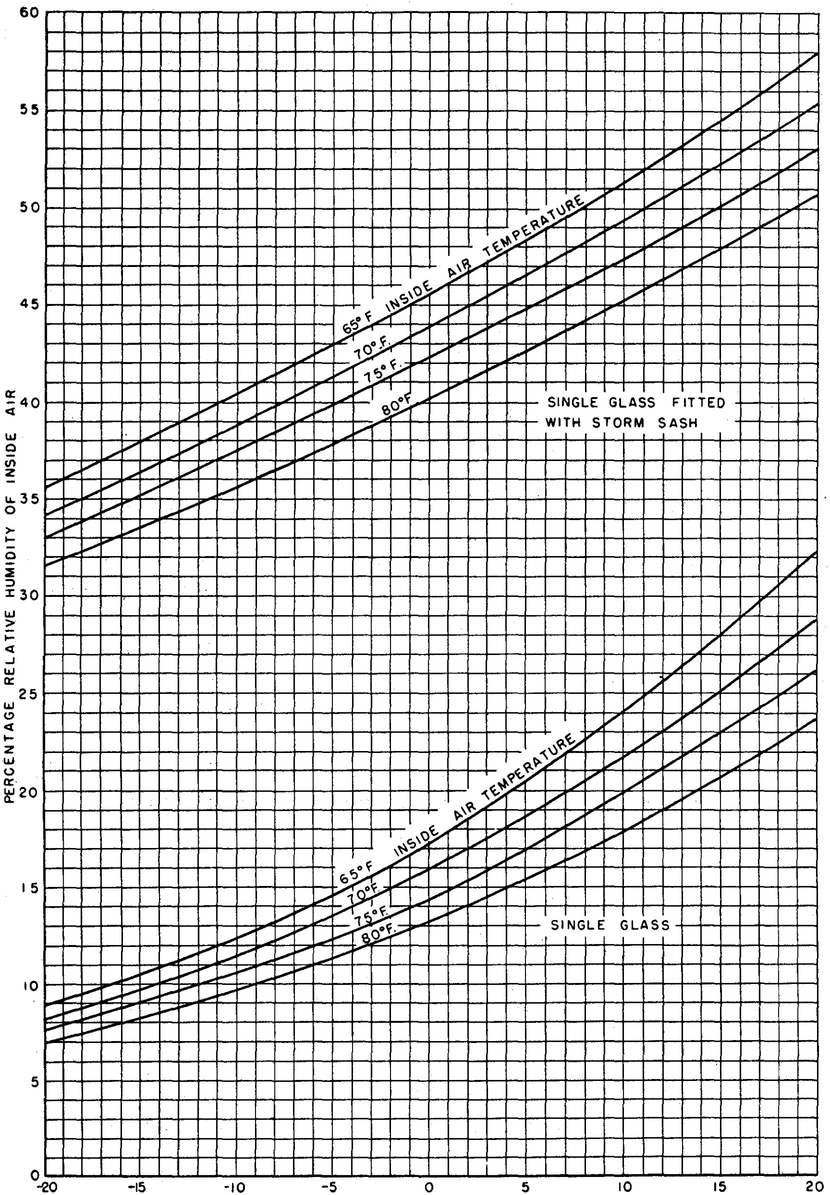

FIGURE 22. LIMITING RELATIVE HUMIDITIES WHICH CAN BE MAINTAINED WITHOUT EXCESSIVE CONDENSATION ON WINDOW SURFACES

For a constant inside air temperature and relative humidity, the possibility of moisture accumulating on the inside surface of the windows is increased as the outside temperature is lowered. Figure 22 indicates the maximum relative humidity which may be maintained for different outdoor air temperatures both for windows with and without storm sash. If the humidities indicated in this figure are exceeded, excessive condensation on the inside surface of the glass may be expected.

PREVENTION OF WALL AND ATTIC CONDENSATION BY USE OF VAPOR BARRIERS

With new construction, the simplest method of perventing condensation is to apply a vapor barrier in all outside exposed walls and ceilings. This vapor barrier should be located on the inside surface of the studs prior to the application of the inside surface materials unless these include a vapor barrier in their fabrication. In the case of attic spaces the vapor barrier should be applied to the warm side of the ceiling joists prior to the application of the plaster base.

There are many types of barriers available on the market which may be applied separately or as an integral part of the insulation. Many of the batt or blanket insulations have a barrier attached. Whether the vapor barrier is separate or a part of the insulation, precautions should be taken that all joints are well sealed over studs and joists, over the top and bottom stud plates, around electrical outlets, and around any other miscellaneous openings through which vapor may escape to the interior of the wall. To provide the maximum vapor seal at the least expense all vapor barriers should be lapped over the studs or joists.

As a guide to the selection of a proper type of vapor barrier, the following general specifications have been found to meet the requirements for a good protection against condensation within walls or ceilings:

1. An asphalt saturated paper with surface glazed to produce a continuous seal. This may be obtained in rolls of 500 square feet and in weights of 30, 40, or 50 pounds per roll.
2. A 30-30-30 duplex paper consisting of two layers 30-pound kraft paper with a layer of asphalt between the sheets. This type of paper comes in many different weights ranging from light to heavy, and the weight to be selected depends upon the durability desired in handling during installation. Only small differences have been found in the vapor sealing properties of the papers for the different weights.
3. Kraft paper with one side coated with a continuous surface of glazed asphalt. This type of vapor barrier is usually found applied as an integral part of a batt or blanket type insulation and, in general, has been found to be satisfactory.
4. Paper manufactured with a continous uniform coating of paraffin over the surface.

In addition, there are several types of papers other than those enumerated above which have been found to be satisfactory as vapor barriers. In general, a paper having a continuous coating of asphalt on at least one surface or laminated between two sheets has been found to be satisfactory as a vapor barrier. It has been found that the cost of vapor barriers and the expense of installation is a negligible factor as compared with the total cost of construction and that they will yield great dividends in furnishing protection against wall or ceiling damage through condensation.

PREVENTION OF WALL AND ATTIC CONDENSATION BY USE OF VAPOR RETARDANT SURFACE COATINGS

In constructions where the walls have been insulated but no vapor barriers have been installed it is impractical to place a vapor barrier such as described in the previous section beneath the plaster. In such cases the simplest method of preventing condensation difficulties is to control the relative humidity of the inside air. Under certain circumstances this is both difficult and undesirable, and it is then necessary to provide some form of barrier to the inside surfaces of the exposed walls and ceilings. Such a barrier may be in the form of a paint or of some other type of wall covering which has a high resistance to the passage of moisture and which may be applied directly to the finished walls or ceilings. Both ordinary wall paper and plain plaster have very little resistance to vapor travel and are not considered satisfactory as vapor barriers. Neither do cold water glue sizes such as used in sizing plaster walls before papering, cold water paints, or casein paints provide effective barriers. However, there are some paints on the market which have a high resistance to moisture travel and which may be applied to the inside surface of the plaster. These are usually obtainable as primers for plaster surfaces. A typical composition of this type of paint consists of 40 per cent pigment and 60 per cent vehicle, with the pigment composition 100 per cent titanium calcium. The vehicle composition is 16.7 per cent resin, 28.8 per cent vegetable oil, and 54.5 per cent dryer and thinner. It is recommended that two coats of such paint be used to obtain a uniform seal over the entire surface. These may then be followed by final coats of any paint desired for interior decoration. In addition to paints there are several types of wall coverings on the market which are very good barriers. Some surface-treated canvas wall coverings such as are frequently used on kitchen and bathroom walls serve as satisfactory vapor barriers.

PREVENTION OF ATTIC CONDENSATION

The addition of insulation to a top floor ceiling causes a very low temperature within the attic space and reduces the surface temperatures of the roof and floor boards. Where no vapor barrier has been installed in the ceiling and condensation in the attic occurs, it is possible to reduce or entirely eliminate such moisture difficulties by the addition of attic ventilation. The ventilation of attic spaces in structures where the top floor ceiling has been insulated does not materially increase the heat loss of the structure. All openings, such as doors leading into the attic, should be well sealed either by weatherstripping or by providing some type of gasket around these openings in order to prevent any excessive moisture movement into the attic space. For low roofs such as used over apartments and flat roof structures, roof ventilators uniformly spaced, together with side wall openings are recommended whenever no flooring is used over the joists. However, the use of roof ventilators alone will tend to aggravate the condition and is not recommended unless used in combination with side wall openings. In all cases it is important to obtain cross ventilation through the attic so that all portions of the attic may be freed of moisture. These openings should be of the same size and should be so proportioned as to allow ¼ square inch per square foot of ceiling area.

SUMMARY OF METHODS FOR THE PREVENTION OF CONDENSATION

Several methods have been outlined by which excessive condensation within walls and attics may be eliminated. These may be summarized as follows:

1. The maintenance of reasonably low inside relative humidities either by the proper control of artificial humidification, or by ventilation of the structure when it is well sealed and weatherstripped and the excessive humidity is caused by the presence of uncontrolled sources of moisture.
2. The provision of a good type of vapor barrier underneath the plaster base for all outside exposed wall and ceiling areas in buildings at the time of construction.
3. The application of an interior surface finish in the form of a paint or special wall covering to the inside surfaces of all outside walls and ceilings. This is for constructions already completed but in which the vapor barrier has been omitted.
4. The provision of adequate cross ventilation in attics where condensation difficulties are likely to be experienced. Where attic flooring is used, the barrier may be applied in the form of a paint or a wall covering to the interior surface of the ceiling. A vapor barrier applied between the joists and the plaster base may also be used.

SUMMARY OF FUEL CONSERVATION METHODS

INSULATION OF WALLS AND CEILINGS

1. Application of insulation to the ceiling of the top floor will save from 10 to 20 per cent of the yearly fuel costs.
2. Application of insulation to walls of a residence will save from 10 to 20 per cent of the yearly fuel cost.
3. Application of insulation to walls and top floor ceilings will result in an increase in the inside wall and ceiling surface temperatures. This will result in increased comfort and decreased fuel costs.

STORM WINDOWS AND STORM DOORS

4. Application of storm windows and storm doors will result in a fuel saving of 10 to 25 per cent.
5. Application of storm windows will raise the inside window surface temperature and thus result in increased comfort and increased fuel savings.
6. Application of storm windows will permit the maintenance of higher relative humidities inside the structure without condensation of moisture and formation of frost on window surfaces.

AIR LEAKAGE

7. The installation of weatherstripping to doors and windows will result in fuel savings of 5 to 10 per cent.
8. All windows and doors should be kept closed except to maintain a minimum of ventilation.
9. If heat is reduced or shut off entirely from bedrooms, storage rooms, etc., door cracks leading to these rooms should be plugged in order to prevent drafts of cold air from entering the remainder of the house.

10. All fireplace dampers should be tight fitting and maintained closed during the heating season except when in use.

11. All doors leading from heated portions of the house to unheated attic spaces should be well sealed to prevent leakage of cold air.

12. Over a period of years there may be a separation of the window and door frames from the exterior building materials because of continual expansion and contraction of these frames and materials when subjected to varying temperatures. Air leakage through such cracks may be largely eliminated by filling or, as it is commonly termed, "calking" these cracks and crevices.

13. Air leakage through cracks between the upper and lower sashes of a window may be eliminated by the application of a piece of cellulose tape to joints.

14. The air leakage into basement areas should be reduced to a minimum so that the heat escaping from the heating plant is put to good usage in eliminating cold floors above the basement. All broken basement windows should be repaired and all cracks should be well calked.

STEAM AND HOT WATER HEATING SYSTEMS

15. For highest efficiency all steam and hot water piping should be quickly freed of air during operation and completely filled with steam or hot water.

16. Any steam or hot water pipes which are not actually used to aid in heating rooms should be well insulated.

17. Any radiators which are not in use either should be covered or the lines leading to them should be disconnected. (See page 28.)

18. Any objects which shield radiators such as drapes and curtains, magazines, cabinets, etc., should be removed in order to obtain the maximum output from the radiators.

19. Any collection of dirt between the sections of fins or radiators of convectors should be removed to obtain maximum radiator efficiency.

20. For maximum efficiency, radiators should not be covered with a coating of bronze or aluminum paint. The radiator efficiency may be improved as much as 10 per cent by the application of ordinary oil paints, preferably of a dark color.

21. Some fuel saving may result and some increase in radiator efficiency may be experienced if a surface of high reflectivity is placed behind each radiator. Much of the heat which normally would be absorbed by the surface of the wall back of the radiator would then be reflected into the room.

22. If a forced circulation hot water heating system is used, the motor bearings of the water pump should be oiled at least once each season.

23. Any insulation missing from the boiler covering should be replaced to reduce the loss of heat from the boiler to the basement.

24. All flue surfaces should be cleaned annually, preferably with wire brushes and a vacuum cleaner. Collections of soot on the flue surfaces may reduce the efficiency of the heating plant as much as 5 per cent.

WARM-AIR HEATING SYSTEMS

25. The air filters of a forced air heating system should be either cleaned or replaced at least once each year or oftener if necessary.

26. With both gravity and forced air heating systems all the joints in both the supply and return air ducts should be sealed with strips of asbestos or made tight in some other approved fashion. However, the entire duct work should not be covered with a layer of asbestos paper as the change in color and nature of the surface when covered with paper will increase instead of decrease the loss of heat from the ducts.

27. All supply and return air registers and grills in both gravity warm air and forced air heating systems should be open and unobstructed. In no case should furniture, rugs, or other articles be allowed to prevent the free flow of air through these openings.

28. With a forced air heating system, additional heat is required if outdoor ventilation air is taken into the unit and distributed throughout the house. The most economical operation of the heating plant will be obtained when the introduction of outdoor air is entirely eliminated and all air passing through the heating unit is 100 per cent recirculated from the room.

29. In gravity warm air heating systems all return air ducts should be insulated from any high temperature source of heat. If this is not done, the air returning to the furnace will be heated before reaching the furnace and this will reduce the ability of the system to circulate air by gravity.

30. If a cast iron furnace is used in conjunction with a gravity warm air heating system, the joints between the castings of the furnace should be reset and recemented every three or four years by a reputable heating contractor.

31. The motor and blower bearings of a forced air heating system should be oiled at least once each heating season.

32. The flues and heating surfaces of any air heating system should be cleaned of all soot periodically to maintain highest efficiency. A deposit of soot on such heating surfaces may reduce the overall efficiency of the heating plant as much as 5 per cent.

DOMESTIC HOT WATER

33. A hot water storage tank should be thoroughly insulated to reduce the loss of heat from the hot water in the tank to the surrounding air.

34. All leaky hot water faucets should be repaired to eliminate this waste of both water and heat.

35. If it is found necessary to allow water to run during cold weather to prevent freezing of piping, this defect in the piping system should be repaired. The application of insulation at the correct points will usually eliminate the necessity of running the water.

36. The amount of fuel required for heating domestic hot water may be reduced by heating only during morning and evening hours and never heating water above a temperature of 140° F.

MAINTENANCE OF CORRECT TEMPERATURE WITHIN THE HEATED STRUCTURE

37. Appreciable savings in fuel may be effected by the maintenance of the lowest practical temperatures within the heated structure. (See page 26.) It is usually possible to maintain much lower temperatures during the night-time hours than during the day-time hours to effect even further savings. (See page 27.)

38. Reduce or turn off completely all heat supplied to unoccupied spaces. If there is any danger of damage by freezing in such cases, maintain the temperature slightly above freezing at all times. In the case of radiators in unoccupied spaces, the simplest means of shutting them off without causing damage to the radiators or the piping is to cover them. (See page 28.)

39. If a structure is to be unoccupied for several days, the temperature may be reduced to 45° or 50° F. It should be kept in mind that if the temperature is reduced much lower than this, there may be some damage by freezing of pipes in walls or of plumbing because the temperatures to which such pipes are exposed would be somewhere between the indoor temperature and the outdoor temperature.

40. Install thermostatic control, if possible, to prevent overheating and a consequent waste of fuel.

COMBUSTION EFFICIENCY

41. If automatic fuel is being used in the heating installation, the percentage of carbon dioxide in the flue gases (see page 20) should be checked by a reputable heating contractor in order to ascertain whether the fuel is being fired with maximum efficiency. In addition, the chimney draft and the stack temperature should also be checked. For best results, all of these determinations should be made by instruments as it is virtually impossible to determine the correct setting for firing a fuel by any other means.

42. All heating installations firing automatic fuel should be equipped with automatic draft regulators in the stack for maximum efficiency. Without such a device it is impossible to set any installation for maximum efficiency under all conditions as the stack draft will vary considerably with changes in outdoor temperature and wind velocity.

43. The fuel input to an automatic heating installation should be adjusted to the lowest practical value which will satisfy the heating requirements during the coldest weather conditions. (See page 20.)

44. If the heating surface of a boiler or furnace is insufficient to satisfy the maximum heating requirements and still maintain reasonable efficiency, it may be possible to increase the heating efficiency of the installation by the use of a fuel-saver. (See page 24.)

45. If hand-firing of coal is used in the heating installation, care should be taken that the methods of firing are those which will result in a minimum waste of fuel. (See page 25.)

GENERAL

46. A minimum loss of heat through windows will result if all shades and drapes are fully drawn during the evening and night hours and if the shades are half drawn during the day hours. Drawing of shades and curtains will not only result in a reduction in heat loss through the windows but will also raise the average surface temperature of the room and thus result in a greater feeling of warmth to the occupants for the same temperature conditions within the room. (See page 33.)

47. A considerable saving of fuel may result if all windows are kept closed during the night hours. From the standpoint of actual ventilation requirements, there is sufficient leakage of air from the outside of the house to the inside of the house to take care of any needs from a health standpoint. The necessity of opening windows in bedrooms during night hours is principally psychological. The only time when opening of windows in a residence during winter months is truly justified is for the elimination of odors.

48. Some rooms which are heated during normal times and which have very high heat losses may have the heat cut off for the duration of the war without any undue discomfort. For example, heated garages are a luxury, as the amount of fuel required to heat the average garage, even when attached to the house, is great in comparison with the advantages gained. Sunrooms are also usually very difficult to heat because of the excessive glass areas. The heat supplied to such rooms may often be entirely disconnected or greatly reduced without any undue discomfort. (See page 28.)

APPENDIX

DEFINITIONS

Comfort line: The effective temperature at which the largest percentage of adults feels comfortable.

Comfort zone: The range of effective temperatures between 30 and 70 per cent relative humidities over which 50 per cent or more of adults in normal health feel comfortable.

Conduction: The transmission of heat through solid material objects unaccompanied by any obvious motion of the matter constituting the object.

Convection: The transmission of heat by the circulation of a liquid or a gas. The circulation of the liquid or gas may originate from either forced or natural means.

Degree-day: A degree-day is a unit used in specifying the nominal heating load in winter and is based upon time and temperature difference. For any one 24-hour period, there are as many degree-days as there are degrees difference in temperature between a base temperature of 65° F. and the average outdoor temperature.

Design heat loss of a structure: The amount of heat, expressed in Btu per hour, required to maintain a structure up to the desired indoor conditions under the most rigid outdoor conditions to which the structure will be subjected for any appreciable length of time.

Dew point temperature: The temperature corresponding to saturation (100 per cent relative humidity for any given moisture content). This is the temperature at which condensation of moisture starts when a mixture of air and water vapor is lowered in temperature.

Dry bulb temperature: The temperature indicated on a standard thermometer not affected by the water vapor content or relative humidity of the air, or by the temperature of any surrounding objects which may be different from that of the air.

Effective temperature: An arbitrary index of the degree of warmth experienced by persons in response to the factors of dry bulb temperature, relative humidity, and air movement.

Heating value of fuel: The amount of heat available in the fuel expressed in Btu per unit weight or volume of fuel. In the case of coal, this is expressed in Btu per pound; in the case of oil, Btu per gallon; and in the case of gas, Btu per cubic foot.

Overall coefficient of heat transmission
or
Thermal transmittance ("U"): The amount of heat transmitted across a wall, floor, roof, or ceiling expressed in Btu per hour for each square foot of area and for each degree temperature difference between the air on the inside and that on the outside.

Radiation: The transmission of heat through space by means of wave motion. Such radiant heat transfer is similar to and closely allied with the transmission of visible light, radio waves, or X rays by wave motion.

Relative humidity: Relative humidity is a ratio, usually expressed in per cent, used to indicate the degree of saturation existing in any given space resulting from the water vapor present in that space. Theoretically, it is usually defined as the ratio of the actual partial pressure of the water vapor associated with the air to the saturation pressure at the same dry bulb temperature.

Wet bulb temperature: The lowest temperature which a water-wetted thermometer bulb will attain when exposed to an air current. Wetting of the bulb is usually attained by covering the bulb with a fine mesh fabric bag and moistening with pure water.

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