Electric and Other Types of House Heating Systems

By
LOUIS SLEGEL
Research Professor of Mechanical Engineering

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Electric and Other Types of House Heating Systems

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I. INTRODUCTION

1. **Purpose and scope of study.** Because of increasing interest in the use of electricity for domestic heating purposes, it is felt to be both timely and desirable to make a study of the various methods of, and systems for, home heating with special emphasis on electric heating methods and systems. This is particularly appropriate in a region such as the Pacific Northwest where electric energy is available at rates which are among the lowest in the nation.

The principal purpose of this bulletin is to discuss various domestic heating systems and methods of heating, pointing out the advantages and disadvantages of each system, and to call attention to some of the latest developments in domestic heating, particularly as related to heating with electricity.

In discussing these various heating methods, some mention must necessarily be made of fuels. It is not the purpose here to make a detailed study of the various fuels used for heating purposes. In order to furnish a basis of comparison, however, a number of fuels will be discussed; and their advantages and disadvantages compared with those of electric energy as a heat source.

2. **Acknowledgments.** This study has been made possible through a cooperative research grant from the Bonneville Power Administration and is the first of several publications that are contemplated covering a broad investigation of the utilization of electric energy for home heating. The author wishes to acknowledge his indebtedness to several individuals who cooperated in the preparation of this bulletin. Thanks are due H. G. Kelsey, formerly Manager of Public Utility District No. 1 of Cowlitz County, Washington, for his generous cooperation in furnishing data and information; to B. J. Sickler, Chief of Division of Power Sales and Service, of the Bonneville Power Administration for his review of the manuscript; to Professor S. H. Graf, Director of the Engineering Experiment Station, Oregon State College, for suggesting this bulletin, for his critical review of the copy, and his assistance in preparing the manuscript.

II. GENERAL REQUIREMENTS OF A HOUSE HEATING SYSTEM

1. **Body heat loss.** A great many people have the impression that when they heat a house they are furnishing heat to, or are heating, the occupants of the house. While the purpose of a house heating system is to keep the occupants warm, the system actually does not furnish heat to the occupants themselves. In fact, the process is just the reverse; that is, the occupants give up

heat to their surroundings. The heating system regulates the rate at which a person gives up this heat to his surroundings.

An adult person at rest and normally clothed will dissipate or give off to his surroundings about 400 Btu per hour, which is approximately equal to the rate at which energy is dissipated by a 100 watt lamp. A Btu is a British thermal unit and is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit, or to be exact, from 59 F to 60 F. This heat is generated by the metabolic processes of the human body, and the amount of the heat thus generated varies almost directly with the degree of activity of the body. For example, while a person at rest dissipates about 400 Btu per hour, a person bowling gives off about 1500 Btu per hour; and one walking upstairs gives off heat at the rate of about 4300 Btu per hour.

This body heat is given off or dissipated in three ways: by convection, by radiation, and by evaporation. The proportion dissipated by each method depends on the environment of the body. The temperature of the air and the degree of air movement are probably the principal factors affecting convected heat; the temperatures of the surroundings to which the body may radiate heat or from which it may receive radiated heat determine the amount of heat interchanged by radiation; and the temperature, the relative humidity, and the air movement determine the amount of heat loss by evaporation of body moisture.

So it becomes apparent that instead of actually warming the body, the function of the heating system should be to maintain the temperature of the surroundings such that the body will not feel too warm or too cold; in other words, the heating system should maintain "comfort" conditions. While we speak of the heating system maintaining these "comfort" conditions, it is, of course, often necessary that a cooling system be employed for this purpose.

2. **Comfort temperature.** Comfort temperature has already been mentioned above. Technically speaking, the term "comfort temperature" should probably not be used in just the way we use it here, as, technically, the term "effective temperature" is used to denote the factor which we term comfort temperature. Since the former term seems to have a little more meaning to the average person than does the other, we shall use the term "comfort temperature."

In any case, this is not a measurable quantity, but it is simply a scale or index which denotes sensory heat level, or the degree of comfort of the person or persons involved. There are a number of factors which determine or affect the comfort temperature. The temperature of the surrounding air, the relative humidity and movement of the air, and radiation effects are the principal factors which affect the sensation of warmth, or comfort conditions. All of these factors must be given consideration in any well-designed heating system although, of course, some factors are of more importance than others.

3. **Heat losses from a house.** There are two principal ways in which heat escapes from a house. One of these ways is by means of a combination of convection and conduction whereby heat passes through the walls, windows, roof, and floors of a house. The other way is by means of the warm air that leaks through the cracks and structural parts of a house, or the necessary heating of the cold air that leaks into a house or which comes in when doors or windows are open.

When the warm air in the house comes in contact with the outside walls, the ceilings, and the floors, the warm air raises the temperature of these surfaces. Thus heat is transferred from the warm air to these surfaces by convection. This heat tends to pass directly through the wall and out into the

air on the other side, assuming, of course, that the outside air is colder than the air in the house. The heat passing through the wall, floor, or any other part of a house in this way does so by conduction. That is, the heat is conducted from one particle of the structure to the next particle until it reaches the outside surface. It then is transferred from the outside surface to the outside air by convection, just as it was transferred from the inside air to the inside surface by convection.

The process by which cold air leaks or infiltrates into a house, or by which the warm air leaks out of a house is, of course, not at all complicated. The principal points of infiltration are cracks around loose-fitting windows and doors, through floor cracks, and even through cracks in the house siding, especially attic space siding where the inside walls are often unfinished. Nor is it necessary that cracks exist to have infiltration. If the wind is blowing hard enough, it can blow the outside air even through a brick wall, for example. But wherever there is infiltration, it means heat loss, because the cold air that infiltrates must be heated.

From the standpoint of health, this infiltration may not be undesirable. Even if a house were perfectly air tight, some fresh air would be required for considerations of both health and comfort. One of the common causes of trouble as far as infiltration is concerned is that there is often too much of it. More cold, fresh air leaks into the house than is necessary for good health, and this means that an excessive amount of cold air must be heated in order for the occupants to be comfortable. This is often the reason why many houses are "hard to heat."

On the other hand, during recent years particularly, the value and desirability of good insulating and weather-stripping have become increasingly apparent among home builders. In fact, weather-stripping in many cases has reached the point where infiltration losses have been reduced so far that insufficient air is admitted to the dwellings. This is particularly true in houses that have no ventilating systems and in which the heating systems are of a kind that do not draw outside air into the house. In most of these instances doors and windows are kept tightly closed and consequently provide very little admittance of fresh air to the house.

The occupants of houses in which all of these factors or conditions occur have noticed a definite feeling of stuffiness and stale air, particularly when more than the usual number of people are in the house.

In order to eliminate, or at least improve this condition, a number of builders are now modifying their specifications by eliminating all or a part of the weather-stripping. These modifications accomplish several things. First, they eliminate the expense of weather-stripping; second, they eliminate the necessity and expense of a fresh air ventilating system; and third, they permit the entrance of what is usually a sufficient amount of fresh air to the house. Thus two savings are made possible; the expense of weather-stripping and the cost of a fresh air ventilating system.

Naturally, there is some disadvantage that at least partly compensates for this decrease in costs. This disadvantage is the fact that the amount of air that infiltrates into the house cannot be controlled. Consequently, at times too much air infiltrates; and at other times, too little. In addition, dust and dirt, and possibly smoke and fumes, are admitted also.

Everything considered, this idea of eliminating weather-stripping may be false economy. But in those cases where insufficient air is admitted to the house, either the weather-stripping might be eliminated or a fresh air ventilating

system should be provided. Opening of doors or windows could be resorted to, with consequent lack of control of the amount of fresh air admitted, drafts of cold air, and resulting discomfort.

4. **How to decrease heat losses from a house.** There being only two principal means by which heat losses occur in a house, there are, of course, only these two means which need to be eliminated in order to make a house that has no heat losses. The elimination of heat loss, however, may be a complicated and expensive undertaking. In fact, to eliminate all heat losses from a house would be impossible, and even if it were possible, would cost more than it would be worth. Usually a compromise is made whereby the worst of the losses are eliminated and the smaller losses are allowed to occur.

Due to the high conductivity of glass, the windows of a house, especially if the window area is large, are often the means by which a great amount of heat escapes. There are several ways of reducing heat losses through windows. Probably the easiest, although possibly not the most satisfactory way, is to pull down the shades. When shades are pulled down for this purpose, they should be pulled all the way to the sill. Shades should not be pulled down, of course, over windows on which the sun is shining, because windows admit a great deal of the sun's heat, if the sun is shining on them, and this heat can be used to help heat the house. Shades should be pulled on the windows on which the sun is not shining and on all windows at night, if a reduction in heat loss by this means is desired.

Storm windows are effective not only in reducing the heat loss through the window glass, but they also reduce infiltration losses especially if the windows are well-fitted. Conduction losses through the glass are reduced by the adding of another thickness of glass and a layer of air between the permanent window and the storm window.

There are also several windows made commercially that have 2, 3, and even 4 thicknesses of glass mounted in a frame and hermetically sealed. While these windows are somewhat expensive, they are quite effective in reducing heat losses through the windows; and their cost will, in many cases, be justified by the resulting heating economy.

Infiltration losses can be reduced to some extent by the application of well-fitted storm windows, and to a large extent by a thorough job of weather-stripping on all windows and outside doors. There are many kinds of weather-stripping on the market today. Some are good and some are poor. Probably the best will prove to be the least expensive in the long run, as it will effectively reduce infiltration and will last for a number of years.

There is one other important means employed for reducing heat losses from dwellings and structures of all kinds; by far the most commonly employed, this method is the application of heat insulation. This subject is discussed in the following section.

5. **Insulations and vapor seals.** While this section will deal primarily with insulations, the subject of vapor seals is included because a well-designed insulation application should include a vapor seal. As a matter of fact, there are a number of insulations now on the market which include a vapor seal or vapor barrier as an integral part of the insulation.

Ordinarily during the heating season, the air on the inside of the house is warmer than that on the outside. Under these conditions, the pressure of the vapor, or the moisture in the air, is greater on the inside than it is on the outside. This greater vapor pressure on the inside tends to push the moisture in

the air through the walls of the house from the inside toward the outside. In cold weather the temperature gradient of an outside wall of a house slopes downward from the inside to the outside; that is, of course, the wall is warmer on the inside and gets colder toward the outside, the outside surface being the coldest part of the wall. Now as the moisture, which is being pushed through the wall by the vapor pressure, progresses through the wall it reaches a point in the walls where the temperature is low enough to cause condensation of this moisture which up to this point has been in the form of vapor. When this vapor condenses, very small drops of water are formed, and these water droplets adhere to the parts of the wall, or in case the wall is insulated, the drops are distributed throughout at least a part of the insulation.

Two things can now occur, both of which are undesirable. This moisture may remain in the insulation in the wall as moisture, or it may be frozen and thus be contained in the wall in the form of ice. In either case, the insulating properties of the wall are impaired. Not only is the insulating value of the wall reduced, but if this moisture remains in the wall for any appreciable length of time, rotting or a gradual deterioration of the insulation or of the wall structures itself may result.

The way to prevent moisture from entering into the wall structure in this way is to provide a vapor barrier or vapor seal. The barrier should always be placed on the warm side of the wall. In a house, probably the best place for the barrier is on the studs, next to the lath or plaster base or interior surface material.

This vapor seal or barrier may be in the form of metal foil sheets or rolls, asphalt-impregnated and asphalt-coated papers, laminated and plastic-coated papers, etc. A well-painted wall surface has some properties of a vapor barrier. There are several insulating building boards that are coated for this purpose, and there are also a number of insulations which have an impregnated or coated paper on one or both sides that acts as a vapor barrier.

The value of an insulation is, of course, its ability to retard or slow down the process of heat flow or heat transmission. A measure of the insulating property of a material is its heat transmission coefficient; the higher the coefficient the more readily heat can pass through the material. Heat transmission coefficients are usually expressed in Btu per square foot per hour per inch per degree Fahrenheit. This means the number of Btu of thermal energy that will pass through a layer of the material one square foot in area and one inch in thickness in one hour for each degree of difference between the temperature of one side and the temperature of the other side.

The ability of typical insulating materials to retard heat flow is due primarily to the minute air pockets or spaces that are distributed throughout the fibers of the materials. In fact, in most of these materials, these minute pockets or cells of air are the real insulators; the insulating value of the materials themselves lies in the ability of the materials to entrain or entrap these small quantities of air and keep them separated, without letting the air flow or move from one cell to another.

Thus the specific weight of a material, at least an insulating material, is often an indication of its value as an insulator. In order to make the data more informative, the apparent specific weight of a material should be given along with its heat transmission coefficient.

Building insulations are made in a number of forms and of a very wide variety of materials. The forms of insulation include blankets and bats of various thicknesses, loose-fill type, insulating boards and slabs, plaster base

boards or sheets, and foil in rolls and sheets. Insulating materials include wood fibers, grasses, vegetable fibers including sugar cane, cotton, and ceiba fibers, animal hair, redwood bark, glass wool, mineral wools of various kinds, saw dust and wood shavings, vermiculite, and various combinations, some of which many contain diatomaceous earth, asbestos, gypsum, etc.

Any material which has a low coefficient of heat transmission will be a good insulator and will reduce heat losses if properly applied. However, some insulating materials are much better than others for particular applications. Besides the coefficient of heat transmission of the materials, there are other factors which must be considered. Is it impervious to moisture, or if not impervious, will the presence of moisture have a deteriorating effect on the insulation itself? Can it be easily and effectively applied; once applied, will it retain its insulating properties? Is it economical? Will it support combustion? These are some of the factors by which an insulating material should be judged; factors which should be taken into consideration when selecting an insulation.

For insulating walls or sloping areas such as roofs, insulations of the blanket, bat, slab, or board forms are recommended in preference to the loose-fill type, particularly in vertical spaces. A large part of the loose-fill insulations are applied after the retaining parts have been put in place. When insulation of the loose-fill type is blown in studding spaces, it is not easy, if at all possible, to determine reliably just how well the insulation has been distributed, whether it has been packed in some spots and left with voids in other places. However, methods of applying insulation of this kind have been developed to such an extent, the principal method being high pressure blowers, that entirely dependable applications are obtained, particularly when the applications are made by reputable and experienced concerns.

Loose-fill insulation is also quite satisfactory for level spaces, as between joists over ceilings, particularly when it is applied before flooring has been laid over the joists. When applied in joist spaces without flooring above, a uniform depth of insulation can be obtained, with the assurance that cold spots will not develop due to poor distribution of the insulation.

Estimates have been made, based on actual tests, that the heat loss from the average uninsulated house during cold weather takes place about as follows: 30 per cent to 35 per cent through ceilings and roof; 25 per cent through outside walls; 25 per cent through doors and windows; the remaining 15 per cent to 20 per cent by infiltration through openings and cracks. Heat losses through floors may vary, depending primarily on whether the house does or does not have a basement. In either case, heat loss through the floors is not particularly serious, especially if basement windows and ventilating openings in foundations are kept closed in cold weather. However, warm floors and low heat loss through the floor can often be accomplished by placing a heavy deadening felt between subflooring and finished flooring, this felt being brought up the sidewalls behind the wall finish. This construction is very effective in reducing both conduction and infiltration losses through the floor. The same thing is often accomplished by placing insulating board between sub- and finished floors or under the subflooring.

Since the ceiling is the one part of the house that is usually the easiest and cheapest to insulate, this is the part that should be insulated if only partial insulation is to be applied.

In the writer's opinion, one of the best types of insulation for general application is that of the blanket type which encases the insulation material

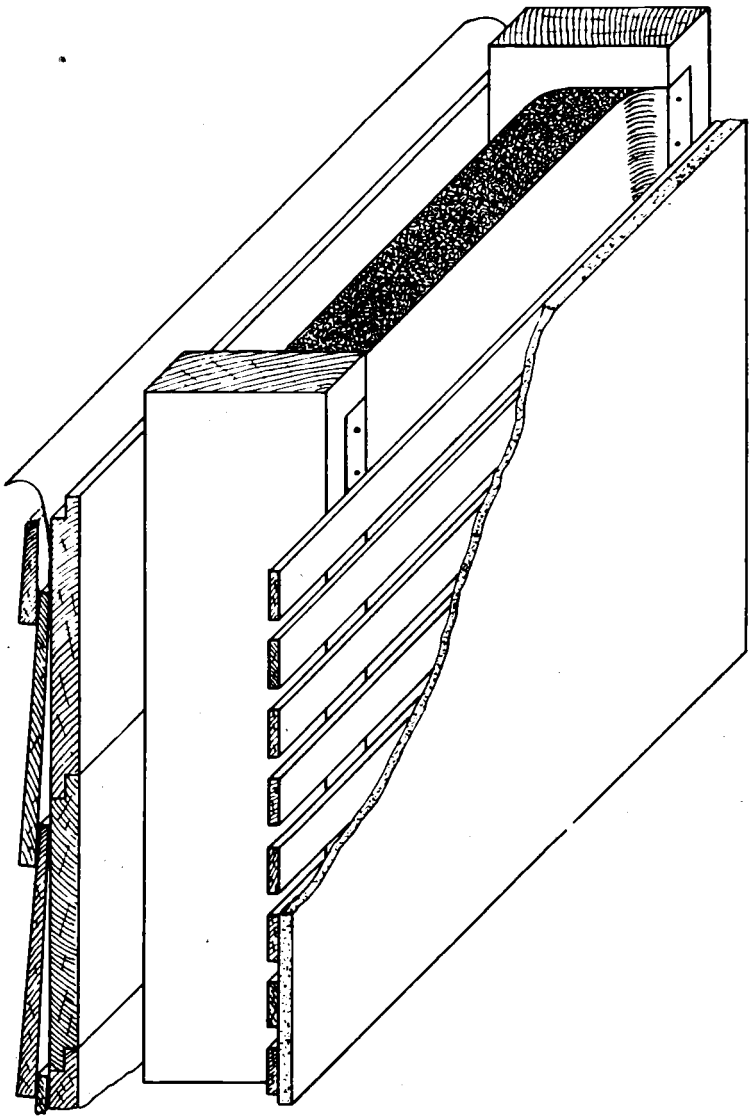

Figure 1. Section of Outside Wall Showing a Good Type of Insulation Placed Between Studs.

within an envelope of paper, the paper on one side having been treated to serve as a vapor seal or vapor barrier. It is not necessary, however, that a paper cover be provided on both sides of the insulation. Insulations of this kind are designed primarily to be applied during construction and, when applied at this time, are easily put in place, do not sag or settle, and have the added advantage that, being located in studding or joist spaces, they do not require any otherwise usable space. There are a number of insulations of this type on the market. One of these in particular is good in that when in place, an air space is left on each side of it as indicated in Figure 1. This particular insulation provided a vapor barrier, the insulating effect of the insulation itself, and two air spaces that, in themselves, serve as insulation.

Some insulations, particularly those of the board type, are represented as being both insulators and vapor barriers because, in addition to the insulating material, they have been coated on one side with asphalt or similar material. However, in the course of shipping, handling, and installing, these boards become flexed to some extent, and the minute fibers are pulled apart a very small amount. As this occurs, the asphalt coating may be cracked into a myriad of minute fissures. As a consequence, the vapor barrier is broken, and this coating is no longer effective in stopping the movement of the vapor. An effective means of correcting this condition is to coat the insulation after it has been put in place.

Because of the particular way in which they act as insulators, mention should be made of foil insulations. Most of the insulating materials mentioned previous to this point cut down the flow of heat by impeding its conduction. Foil insulators act in an entirely different way by acting as reflecting barriers. When the foil is hung in strips between studding, the effect is to reduce the amount of heat transferred by radiation; when the foil is hung in multiple strips as wide as the studding space, the effect is to reduce the heat transferred by radiation, primarily, but due to air films on the foil surface, there is some slowing down of heat flow due to these air films. Generally, however, foil serves as a heat barrier by reflecting the energy that is transmitted by radiation, due to its high reflectivity and very low emissivity. To retain its characteristics as a reflector, the foil must stay bright, free from corrosion or dust accumulation; otherwise the high reflectivity of its surface is impaired.

As has already been indicated, there are many types and kinds of good insulating materials. Often, when a choice is made, it is based on personal preference. A number of factors which should be considered when selecting an insulation have already been given. Whenever it is economically feasible to do so, insulation should be applied. Often insulation means the difference between a comfortable or a cold house, between unnecessary fuel handling and furnace tending and a nominal amount of heating attention, between high fuel bills and low-cost heating. Good insulating is absolutely necessary if certain fuels, the cost of which would be exorbitant without it, are to be considered.

One other definite advantage of insulation that has not been mentioned is the reduction in the size of the heating system which is made possible by a good insulation application. A good insulation application, then, is effective in reducing heat losses from the house, reducing the required size and original cost, as well as operating cost, of the heating plant, and if a vapor seal is provided, in protecting the structural parts of the house from the deteriorating effects of moisture.

6. **Controls.** The increasing efficiency of modern heating installations is due, to a large extent, to the development of efficient and reliable automatic

controls. Probably all controls are based on the use of a thermostat of some type. The purpose of the thermostat is to control the temperature of the surroundings in the vicinity in which the thermostat is located. Most thermostats are so made that, within close limits, they can be set to function at any desired temperature. This functioning operation is as follows: Let us suppose that the thermostat is of the ambient air temperature control type, which means that its job is to keep the air in the room in which the thermostat is located at a given temperature, or at least within a very small range of temperature. Let us assume that the thermostat is set for 75 degrees and is attached to the wall of a room in which the air is at 75 degrees. As soon as the temperature of the room air drops below 75 degrees, the thermostat closes, thus completing an electric circuit which may: open the draft in a furnace; open the draft and start a circulating fan; open the draft and start a coal stoker; start or increase the flow of oil to an oil burner; open a gas valve; close an electric heat resistance circuit, etc. Any one of these functions will result in the air in the room being warmed up. As soon as the air has again reached the temperature of 75 degrees, the temperature at which the thermostat was set, the thermostat opens, the circuit is broken, and the draft controls are closed, fans stopped, the flow of oil or gas to the burner is stopped, etc. When the room air again drops to a temperature below 75 degrees, the cycle is repeated.

There are many kinds and types of thermostatic controls. Some control the temperature of the water delivered to and circulated through radiators; at least one type controls both the amount and the temperature of air delivered to the room. Other temperature controls are of the so-called heat anticipating type. This type of device functions in such a way as to reduce over-runs, or lag. In other words, this device shuts off the heating apparatus just before the room has reached the desired temperature, anticipating that the heat that will continue to be delivered to the room after the thermostat has closed the draft, turned off the oil, or whatever other function it may have performed, will raise the temperature in the room to the desired level. In this way the room temperature does not over-run or rise above the desired temperature. The result accomplished is a narrower temperature differential in the room. Adequate control also minimizes the peak demands on the source of fuel or power. This is of considerable importance in connection with electric heating systems and of some importance with gas furnaces or heaters.

The purpose of all controls is the same: to deliver only as much heat to the house as is required for the desired comfort conditions, and to keep the room temperature as close to the desired temperature as is practicable. In performing these functions of keeping the temperature conditions uniform or constant, and delivering the correct amount of heat to the room, the thermostatic control almost invariably accomplishes one other thing; it saves fuel.

This fuel saving is accomplished in two ways, primarily. First, the temperature of the room is controlled so that it rises very little above the desired temperature. Second, the temperature of the rooms does not fluctuate over a wide range, thereby, the firing rate of the heating plant is kept more uniform, or at least without as wide variation as would be experienced without the control. Generally, the more uniform the firing rate is, the higher the efficiency of the combustion process. This is not always true; but, as stated, it is generally so. While the first of these two means of realizing fuel economy applies to electric heating as well as to other methods, the second, of course, does not.

Automatic controls, then, are necessary in order to keep the room temperature as uniform as possible, and are highly desirable from the standpoint of

economy. They are a basic part of any up-to-date heating plant. While the thermostat may be considered as the principal control in any heating system, it is not the only control that is used although it is the one most commonly used. Or, stated in another way, most modern heating systems make use of a thermostatic control only, while other systems incorporate additional controls.

One of these additional controls commonly made use of is a high-limit control which is placed in the bonnet of a furnace for protective purposes. This control may start a fan, close the dampers, or turn off the oil or gas, independently of the room thermostat, in case the bonnet temperature rises above 200 to 225 F. The purpose of this control is, of course, to protect the furnace. Another control stops the functioning of the system entirely in case of oil or gas burners, if the fire goes out or if the ignition systems fails. Still another control that is sometimes used, particularly in the case of automatic coal stoker installations, is one that will start the operation of the stoker whenever the bonnet temperature indicates the fire is getting too low, or the control may be such that it will start and stop the operation of the stoker at set time intervals in order to keep the fire going at a minimum rate. The controls function independently of the room thermostat.

In summary, the general requirements of a good heating system might be listed as follows: it must have a capacity large enough to take care of all heat losses of the house in the severest conditions encountered, and maintain a comfort temperature in so doing; it should be flexible—automatic control is highly desirable from the standpoints of flexibility, comfort, and economy; it should not be too time-consuming or difficult to operate; it should be efficient in operation. Cleanliness, space requirements, and cost are additional factors to be considered.

Regardless of the type of heating system being used, the degree of comfort and personal satisfaction of the occupants of the house depends upon the correct operation of the heating system. Even when the control of the system is fully automatic, the degree of comfort of the environment may still depend laregly on the personal factor that is involved in the operationg of the system. For example, many people believe that a large saving of fuel is realized by shutting down the heating system at night and starting it again in the morning. This procedure results in two undesirable conditions; first, the house is cold throughout most of the night and, second, if the heating system is not put in operation early enough in the morning, the house is cold even after occupants arise.

A considerable amount of data has been accumulated which indicates that this procedure of shutting down the heating plant at night accomplishes very little if any fuel saving. This is because the air, the walls, floors, ceilings, as well as the furnishings in the house become cold at night with the system turned off. All of these must be warmed up again in the morning before the environments are again comfortable. Accumulated data show that in most cases it takes very little more, if any more, heat to keep the house and its furnishings warm throughout the full 24 hours than it does to heat in the daytime only and shut the heating system down at night. Turning the thermostat down about five degrees for night operation might result in a slight saving of fuel, but shutting the heating system off completely is of very little, if any, further advantage. Furthermore, by eliminating or minimizing the morning warm-up period, the early morning demand, or rate of delivery of electric energy, for an electric heating system is substantially reduced. This lightens the burden on the utilities system and avoids demand charges where such charges are made.

III. TYPES OF HEATING SYSTEMS

In the following discussion of various types of heating systems, the discussion will pertain primarily to those designed for use in houses or dwellings and will refer, to only a very limited extent, to heating systems for buildings of any other nature.

For the purpose of establishing a definite basis for comparing the costs of the several types of heating systems which will be discussed, all cost figures given will be for a complete heating system installed in an average-size, six-room house located in a climate where moderately cold weather prevails in winter. This, of course, is not a precise basis, but since cost figures will usually be given within a range, exact figures are not necessary, even if it were possible to give them. It is not possible to give exact figures since costs vary considerably from one part of the country to another.

Any general discussion of costs of heating plants is difficult. Costs depend on many factors including quality of workmanship and materials, the ease or difficulty of installation in the particular house involved, the geographical location of the house, etc.

Rather than try to give a cost figure in dollars for each type of system, it seems more desirable to give cost figures on a relative basis only. For this purpose, costs will be given using the cost of a gravity warm air system as 1.00 If the cost of another system, for example, is given as 1.50, this means that the other system costs 50 per cent more than a warm air gravity system. All such cost figures are based on original costs and are not relative as to maintenance or up-keep costs. Original cost figures quite obviously do not give the whole picture. Maintenance costs, however, too often depend on too many factors to justify any attempt to evaluate them here. Comments may be made, however, in connection with maintenance costs pertaining to the individual types of systems.

1. **Convection systems.** Nearly all house heating systems are of one of two kinds: convection or radiant heating. While some systems transmit heat by both radiation and convection, they usually are principally one or the other. One possible exception to this is a radiator, which is considered to emit about one-half of its heat by radiation and one-half by convection, but which in most cases probably transmits most of its heat by convection.

Convection type heating systems may include: warm air furnaces, stoves, and some hot water, steam, and electric systems. In any convection system the heating effect is accomplished by the warming of the air in the room, or house. This warming of the air may be done at the point of heat source, such as with a warm air furnace, or it may be done within the room itself, as by a radiator or convector, or perhaps a unit heater. The convection heating systems will be discussed first.

A. **Warm air heating systems.** Warm air furnaces are of one of two types: gravity or forced circulation. In the gravity system, the delivery of the warm air to the rooms and the return of cold air to the furnace depend upon the difference in the densities of warm and cold air; the warm air, being lighter, rises through the ducts to the rooms, and the cold air sinks into the cold air registers, usually placed under a window or near an outside door, and returns through the cold air duct to the furnace where it is warmed and recirculated. Furnaces of this type should not be confused with the one-register or ductless type of furnaces which cannot correctly be considered central heating systems. While ductless furnaces can and do deliver warm air to the room

located immediately above the furnace, they are not effective in delivering warm air to spaces which are remote from the furnace.

With any warm air central heating system, there are several factors of primary importance: first, the furnace must have sufficient grate area; the furnace must have sufficient air heating surface; and all duct work must be of sufficient capacity and of proper design to assure proper circulation of the air through the system. In order to assure as good performance as possible with this type of heating system, the furnace should be centrally located in the basement. Locating the furnace in this way reduces long leader runs and aids materially in the proper distribution of warm air.

The advantages of warm air gravity heating systems are low installation costs and low maintenance expense, simple regulation, absence of radiators, and no likelihood of freezing.

The disadvantages of this type of system are the fact that frequently its operation is influenced by outside temperature and wind conditions; it is sometimes difficult to apportion properly the air and heat supply to each room so that the relation between the heat and air requirements for each of several rooms may be satisfactorily distributed; there are physiological objections to overheated furnace surfaces when such surfaces exist in the system; frequently too high temperatures are registered and drafts are present; larger ducts are required; no air filtering is possible. The relative cost of a good warm air gravity type furnace for the house assumed, designed for burning coal, slab wood, or saw dust, all hand-fired, and equipped with thermostatic draft control and protective high limit control as mentioned previously, is 1.00.

In a mechanical or forced circulation warm air system, the air circulation is effected by motor-driven fans instead of by the difference in density of warm and cold air. There are a number of advantages of the forced circulation system as compared with the gravity systems. Some of these advantages are:

1. The furnace does not need to be centrally located, but can be placed anywhere in the basement or in other parts of the house.
2. Air circulation is positive and can be distributed accurately according to requirements.
3. The velocity of the air circulated is increased, making the heat transfer at the heating surfaces more effective and insuring a sufficient volume of air to obtain proper heat distribution.
4. The duct work in the basement can be made smaller and can be so located as to give full head room in the basement.
5. Air conditioning or partial air conditioning is much more easily attained.
6. The duct work can be used for a cooling as well as a heating system.

With both the warm air gravity and the forced circulation system, but more commonly with the latter, the system may be closed; that is, the air in the house is circulated and recirculated without any air being brought into the system from the outside, except the air that leaks into the house or which comes in through open doors and windows; or the system may be designed to bring in from the outside some of the air required for ventilation. At least a part of the air that is brought in from the outside is generally circulated through the heating chamber of the furnace or air heater before it is delivered to the rooms.

The initial cost of the average forced circulation warm air system is somewhat higher than for the average gravity warm air system, due to the added cost of motor and fan and additional control equipment.

The relative cost of this type of furnace, equipped with room thermostat control, high limit control and an automatic fan switch, the furnace designed for hand firing coal, saw dust, or slab wood, is about 1.15. However, in view of the advantages of the forced circulation systems, including increased efficiency and effectiveness, very probably this system is the more economical in the long run.

A warm air furnace equipped with automatic coal stoker and all necessary controls costs, relatively, in the range of 1.50 to 1.60; while a warm air gas furnace would probably cost about 1.35, relatively. The prices given for both of these types of furnaces are based on forced circulation systems.

The trend, particularly in forced circulation warm air systems, is toward the so-called "packaged unit." There are a number of well-designed units of this type now on the market. Units of this type contain in one casing or jacket equipment for heating, humidifying, filtering and circulating the air, all of these operations being done automatically. These units are specifically designed for using coal, gas, or oil for fuel. All-electric units of this type are also available.

Being warm air heaters, probably stoves should be mentioned here. This type of heater is, of course, not considered as being a central heater, even though there may be only one in the house or dwelling unit being heated. Heaters of this type usually use wood, coal, or oil for fuel. While some stoves and oil heaters are equipped with a fan for attaining circulation of the warm air, most of them are not so equipped; and, consequently, the functioning of these units depends entirely on gravity or natural convection. The dependence on natural circulation of warm air from stoves and oil heaters usually results in poor circulation and poor distribution of heat, parts of the house being over-heated while other parts are almost unheated. Even when these types of heaters are equipped with a fan, the delivery of warm air to remote parts of the house or to spaces outside of the room in which the stove or heater is located is often not satisfactory. The principal purpose of the fan in this type of installation is to increase the heat transfer at the heating surfaces, and the fan does not necessarily distribute the warmed air to the various parts of the house.

The rate of firing in stoves is often difficult to regulate, resulting in wide fluctuations in temperatures within the space being heated. The advantages of stoves or oil heaters might be summarized as follows: They permit rapid heating of rooms, are more or less flexible in operation, are simple to install, and low in first cost if only one or a very few units are required.

The disadvantages of stoves or oil heaters are as follows: they require the burning of fuel in the room or rooms of occupancy which may be decidedly undesirable physiologically; overheated surfaces are also undesirable; too frequently the circulation of air obtained is inadequate or poor, resulting in drafts and uneven heat distribution in the room; they take up important space in the room; fuel and ashes, in the case of stoves, must be handled in the occupied space, resulting in dirt, inconvenience, and sometimes the presence of noxious gases in the room; stoves require frequent refueling and attention; and, lastly, there is some added danger of fire hazard. For these reasons, and the fact that the distribution of heat from a stove is limited, this type of heating unit is not too satisfactory.

B. **Hot water heating systems.** Hot water systems, like warm air systems, may be divided into two general classes, gravity systems and forced circulation systems. They may be further classified as radiant or convection systems, depending on whether radiators or convectors are used to deliver the

heat to the heated space. Since radiators actually transfer a large part of their heat by convection, for general discussion, hot water systems will be considered here as being convection systems.

Hot water gravity systems depend upon the difference in densities between hot and cold water for the circulation of water; the water is circulated by a pump in the forced circulation system. Hot water gravity heating systems are rapidly becoming obsolete; the trend is almost entirely to the forced circulation systems.

In any hot water heating system it is of importance that the combustion chamber of the heat exchanger or water heater be of proper size to handle the necessary amount of fuel; that the heat exchanging surfaces of the boiler be large enough; that all piping and radiators be of correct design and of proper capacity.

The sizes of radiators will, of course, depend on the temperature and quantity of water delivered to them as well as on the temperature drop of the water that is expected in the radiator.

Unlike warm air systems that heat the air at the heat exchanger and deliver it to the room or other space, hot water systems deliver hot water through pipes to the space to be heated, and by means of radiators or convectors, the air is heated in the room or other space.

Hot water systems may be 2-pipe or 1-pipe systems for either gravity or forced circulation. A 1-pipe system is one in which water flows through more than one radiator before it returns to the water heater to be reheated. In a 2-pipe system water leaving the water heater may flow directly to any one of the radiators in the system.

Additional factors which must be given consideration in the design and installation of any hot water heating system are: all piping must be installed to allow for expansion and contraction due to changes in temperature, an allowance of 1 inch per 100 feet of pipe being generally sufficient; all piping must be pitched so that all the air in the system can be vented either through an expansion tank, relief valves, or radiators; piping should also be so arranged that the entire system can be drained; the connections from the boiler to the mains should be short and direct, to reduce the friction head and allow for expansion; the mains and branches should pitch up and away from the boiler with a pitch of not less than 1 inch in 10 feet; the connections from mains to branches and to risers should be such that circulation through the risers will start in the right direction; and unless used as heating surface, all piping should be well insulated.

The advantages of a hot water gravity system are: it is possible to deliver the desired quantity of heat to each room by means of regulation at both the furnace and at the radiator; the heating surfaces have relatively low temperatures, which is physiologically desirable; a more uniform heating of the rooms is attainable; and the systems are noiseless.

The disadvantages of this type of system are the possibility of freezing and the difficulty that is sometimes experienced in draining the system to prevent freezing in the event that it is not to be used during freezing weather; the system is sluggish due to the large amount of water contained in the pipes, radiators, and water heaters, and as a consequence, this type of system is not desirable where the demand for heat is intermittent or unusually variable; and the initial installation cost is higher than for a warm air system.

Since higher water velocities are used in the forced circulation system than in the gravity system, the first cost of the installation may be reduced by using smaller pipes. Even with this saving, the cost of the installation as well

as operating cost for the forced circulation systems is usually higher because of the additional equipment required, the pump, motor, and controls, and the power required to operate this equipment.

The advantages of the forced circulation system are shorter heating-up periods, more flexible control and operation, and possibly a little better heat transfer in the boiler.

A gravity hot water system, with controls, costs relatively about 1.35; forced circulation hot water system, with controls, about 1.50.

Relative maintenance costs of heating systems might be mentioned here. As has already been stated, the original cost of a heating system may not, or at least should not, be the only consideration in determining the longtime cost of a heating system. Some heating systems are much more economically maintained than are others. A good steam or hot water system, for example, may last from 50 to 60 per cent longer than a hot air system. Such factors should be considered when the installation of a heating system is contemplated and when a choice of systems is possible.

C. **Steam heating systems.** Steam heating systems are of such a wide variety that no attempt will be made here to describe each kind of system now being used. The piping arrangements, the methods used for removing the air from the system, the types of controls and accessories used, and the pressure or vacuum conditions for which the systems are designed are all factors that determine the classification under which any one of the various systems falls.

Generally, steam heating systems can be classified as gravity or mechanical systems, according to the method used for returning the condensate to the boiler. In gravity systems the condensate returns to the boiler by gravity. In this type of system, the boiler must be sufficiently below the heating units to permit the return by gravity. In mechanical systems the condensate returns to a receiver by gravity and is then forced into the boiler. There are three types of mechanical return devices commonly used: the mechanical return trap, the vacuum return, and the condensate return pump. There are a number of factors which determine the type of system that should be installed for any individual application.

A common type of steam heating system is the gravity 1-pipe airvent system. Preference for this type of system has been due primarily to its low cost and simplicity of operation. However, this type of system is being made obsolete by more efficient and more dependable designs, particularly the 2-pipe vapor and orifice systems. In gravity systems it is important to keep the lowest points of the steam mains or radiators sufficiently above the water line of the boiler to prevent flooding. The heat cannot be modulated at the radiator in this type of system; the steam is turned all off or all on. There are several devices which make it possible to obtain a partial modulating effect with a 1-pipe system, however.

The advantages of a steam heating system, as compared to hot water systems, are: more flexibility and more adaptability to changing heat requirements, and less danger from freezing. The disadvantages are: surface temperatures may be higher, therefore less desirable; the system is not as reliable for centralized regulation; heat losses are probably greater; there is possibility of disturbances in the return lines.

A steam heating system of the gravity 1-pipe air-vent type would probably cost about 1.40.

With the exception of stoves and oil heaters, which probably should be classified as unit heaters rather than central heating units, the heating systems

discussed above, the warm air, hot water, and steam systems, are usually central heating systems. Systems of these kinds may or may not require a basement. If the basement is not required for any purpose other than to accommodate that part of the heating system that is located there, then, in addition to the costs which have been given for the various systems, the cost of the basement should also be charged to the cost of the heating system.

All of these systems of heating have been adapted to use sawdust, wood, coal, oil, gas, and electricity as fuel. All units using any of these fuels, except electricity, require a chimney both for draft and for the purpose of carrying away the products of combustion. Being a part of the heating system, the cost of the chimney should also be charged to the cost of the system. The cost of storage facilities for fuels will be considered in the discussion of fuels.

D. **Unit heaters.** With the exception of stoves and oil heaters which have been considered as unit heaters, the discussion of heating systems thus far has dealt almost entirely with central heating. However, unit heaters are becoming increasingly popular for some applications and some discussion should be given to them.

There are a number of types of unit heaters which, while they are very well-suited for use in shops, garages, stores, and factories, are almost entirely unsuited for use in homes. Such units may be supplied with steam or hot water from some source removed from the unit; or they may be directly fired using gas, oil, or coal for fuel; or they may use electric energy as the heat source. The units that use electric energy as the heat source will be discussed under electric heaters.

One type of gas heater that has been used for a number of years, but more or less as an auxiliary heater, is a natural convection heater, that is, it is not furnished with a fan. The circulation of the air past the heater and the circulation of the air within the heated space depends on natural circulation. This often results in poor distribution of warm air within the room. Heaters of this kind are usually not high-priced and are fairly satisfactory as warm-up heaters or where their continuous use is not required.

Another type of unit gas heater which has been made available recently is a radiant-convection built-in wall heater. This heater is obtainable in various sizes and may be either manually or automatically controlled. The unit fits into the studding space of a wall and protrudes somewhat from the wall surface. The combustion of the gas takes place in long, vertical metal tubes so that there is no exposed flame. This type of heater requires vent pipes for disposing of burned gases.

Gas-fired unit heaters of the forced circulation type are furnished with one or more fans and are high-capacity heaters. These are usually of the fin-tube type. Air velocities through the unit vary from 400 to 2500 fpm depending on the distance the warm air is to be projected and on the type of unit. Heaters of this kind are unsuitable for use in homes because of the high air velocities with their resulting drafts and noise.

Steam and hot water unit heaters may be quite similar in construction to the gas-fired heater and operate in the same way. The steam or hot water is supplied by a water heater or boiler which is not necessarily located at the heater. The heating surfaces of this type of heater may be made up of pipe coils with or without fins or it may be made of cast iron sections, or they may be of the automotive radiator type. Heaters of this kind are usually high-capacity heaters, their capacity depending on the heating surface area, the velocity and temperature of the water or steam, and the velocity of the air through the heater or past the heating surface.

Before leaving the subject of nonelectric convection type heating systems, some mention should be made of several of the newer developments in heating appliances, especially heat exchanger units and ways of installing these units. The trend is more or less to the smaller, more compact, and often recessed or concealed units.

One of these units is a convector of small cross-sectional dimensions, made up of standard length units which may be joined together to furnish a complete convector of any desired length. This unit, which is designed for using hot water or steam as the heating medium, is placed in the wall space, behind the baseboard. Suitable openings are made at the bottom of the baseboard and above the baseboard to provide for the circulation of air over the convector. The advantages of this type of unit are that it is completely concealed and, being placed in the wall space, it is entirely removed from the room and consequently takes up no room space; it gives a better distribution of heat throughout the room, with more uniform temperature distribution.

Another type of convector unit is one of the fin-tube design that is recessed into the wall. Grills placed at the bottom and at the top of or above the unit provide for air circulation over the convector. While these units are primarily convectors, some radiant effect is obtained also, since the unit itself is concealed by a panel that radiates, just as does the baseboard in an installation as just described above. Some convectors of this type are equipped with fans, an arrangement which results in high heat transfer capacity. These units are usually used with hot water as the heating medium.

E. **Electric heating systems.** Up to this point the heating systems described have been classified according to the type of system and not with respect to the fuel used in the system. It seems a little more desirable, however, to treat electric heating systems separately even though all types of electric heating systems might be included in the other classifications.

In view of the increasing number and wide variety of electric space heating furnaces that are being developed, no attempt will be made to describe each furnace or heating system in this category. Instead, a more or less typical system of each of the several kinds will be discussed and some of the other individual designs may be mentioned only briefly.

One type of electric heating system which has been quite widely used and which has proved satisfactory for the most part is made up of one or more individual heating units in each room. These are not units of the portable type, but are permanently fixed in place and each is equipped with its own thermostat. These heaters are usually placed within the studding space with the bottom of the heater at floor level or slightly higher.

As has already been indicated, units of this type are installed in both inside and outside walls. In many installations the units are placed under windows. The proper placement of these units is of considerable importance if satisfactory performance of the system as a whole is expected. Placing units in outside walls results in the wall itself being warmed to some extent, which is desirable, and frequently minimizes the drawing of cold air across the floors since the cold air ordinarily passes down the outside walls and hence directly into the heating unit without having to pass across the floor to reach the unit.

The heating element in these units is usually a helical coil of resistance wire and may be wound around a porcelain or ceramic tube through which some of the air passes by natural convection. Units are made of one or more heating elements, in capacities of from 1000 to 8000 watts. Units of capacity greater than 3500 watts are ordinarily not recommended for residential installations.

Between the heating elements and the back of the unit is placed a polished sheet of metal that acts as a reflector and also forms a channel for air passage behind it. Cold air from the floor or from near the floor enters the heater at the bottom, passes up back of the heating elements through the passage formed by the reflector, and out at the top of the heater. Heat is transmitted to the room to some extent by radiation, but principally by convection by means of the stream of air that flows through the heater by natural convection. This type of heater is automatically controlled by a thermostat placed within the unit itself, or by a thermostat placed elsewhere in the room. The number of heaters placed in each room depends upon the heat requirements of the individual room.

This type of heater operates at fairly high temperatures of the heating elements. To provide against contact with these elements, a grille-guard is placed in front of them, this guard being a part of the unit.

Other heaters of this type are designed in different ways. The heating elements may be wound around strips of mica or some other nonconducting material and the unit designed to obtain a flow of air past or around these elements. The air may enter through holes or channels at the top or it may be deflected out the front of the heater by the reflector.

As has already been mentioned, the circulation of air through the heater and the distribution of heat throughout the room depend entirely on natural circulation. Some heat is transmitted from the unit by radiation. This is

Figure 2. AN ELECTRIC RADIANT-CONVECTION UNIT HEATER INSTALLED.

radiation from a source at fairly high temperature. It is important on this account that these heaters be installed in locations in the room so that they do not radiate directly on other parts of the house or on furniture or other objects placed too close in front of the heaters.

The trend in this type of heating unit is toward larger heating surfaces at lower temperatures. This, of course, reduces the objections to high temperature surfaces that have already been mentioned.

It is not implied that high temperature surfaces are or have been inherent only in electric heaters. Other types of heating systems have been or are what might be called offenders in this respect. Except for unit gas heaters, however, the high temperature surfaces are usually enclosed and are not exposed in the heated space itself. Generally speaking, the trend in heating systems of all kinds is toward surfaces of lower temperatures and with better heat transfer characteristics.

Aside from the inherent advantages of electric energy which will be discussed in another section, the advantages of electric unit heater are: low cost of initial installation; ease of installation; long life of the heaters with resulting low maintenance costs; assurance of sufficient heating capacity being allocated to each room, with the amount of heat delivered to the room and the temperature of each room being controlled within the room itself; no basement is required.

The disadvantages are: the circulation of air and the distribution of heat in the room are sometimes uncertain; heating the air with surfaces at high temperature is undesirable physiologically; there may be some fire hazard due to a heating element at high temperature being placed in the room.

Again basing our figures on an installation of sufficient capacity to heat a well-insulated six-room house, the relative cost of a system of this kind, installed, would be around 0.75. This includes the cost of the heaters and controls and the materials and labor of installing.

F. **Central heating systems, electric.** There have been a number of electric central heating furnaces developed within the past few years, a number are in design stages, and no doubt many more will be developed. Some of these furnaces and reasons for their designs will be discussed.

In order to diversify the load on the power transmission equipment, that is, to spread the load out over as much of the time as possible during each 24-hour period, some power companies offer an off-peak or lower rate for power used during the night than for power used during the day. The object of the off-peak rate is to increase the use of electricity during the night when the load may normally be much less than during certain periods of the day. The spreading out of the use of electricity during off-peak periods may have two effects: it enables the power company to make use of its facilities over a larger part of the 24-hour period, and it may reduce the overall capacity of the generating and transmission facilities by decreasing the peak demands.

Several electric furnaces have been developed either to take advantage of such off-peak rates or to maintain a high load factor on the system. This is accomplished in a very simple way by using the electric energy at night to heat some substance and storing the heat or thermal energy in the substance for use during the day. In those parts of the country where off-peak rates are not available, systems of this kind are, of course, not attractive. In the Pacific Northwest, for example, it is reported that no utility offers such an off-peak rate. In those regions where off-peak rates are available, however, such systems may be entirely practical.

The materials being used for the thermal-storage mediums are concrete, gravel, boulders, rocks, and fire bricks. The specific heats of these materials are all close to 1/5 Btu per pound. From the standpoint of specific heats, these materials are not nearly so good as water for thermal storage, because the specific heat of water is about five times as great as it is for these other materials. However, while water can be heated to only 212 F at atmospheric pressure, these other substances can be heated to much higher temperatures, say 300 to 600 F.

The general details of design of these thermal storage electric furnaces are as follows: On a layer of three to four inches of insulating brick is laid a checker-work of fire brick. The heating elements may be inserted in this checker-work, may be made a part of the grid which supports the rocks in the furnace, or they may be inserted into the pile of rocks itself. A grille or grate made of steel or cast iron is laid over the top of the brick checker-work and the rocks are piled on the grille. Another checker-work of fire brick is built on top of the rocks. The two checker-works and the rocks are enclosed on the sides and top by a layer of fire brick, then a layer of from 4 to 5 inches of good insulation such as mineral wool or fiberglass, then a layer of brick. A good design would provide a 2- or 3-inch air space around the brick work and the entire assembly then enclosed in a steel jacket. However, the jacket is not absolutely essential.

The cold air duct is led into the checker-work at the bottom of the furnace, and the warm air duct from the checker-work is at the top of the furnace. Since the air leaving the furnace during operation is very hot, the system must include some means of tempering this air. This is done by providing a by-pass which connects the cold air and the warm air ducts. The tempered air is then forced to the warm air registers by fan.

Heat generated in the heating elements is dissipated by convection as the air passes the elements and rises through the air spaces between the rocks or bricks. The heat then is absorbed by conduction through the rocks. After the air is cooled by having its heat removed by the rocks, it returns down the sides of the rock pile, this being the cooler part of the pile, and passing over the heating elements, it is again warmed and rises into the pile.

In order to improve the electrical load characteristics of the furnace, the heating elements should be broken up into circuits of not more than 3 to 3.5 kw capacity each. The electrical capacity of the heating elements is determined by the heating requirements which the furnace is expected to satisfy. The heating element circuits may be controlled by thermostats with sensitive elements inserted into the rock pile and these circuits should be staged, that is, the thermostats controlling them should be adjusted to close the circuits at different temperatures. In this way all circuits do not generally come on at the same time and the demand on the power line is built up in stages. In addition to the thermostats controlling the heating element circuits, some type of timing device is also required to close the circuits at the desired off-peak period. At the end of this period, or when the desired temperature of the rocks has been reached, the circuits are opened, but may be closed again when the temperature of the rocks falls below a predetermined point.

When heat is called for by the room thermostat, this thermostat closes the fan circuit and starts the circulating fan which may be placed in the warm air duct. The cold air from the cold air registers enters the bottom of the furnace, passes through the brick checker-work at the bottom, continues on up through the open spaces in the rock pile and through the checker-work at the top, and passes on out through the hot air pipe at the top of the furnace. Here it is

blended with the cold air that comes from the cold air registers but which by-passes the furnace. From here it is delivered to the warm air registers in the house. The mixing of the by-passed cold air and the hot air can be controlled by a thermostat that is placed in the warm air duct and controls a damper in each of the hot air and the by-pass ducts. This controlling could be done also by a modulating control actuated by a thermostat placed in the warm air duct. As a safety control, a thermostat may be placed in the warm air duct to stop the fan in case the air in this duct becomes too hot due to some malfunctioning of the mixing damper or damper control or some other part of the furnace.

The quantity or weight of rocks, or other thermal-storing material in the furnace, is determined by the amount of thermal energy to be stored. If the charging time, or the time for storing the energy takes place during an 8-hour period, for example, it would probably not be practical to store more than enough energy to last until the next charging time, or 16 hours. The heating capacity of the elements must be sufficient to produce the heat requirements of 24 hours within 8 hours, assuming that electrical energy is to be used during only the 8-hour charging period. This is not absolutely necessary, however, and some energy may be used during the day if required. The charging time may vary from 8 to 16 hours. The 8-hour charging time is mentioned only as one possibility.

After the heat losses of the house have been determined from design conditions and it has been decided what the storage capacity of the furnace and the charging time are to be, the capacity of the heating elements and the weight of rocks can be determined.

Let us assume a house in which such a furnace is to be installed required 20,000 Btu per hour for each of the 24 hours of the day. This makes a total of 480,000 Btu per 24 hours. These 480,000 Btu are to be supplied in an eight-hour charging time, or 60,000 Btu per hour. This is the equivalent of approximately 17.6 kilowatts. This would require five heating element circuits of about 3.5 kw each.

Assuming that during the charging time the heat requirements of the house of 20,000 Btu per hour or 160,000 Btu for the eight hours are dissipated directly to the air stream from the heating elements and are not stored in the rocks at all. This leaves 320,000 Btu to be stored in the rocks.

Assume a specific heat of the stones to be 0.20 Btu per pound and the specific weight to be 156 pounds per cubic foot, and assume also that the stones are heated to 600 F and not allowed to cool to lower than 200 F, making a temperature differential in the stones of 400 F. The weight of rock required would then be $320{,}000 \div (400 \times 0.20) = 4000$ pounds of rocks required. Dividing 4000 by 156, we see that about 25.6 cubic feet of rocks are required. Of course, the rock pile cannot be solid rock; air spaces must be left between the rocks for the air to circulate through. Assuming that these cracks and air spaces amount to 15 per cent of the total space, approximately 30 cubic feet of space is then required for the stones or rocks. A cube-shaped space a little over three feet on a side would be sufficient for this requirement.

Most kinds of gravel, rocks, or bricks are satisfactory for use in a thermal storage furnace of this type. The stones should be clean, free from dust and dirt. Types which disintegrate, spall, or decompose at the fairly high temperatures of use should not be used. Granite, basalt, fire brick, or concrete would all be suitable for the purpose.

As has already been mentioned, a steel or metal jacket, while it would be of some advantage in reducing heat losses from a furnace of this type, is not

absolutely essential. If such a jacket is provided, however, it should be kept as bright as is practicable on both the inside and outside surfaces. This would aid considerably in reducing heat losses from the furnace by radiation. Because of the high temperature of the rock pile, a good, thorough job of insulating the furnace is of considerable importance in reducing what can be very high heat losses from the furnace.

One modification of the furnace construction outlined above which would have some insulating effect and should also result in some improvement in the performance of the furnace, is to bring the air into the space between the outside brick work and the metal jacket, if a jacket is provided. Such an arrangement would cool the brick work and the jacket when the furnace is operating.

One other modification is the placing of one or two 3.5 kw heating elements in the hot air outlet duct. These elements should be controlled separately from the main heating elements, but in series with the ventilating fan and would be used in mild weather or when only a limited amount of heat is required and the other heating elements and the heat storage are not operating. In this way, the heat from this auxiliary element could be delivered to the warm air duct without passing through the rock pile.

To make an installation of this type of furnace complete, a control panel should be provided for time switches, heat control switches, and the other controls required for the proper operation of the heating system.

The principal advantage of this type of heating system, assuming that an off-peak power rate is available, is the lower heating cost due to the off-peak rate. Other advantages are that the thermal-storage medium can in many instances be supplied by materials that are already close at hand. With the exception of the fact that outside weather conditions do not affect the operation of this type of furnace as they do a warm air fuel burning furnace, the other advantages and disadvantages of this type of system are about the same as they are for a warm air forced circulation, fuel-burning heating system. One other exception is the additional undesirable feature of the thermal storage system of heating the air to a much higher temperature, even though it is later tempered with cool air. It might also be mentioned here that in case of a power failure, in which event the forced circulation fan could not be operated, the thermal storage system would have very little value for furnishing heat since the circulation obtained by natural convection through the system would almost certainly not be sufficient to deliver the required heat to the registers.

Another type of electric central heating furnace that has recently been developed and is now in production is of considerably different design than the thermal storage furnace discussed above. While this furnace does have some thermal storage capacity, it is not sufficient to justify its being considered as an off-peak power storage system.

In this furnace the heating elements are embedded in slabs of soapstone or similar material. These slabs are approximately 4 inches thick, 30 inches high and about 36 inches wide. There are 3, 6, or 9 of these slabs, depending on the capacity of the furnace. Each element, and there is only one to each slab, has a capacity of one kilowatt.

These slabs are hung vertically from a steel frame-work in such a way that the distance between them can be varied and controlled, the controlling being done by a potentiometer-type thermostat and the distance between slabs being varied by means of a linkage and a special electric motor. The basic principle of this scheme is that the amount of heat delivered by the furnace is proportional to the distance between the slabs, assuming that the temperature of the slabs is within a limited range.

The temperature of the slabs is controlled by means of a thermostat that opens or closes the heating element circuits; when the slab temperature falls below a certain point, the heating element circuit is closed. As soon as the slabs come up to a certain temperature, the circuit is opened. Some heat or energy is then stored in the slabs, due to the thermal capacity of the slab material.

In the original design of this furnace, all heating elements were in one circuit; modifications have been made in later designs. To make this, or an electric heating installation of any kind, more acceptable from the power distributor's standpoint, the heating circuits should be in stages so that they do not all come on at one time. In this particular type of furnace the heating element circuits should be broken up into circuits of say 3.5 kw capacity each. This would require a separate thermostat for each circuit, these thermostats to control the temperatures of the slabs in which the heating elements are embedded.

The slabs, the framework on which the slabs are supported, and the linkage for operating the slabs are all enclosed in an insulated metal casing or jacket. The cold air duct enters this casing at the bottom, and the warm air duct leaves the jacket at the top on the end opposite to that in which the cold air duct is located. The motor that actuates the linkage mechanism connected to the slabs and the switches or contactor which controls the heating element circuit are mounted on the outside of the casing.

The sensitive potentiometer-type thermostat is located in the space to be heated, preferably, of course, in a location that will give the most representative response in the control. The ventilating or forced circulation fan is also turned on or off by means of this thermostat. The fan should be placed in the warm air duct rather than in the cold air duct because, should there be any leaks in the furnace jacket or housing, warm air from the furnace will not be blown out through these cracks or openings. The potentiometer thermostat, by means of the operating motor, causes the slabs to move closer together or farther apart, depending on the heat demand at the thermostat.

When there is a large demand for heat, the slabs are moved farther apart and the air that is forced past these hot surfaces then has more space through which to pass, a larger volume of air moves past the heating surfaces and less past the backs of the outside slabs that are insulated. When less heat is called for by the room thermostat, the slabs are moved closer together by the motor, less air passes by the heating surfaces and more passes behind the slabs where it is not heated. When the room thermostat is satisfied and no heat is called for, the slabs are very close together and by means of small overlapping metal lips located at the tops of the slabs, the movement of air past the heating surfaces is shut off entirely. In this way even the heating of air passing by the heating surfaces of the slabs by natural convection, when no heat is demanded, is avoided.

The advantages of this type of heating system are: no basement is required since a furnace of this type, as well as other types of forced circulation furnaces, can be operated at the same level as the space to be heated; and due to the thermal capacity of the slab material, there is some thermal storage in the furnace. With these furnaces it is possible to have a short-time rate of heat delivery that is several times as great as the rate of energy consumption. The capacity of this furnace is about 9 kw and of a kitchen range about 8 kw, therefore, if the furnace is connected by an automatic double throw switch with the range, the peak demand for the residence is kept down to approximately that of the range alone, which is quite unusual for electrical heating. Other advantages and disadvantages of a system of this kind are very much the same as

those listed for any forced circulation warm air system. A furnace of this type, installed, is priced, relatively, in the range of 1.75 to 1.90.

In another type of self-contained unit, both the volume and the temperature of the air delivered are controlled. The cold air enters the top of the unit, passing through louvre dampers that are controlled by the thermostat. This air then goes through the spun-glass filters, into the fan or blower that is located at the bottom of the unit and is driven by an electric motor, and then back up past the heating elements and on out the top of the unit and into the warm air ducts.

The heating elements, of the extended-surface type, are staged. Each element is controlled by a mercury switch. These switches are actuated by means of a specially designed electric motor, which, in turn, is controlled by a sensitive potentiometer thermostat.

Thus all parts of this furnace, with the exception of the room thermostat, are contained in the one unit. The damper thermostat, the special motor and switches and fuses, the blower and motor, the filters, and the heating elements are all enclosed in this one steel cabinet or casing.

It is particularly important with furnaces of this type or any electric central

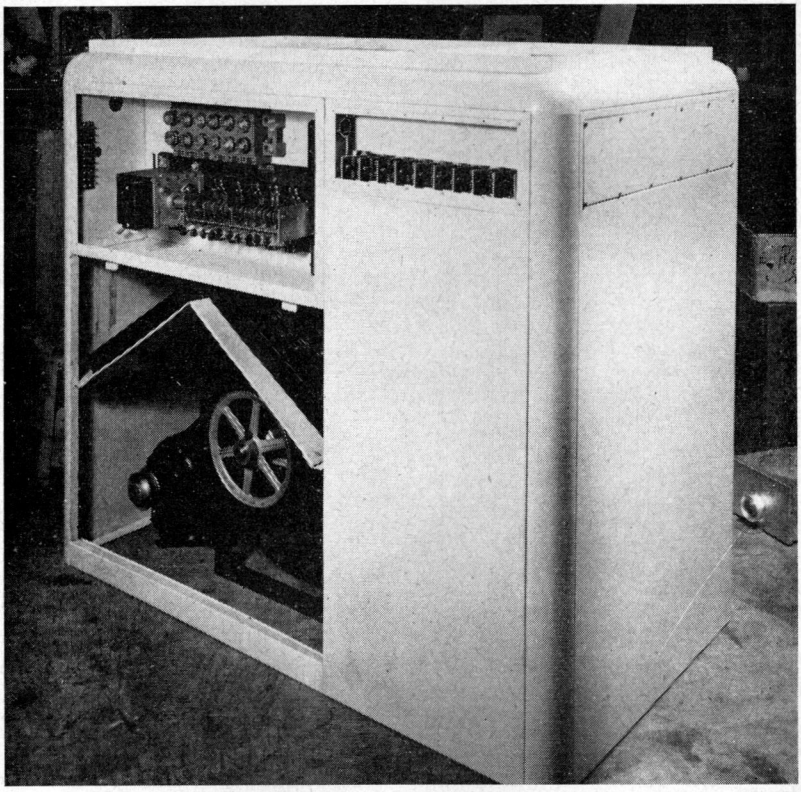

Figure 3. AN ELECTRIC CENTRAL HEATING WARM AIR FURNACE.

heating system for that matter, that the furnace itself as well as the duct work be well insulated. If this is not done there may be an excessive heat loss to the space in which the furnace is located as well as from the ducts. It is of particular importance that risers be insulated if they are located in outside walls.

Installed, this unit costs, relatively, about 1.75 to 1.90 depending on labor and materials required for installing the ductwork, registers, etc.

G. **Reverse-cycle heating.** Before leaving the subject of electric space heating with convection type systems, some mention should be made of reverse-cycle heating. A reverse-cycle installation need not be restricted to convection heating, however. In fact, there are a number of advantages in using such an installation for radiant panel heating.

The principal parts of an ordinary compressor-type refrigeration machine consist of an evaporator, a compressor, a condenser, and a tank to hold the refrigerant. The liquid refrigerant leaves the tank where it is held under a pressure and passes through an expansion valve to a lower pressure and, in so doing, most of the liquid is changed to a vapor and the temperature of the vapor and what liquid remains is greatly reduced. This vapor then flows through the evaporator or cooling coils where it takes heat from the cold-room. thus cooling it while the refrigerant itself is being heated. Leaving the evaporator or cooling coils, the vapor is sucked into the compressor that compresses the gas or vapor, raising its pressure and its temperature. From here the vapor goes into the condenser where it is cooled, either by the cooler air that is blown over the condenser tubes or by cold water that is flowing through the condensed. When the heat is removed from the refrigerant by the cool air or water the vapor is changed back to a liquid which flows to the storage tank from where it starts on its cycle again.

Two basic things should be noted particularly in considering this cycle. One is that when the cooling-room is cooled, the heat removed from this room enters the refrigerant as it flows through the cooling coils. This heat flow is possible because of the fact that the vapor in the coils is colder than the air in the cooling-room or cold space of the refrigerator. The second important fact to be noted is that all of the heat that entered the refrigerant and was thus removed from the cold space or cooling-room plus that which was added in the form of work in the compressor was removed from the refrigerant in the condenser.

In a reverse-cycle system the equipment that is used is practically the same, with some modifications, as that used for refrigeration. The fundamental difference is that in the refrigeration cycle the object is to obtain a refrigerating effect, while in the reverse-cycle the object is to obtain a heating effect; in the one case to cool the cooling-room or refrigerated space and in the other case to heat the rooms of a house.

The interesting feature of the reverse-cycle is that most of the heat that is ultimately delivered to the house is taken from the outside atmosphere or from water. In other words, by means of the reverse-cycle equipment, heat is removed from the outside air or from a supply of water from a well, lake, stream, or from the city water and delivered to the space to be heated. Obviously, this means that if some heat is supplied by some other source, only a fraction of the total heat delivered must be supplied by the user of such an installation. This is the advantage of reverse-cycle heating. In a well-designed unit it is possible to get from three to four times as much heat out of the system as is supplied in the form of energy to drive the compressor.

Because of its unlimited quantity and because it may be obtained for only the cost of delivering it to and forcing it through the evaporator, atmospheric

air is, but for one factor, an ideal source of heat for a reverse-cycle system. This one factor, however, limits to a very great extent the use of reverse-cycle.

As the temperature of the outside air decreases, the amount of heat that can be obtained from it by any practical means also decreases. This signifies, of course, that in cold weather when a large amount of heat may be needed to heat the house, a very limited amount is available from the air. In other words, when heat is needed most, the least is available. This is the factor that limits the use of reverse-cycle heating. Consequently, the use of this method of heating is more or less restricted to localities where the winters are mild and heating requirements are limited.

These comments concerning the limitations of reverse-cycle heating apply almost exclusively to reverse-cycle installations which use atmospheric air as the heat source. With units using water as the heat source, this limitation is not as pronounced. For this reason, units using water as the heat source have several advantages over the air heated units. The principal advantages of the water heated unit are that the temperature of the water usually does not vary as widely as does that of the air, the temperature of the water does not fall as low as the air temperature, and a much smaller volume of water is required than is the volume of air required.

The smaller volume of water required is a result of three things. First, the water temperature is usually higher than that of the air, resulting in a greater permissible temperature drop in the water. Second, the specific heat of water is about four times that of air. Third, the density of water is, of course, much greater than that of air.

These comments pertaining to water temperatures are based on the assumption that well water or water from a deep stream or lake, or service water is being used. The source of water may be the limiting factor in a reverse-cycle installation using water as the heat source. The means for disposal of the required amount of water may also be a limiting factor in a system of this kind. Relatively very few people have a river or lake or deep well from which to draw water. Public service companies would probably not permit the use of city water for this purpose to any very great extent as this would place too great a demand on their systems, especially where the quantity of water is more or less limited.

One other possibility presents itself in this connection, however, and that is to design the system so that instead of just cooling water to near freezing temperature, the water might be frozen. In this way, for every pound of water frozen, 144 Btu of heat of fusion are obtained, as compared with only 1 Btu for each degree that a pound of water is cooled. By freezing the water, then, instead of just cooling it a few degrees, a considerable amount of heat is obtained from a relatively small amount of water.

There are, however, two obstacles of considerable difficulty to be overcome when the unit is designed to obtain the heat of fusion of ice as a part of the heat source. These difficulties are removing the ice from the freezing unit and disposing of the ice once it is removed. The first of these two obstacles is not necessarily insurmountable. The second problem, however, is one which, in the case of domestic heating particularly has proved to be a very difficult one to solve, so difficult, in fact, as to practically eliminate the general use of this method of heat extraction for reverse-cycle application.

Reverse-cycle heating still has great possibilities, however, and the next few years will no doubt show considerable development in this field. Even today there are a number of units utilizing this principle on the market. A number of

office buildings and some houses in this country are being heated by reverse-cycle.

The advantages of reverse-cycle heating are first and principally the low cost of operation. This, of course, is due to the fact that for every unit of heat or energy that is supplied and must be paid for, from 2 to 4 units of heat are extracted from the air or water. This means that from only $\frac{1}{3}$ to $\frac{1}{5}$ of the total heating requirements must be purchased or supplied in the form of electricity or other operating media. Another advantage, which is unique among heating devices, is that the same equipment used for heating can also be used for cooling and air conditioning. In this way year-round air conditioning is made possible with one set of equipment.

The disadvantages of reverse-cycle heating are the limitations imposed upon it by the temperature of the air or by the temperature and quantity of the water available. Should the air or water temperature fall below the temperature for which the unit is designed, it may automatically shut off and no heat whatever would be available from the unit. This would necessitate the installation of auxiliary heating facilities of at least equal heating capacity as the reverse-cycle unit and this, of course, would mean additional expense. This duplication of facilities is in addition to the fact that systems of this kind are, at least to date, fairly high-priced as compared with other heating systems. In view of the possible low operating expense, however, reverse-cycle heating may and should be economical in the long run.

Mention should be made here of the possibility of combining thermal storage facilities with a reverse-cycle installation. An installation of this kind would permit the storing of heat in the day time when the air temperature is higher and using this heat at night to heat the house when the outside air temperature is usually lower than in the day time. It might also be entirely practical to obtain and store the heat resulting from solar radiation in conjunction with a reverse-cycle system, especially in those parts of the country where sunny days predominate during the winter season, even though the outside air temperature may be fairly low. The utilization of solar radiation need not be carried on in connection with a reverse-cycle system, however, but might be used very well in this manner in order to furnish an auxiliary heat source and in this way overcome at least a part of the limitations of the reverse-cycle application.

2. **Radiant Heating.** A Discussion of the Theory of Radiant Heating. The mechanism by which objects interchange heat energy by radiation is rather complex. The heat interchange is not by the radiation of heat itself, but the energy transfer starts as a conversion of the thermal energy of the radiating body into electro-magnetic waves; these waves are then transmitted through space, and then the cold, or receiving, body converts the wave motion into thermal energy. The medium through which the heat transfer takes place does not become heated.

All objects radiate energy, the amount of energy radiated depending on the temperatures of the objects and their emissivities. The amount of energy radiated is directly proportional to the fourth power of the absolute temperature of the radiating object. Thus the energy interchanged by radiation between two bodies is proportional to the difference between the fourth powers of their absolute temperatures. Of course, the radiant interchange also depends on the position of the bodies relative to each other, and the equation for this interchange must include a shape or configuration factor to account for this.

The general radiant interchange equation then becomes

$$q_{1-2} = C(T_1^4 - T_2^4)F_eF_aA_1,$$

where q is the total net energy interchanged by radiation between bodies 1 and 2, in Btu per hour. C is the Stefan-Boltzmann constant or proportionality factor; its value is $0.174(10^{-8})$ Btu per hour per square foot of area per degree Fahrenheit absolute.

T_1 is the temperature of Body 1, degrees Fahrenheit, absolute.
T_2 is the temperature of Body 2, degrees Fahrenheit, absolute.
F_e is the emissivity factor of the two bodies.
F_a is the shape factor of the two bodies.
A_1 is the area of Body 1 in square feet.

This very brief discussion of the phenomenon of heat or energy transfer by radiation is not intended as a complete discussion of the subject. Enough is given here, however, to serve as a basis of understanding of the relatively simple problems of applying the laws of radiant interchange to the heating of houses by radiant heating.

Radiant heating has already been mentioned in the discussion of convection heating. Some details of radiant heating and radiant heating methods will be discussed now.

As has also been mentioned, a person at rest normally gives off about 400 Btu per hour to his surroundings. Depending on the conditions, possibly one-half of this heat may be given off by radiation and the other half by convection and evaporation. Just as a convection heating system is designed to maintain conditions which control primarily the amount of heat that the occupants give off by convection, the radiant heating system is designed to maintain conditions to control, primarily, the loss of body heat by radiation.

Conditions of comfort for the human body depend principally on the temperature of the ambient air and the MRT or mean radiant temperature of the room and, to a lesser extent, on the relative humidity and the velocity of the air in the enclosure.

Probably the term mean radiant temperature should be explained. The mean radiant temperature of a room, for example, is merely the average temperature of all of the surfaces by which the room is enclosed. Ordinarily these surfaces include the floor, ceiling, walls, windows, and doors.

The temperature of the surrounding air is usually the most important factor that determines the proportion of heat given off by the human body by convection. The temperature of the surroundings determines the proportion dissipated by radiation. For example, a person sitting close to a cold window will feel cold on that side of his body which faces the window. This is because that side of his body is radiating energy to the window at a very high rate, the rate at which he is radiating heat to the cold surface depending upon the difference in temperatures of the surface of his body or the surface of his clothing and the cold surface. Likewise, when a person stands or sits facing an open fireplace in which there is a fire burning, he or she feels warm on that side which faces the fire. This is because the fire is radiating energy toward the person and no heat can be dissipated by the person by radiation in the direction of the fire.

Disregarding the velocity and relative humidity of the air, the same degree of comfort may be obtained through a wide range of air temperatures and MRT. For example, when the MRT is low, the air temperature must be high; when the MRT is high, the air temperature must be low. The comfort temperature, which is a function of both the air temperature and the MRT, may be the same for both of these conditions.

This fact constitutes one of the principal advantages of radiant heating; that is, that the air temperature in a room may remain fairly low and, with the proper MRT maintained, the comfort temperature will remain high.

In a radiant-heated room, heat is usually supplied to one or two surfaces of the room, although, of course, any number of the available surfaces may be heated. Theoretically, the best surface to use as the radiant panel is the ceiling. This is because the largest proportion of the heat supplied to such a radiant panel is transmitted by radiation when the panel is placed in the ceiling. The proportion of heat transmitted by radiation from a ceiling, a wall, and a floor are approximately 70 per cent, 65 per cent, and 55 per cent, respectively. Judging the effectiveness of a radiant system by the amount of energy transmitted by radiation, it is obvious that the ceiling is the best location for the radiant panel.

Even though a floor panel transmits about half of its heat by convection, the floor is often preferred as the location for a radiant panel. A warm floor is quite desirable, for example, in a bathroom. Even for other parts of the house, the floor has some advantages as the radiant panel. A warm floor tends to keep the feet warm, a factor of some importance, since most peoples' feet are particularly sensitive to temperature variation. Since the occupants are usually closer to the floor than to any other room surface, the floor panel may furnish a more uniform direct radiation than any other room surface. A floor panel is more desirable in keeping that part of the body warm which may be under a table or desk and which would consequently be shielded to some extent from radiation from walls or ceiling. However, the direct radiation from the panel itself to the occupant of the room is of not very great importance, since the proportion of direct radiation reaching the occupant is very small in any case. Furthermore, the possibility of an occupant being shielded from the direct radiation from a floor panel is about as great as his being shielded from the direct radiation of a panel in any other location in the room.

Fortunately, however, as has already been mentioned, the energy radiated directly from the panel to the occupant is not of great importance since this is only a small percentage of the total energy radiated to the occupant. By far the largest part of the energy reaching the occupant by radiation is the reradiated energy. Since the radiant panel, whether it be in the floor, wall, or ceiling, radiates in all directions, most of the energy which it radiates will be intercepted by the other surfaces of the room. These surfaces may become warmed to some extent, and in any case they reradiate most of the energy that is radiated to them from the panel and thus every surface of the room becomes a radiant panel, but emitting energy at lower rates since the temperatures are not as high as that of the main panel. In this way energy is reradiated in every direction from every surface in the room, some to be reradiated in turn by the other surfaces, some striking the occupants of the room. In this way, the occupant receives radiant energy from every direction.

Even receiving this radiated or reradiated energy from all directions as he does, the occupant may and probably will radiate more energy than he receives. This is because his surface temperature or the temperature of his clothing is higher than the mean radiant temperature of the room. But by receiving the radiant energy that he does from the room surfaces, the net interchange is slowed down and the rate at which the occupant dissipates heat by radiation is controlled.

This is the fundamental difference between convection heating and radiant heating; in convection heating the rate at which the body dissipates heat by

convection is controlled with little attention being given to the rate of dissipation by radiation, while in radiant heating the opposite is true.

This also leads to the explanation of why radiant heating may be more economical than convection heating. One of the largest heat losses involved in heating a house is usually due to the heating of the air which leaks in through cracks, or, in other words, the infiltration losses, or the heat required to heat the air brought in by the ventilating system. The amount of heat required to warm this air depends upon the quantity of air and the temperature rise of the air occurring during the warming process. Naturally, if the same amount of air is not warmed to as high a degree of temperature, less heat will be required.

In a radiant heating system, the air temperature may be slightly lower than would be required in a convection heating system, and in some cases it may be considerably lower. Thus one of the sources of heat loss is reduced, the reduction depending upon the extent to which the temperature of the room air may be allowed to fall and still maintain the desired comfort conditions.

Experience has proved that there are several other advantages resulting from the lower air temperatures which are permissible in a radiant heating system. One of these is the higher relative humidity of the room air without the use of a humidifier, which results in a feeling of increased freshness of the air. People who have lived in radiant-heated houses have noticed a definitely invigorating effect of the air and the absence of the feeling of stuffiness that is often noticeable with convection type heating, especially warm air systems.

The absence of stuffiness and the feeling of freshness is quite probably due to another important feature of radiant heating. Since in this type of heating there are no hot surfaces with which the air comes in contact or over which the air must flow, there is no possibility of the air becoming "used up" or "burned." Of course, the air is not burned in a literal sense, but there is considerable evidence that when air is heated beyond a certain point a change in the ion content of the air takes place which has an adverse effect upon the air. Such air causes a feeling of drowsiness and stuffiness, causes headaches and irritations of the mucous membranes, possibly due to the higher positive ion content which results from the air being heated. Air which has a high negative ion content, on the other hand, has a pleasant, invigorating effect and has the desirable qualities of a healthful atmosphere.

This is not to say that a radiant panel heating system has in itself any air-conditioning properties. It seems well established, however, that such systems do not have the deleterious effects on the air in the heated space that many other types of systems do have, and that the air in the radiant-heated houses is fresher, more invigorating, and less conducive to colds and to nose irritations.

Radiant heating has been in use in Europe, particularly in England, for a number of years, and consequently much progress in the development of this method of heating has taken place there. Most of these systems use water as the heating medium.

Probably the greatest number of the complete panel installations in Europe are of the sinuous, embedded coil type. In an installation of this kind the hot water coils, which may be made of copper, but more often of wrought iron or steel, are embedded in the plaster of the ceiling or wall, or possibly the concrete floor. Other types include sinuous hot water coils to which are attached metal plates that are heated by the coils and act as the radiant panels. These may be mounted in ceilings, walls, or floors.

Another type of system that has been developed in Europe is the cast iron panel consisting of cast iron waterways made in sections to which are attached

panel plates which also are made of cast iron. The waterways sections are placed in recesses in the walls or ceilings and the panel surfaces attached after the sections are in place. Panels of this type do not usually cover the entire surface of the wall or ceiling in which they are placed.

Still another type of cast iron panel is made with the water passage sections and the plates integral, the waterways having extended surfaces on the backs over which air passes and becomes heated by convection. Panels of this type are installed to allow for passage of air behind the plates. Thus this type of panel acts as both a radiant surface and as a convector.

In addition to the types of radiant heating installations which use hot water or steam as the heating medium, systems consisting of resistance wires and, of course, utilizing electricity have proved to be quite popular. Several methods of using the resistances have been developed, but what is possibly one of the most ingenious is the electric fabric type. This is a type of fabric in which the wire or electric resistance element is woven. The element is electrically insulated so that there is no danger from contact with the fabric. The fabric is made in pieces of standard sizes and of standard capacities. This fabric is hung like wall paper and may be permanently attached or may be attached in such a manner as to make it readily movable.

In addition to a number of European residences which are radiantly heated, banks, churches, factories, hospitals, hotels, offices, schools, public buildings, and stores are being heated by radiant heating systems of various types. An interesting fact in this connection is that, due to its inherent characteristics, radiant heating is in evidence in the larger types of buildings particularly.

Even though radiant heating has become popular in this country very recently as compared with Europe, where it has been available to some extent for at least twenty years, a great deal of development work on this type of heating has been done in this country, and the number of installations of radiant heating is increasing very rapidly.

While a considerable number of the installations in this country are in commercial and industrial buildings such as garages, hangars, shops, and factories, an increasingly large proportion is in houses. Probably the largest per cent of the radiant heating applications in this country so far are hot water systems. These installations consists of the water heater, a water pump for circulating the water through the coils, sinuous coils or grid or header and tube arrangements, and the thermostatic control.

Some systems of this type have refinements such as modulating control whereby the quantity of the water as well as the temperature of the water circulated through the coils is varied according to the heat demand of the space being heated.

The hot water coils, either of the sinuous coil or grid construction, are embedded in the concrete floors, concrete or plaster walls, or concrete or plaster ceilings. Both copper and wrought iron or steel tubing and piping are being used for the hot water coils. When iron or steel tubing is used, welded construction is most common, eliminating the possibility of leakage from any of the large number of otherwise required threaded joints.

When coils are to be embedded in concrete, the coils are first fabricated and then laid in place. They are then tested for leaks at a pressure considerably in excess of that at which the system is to operate. This pressure is sometimes maintained while the concrete is being poured and, in any case, the system should be tested again after the concrete is poured. The coils are often laid on gravel or fine aggregate to insure even support. In order to facilitate the distribution of the heat throughout the concrete mass, the reinforcing rods or

a heavy iron mesh may be laid over the coils and in contact with them before the concrete is poured. A layer of from one inch to two inches of concrete, measured from top of tube to floor surface, has been found satisfactory. The thickness of concrete depends upon the diameter of the tubing used as well as other details pertaining to the floor itself. When the concrete floor is laid directly on the ground, it has been found to be of some advantage in decreasing heat flow into the ground to pour first a slab of low density or "insulating" concrete on the ground and then pour the concrete floor on top of this.

Another system using hot water coils in connection with concrete floors, especially where a wood floor is laid over the concrete, is, perhaps, a little easier to construct. With this method the coils are laid on the concrete floor and furring strips are laid, as required, between the piping or tubing. The sub-floor and the finished floor are then laid on the furring strips. The flooring should be well seasoned and laid on the furring strips for two or three days with the hot water circulating in the coils before the flooring is nailed down.

Hot water coils can also be installed between floor joists. If both the spaces above and below the floor are to be heated, one system of coils can by such an arrangement be used to heat both spaces. However, such an arrangement would require very careful designing in order to obtain the proper distribution of heat to the two spaces. If the space below the floor is not to be heated, sufficient insulation must be placed in the joist spaces or below the joists to prevent heat losses in the downward direction.

When the coils are to be embedded in plaster, either in the walls or ceilings, it has been found to be quite satisfactory first to cover the studes or joists, as the case may be, with wire lath. The coils are then placed on the lath and fastened to the lath by wires, the coils being supported also in any other way desired. With the coils hung in this way, in contact with the metal lath, the temperature distribution is improved and the heat dissipation over the entire panel made more uniform. The plaster is placed over the coils, embedding the coils completely. A good job of plastering is particularly advisable here in order to lessen the possibility of cracking the plaster when the heating system is in operation. The coils may also be mounted directly on plaster board instead of metal lath, but the metal lath method is probably preferable.

It is not necessary that the radiating surface be of plaster or concrete, or in the case of floors, wood. As has already been mentioned, metal, particularly, if it is rough and unpolished, makes a very good radiant surface. Metal plates can be used anywhere that radiant surfaces are required. When metal plates are used, it is advisable to weld or braze the coils to the backs of the plates, if possible.

There are practically no limitations as to the type of system or equipment used for heating the water for any of the hot water coil radiant panel heating systems. Practically any equipment which has the capacity to heat the required amount of water to the desired temperatures can be used.

Systems of this kind can be controlled by room thermostats of ordinary design, although thermostats with elements sensitive to both radiation and ambient air temperatures are preferable.

The disadvantages of hot water systems as compared with those of electric systems, for example, are primarily the initial costs of the installation requiring the hot water heater, piping, chimney, etc., which in the electric systems are not involved.

The principal advantage of the hot water system, assuming modulating control is provided, is the possibility of control to provide for a very close correlation between heat demand and heat supply. This may be accomplished by

controlling both the temperature and the quantity of water circulated through the coils.

The cost of a sytem of this kind should be somewhere between the cost of a warm air convection system and a hot water radiator system, as the cost of the furnace and hot water heater should be about the same, while the cost of the hot water coils for the radiant system should be less than the cost of the radiators and piping for the radiator-convection system.

Another fairly recent development in radiant heating is the so-called radiant baseboard. These baseboards are somewhat similar to the cast iron panels which were described under the European developments. These baseboards are made of cast iron and are from 6 to 10 inches high. When installed they replace the usual wood baseboard.

These baseboards are usually installed along the outside walls only. If calculations show that when installed in this way the heating capacity is insufficient, they may also be installed on the inside walls.

The panel surface and the waterways, both of cast iron, are made integral and in sections in various lengths in multiples of a foot. They can be used with either gravity or forced circulation hot water systems. They can also be used with steam, but probably hot water is more satisfactory. The outstanding

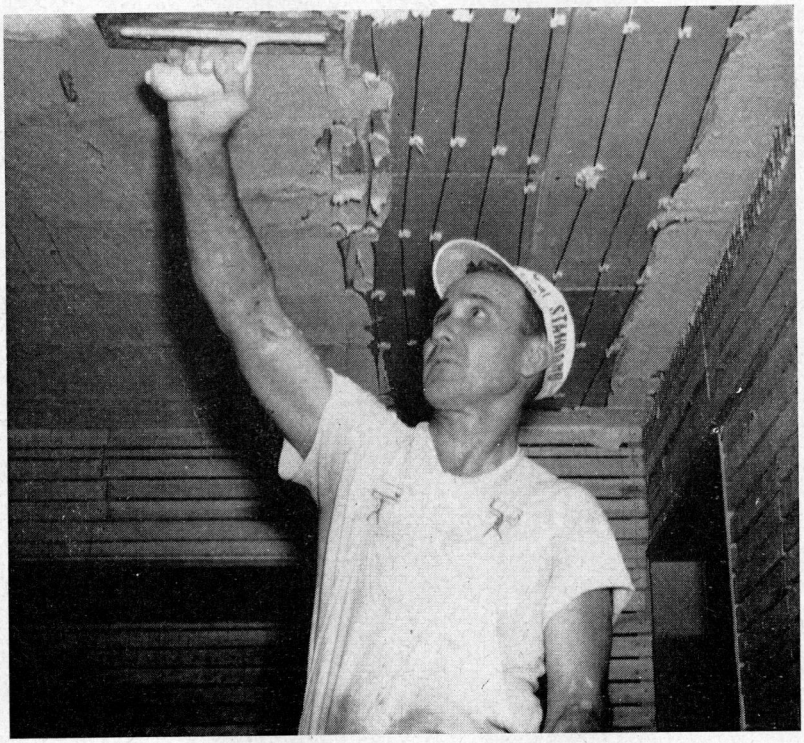

Figure 4. EMBEDDING RESISTANCE WIRE IN PLASTER TO FORM AN ELECTRIC RADIANT CEILING PANEL.

feature of the radiant baseboard is the low temperature gradient between floor and ceiling. This means, indirectly, warmer floors and a little higher air temperature close to the floors.

In addition to the considerable number of hot water radiant heating installations in this country, there are also a few installations which use warm air for heating the radiating surfaces. This is accomplished by passing warmed air over the back surface of the panel, the panel being heated by the warm air which then returns to the furnace to be reheated and recirculated. As already indicated, this method has not been utilized to any great extent.

Considering all radiant panel heating systems in this country, hot water installations probably predominate in number. However, in certain parts of the country, particularly where power rates are low, electric or embedded wire systems may outnumber all others.

In electric applications, electric resistance wires act as the heating elements. These wires may be of copper, bronze, or other alloys. The wires are usually covered with special insulation, although some experimenting is being done with bare wires.

The most common method of application is to embed the wires in the plaster of the ceiling, and in some cases, in the plaster of the walls. The wires are attached by means of special fasteners to the lath or plaster base and are usually strung to cover the entire ceiling area at from 2- to 4 inch spacings, depending upon the length of wire needed for the required overall resistance. The plaster is then applied over the wires, embedding them to a depth of from ¼ to ½ inch.

The wires should be strung closer together over the ceiling areas which are close to windows. Since, for any given kind of wire, the heat dissipated from an electric panel of this type is directly proportional to the length of resistance wire included in the area, placing the wires closer together will result in a greater length of wire for any given area and, consequently, results in supplying that area with more heat. Ceiling surfaces close to large window areas radiate to the windows more heat than ceiling areas which are farther away and consequently provision should be made to provide greater heating capacity in those areas close to the windows.

Because of the possibility of magnetizing the metal lath which would result in a noticeable hum or vibration, electric resistance circuits of this kind should not be installed over metal lath or expanded metal plaster base.

The methods of installing electric resistance wires as outlined above apply primarily to new construction, although, of course, the resistance wiring could be installed on old plaster and the new plaster applied over the wiring.

Rooms or spaces which require less than, say, 3½ kw of energy for heating may be wired with only one circuit. The maximum capacity of any one circuit should probably not exceed 3½ kw. However, there may be some advantage in splitting the circuit to even less capacity than this. With the proper control and switching arrangement, a circuit split in two would offer four possibilities. The two circuits could be used in series, in parallel, or as two individual circuits. Such an arrangement would offer some possibilities of heat capacity modulation, should modulation of this kind prove advantageous.

However, most electric radiant heating systems installed to date have only one circuit per room, and in some cases more than one space, such as small rooms or halls, may be on one circuit. In the cases where more than one circuit is installed in a room, this has been done for one of two reasons: either to split the load to keep the demand of any one circuit below 3½ kw. or to obtain some degree of energy modulation as limited as it is. The scheme of using two

circuits in any room having heat requirements large enough to justify the installation of two circuits may be a very desirable arrangement, especially if the two circuits are of different capacities. Such an arrangement of circuits would probably require either a separate thermostat for each circuit or one thermostat that would control both circuits in steps. Either arrangement would provide two or possibly three different heating capacities: circuit No. 1 alone, circuit No. 2 alone, and both circuits Nos. 1 and 2 operating at the same time. Thermostats of ample capacity to control such circuits directly across the line are available. Thermostats of this kind eliminate the necessity of auxiliary transformers and relays.

If modulating type control is not provided in the resistance circuits, and the circuit control depends on the ordinary type thermostat, then such control will be merely off-and-on control. A considerable number of radiant heat installations equipped with this type of control indicate that such control is quite satisfactory. Some type of modulating control, however, might well prove to be a real factor in improving the performance of these systems.

There is also at least one type of portable radiant panel electric heater on the market at the present time. This heater consists of a glass panel mounted in a frame mounted on a base that holds the panel and frame in a vertical position. This type of heater is primarily for auxiliary use.

The panel is made of two layers of glass between which is the grid of very thin aluminum fused to one of the pieces of glass. The panel is approximately 18 x 22 inches in size. The whole unit is a fairly attractive heater. One of the principal advantages of this particular type of heater is that there are no exposed high-temperature elements on which a person could get burned or which would burn an object which might fall against it. In fact, this heater has most of the advantages of radiant heat except that the panel surface temperature is probably higher than the optimum for best results.

At the present time, there are at least two, and possibly more, manufacturers making prefabricated electric radiant panels. The panels of these manufacturers are so designed that they can be installed in new or old construction. This is a feature of considerable importance as it makes possible the use of electric radiant heating in houses that may not have been specifically designed for it.

One of these two types of prefabricated panels is made of glass. The heating element is a grid of very thin aluminum that is fused onto the back surface of the tempered glass panel. The front or radiating surface of the glass is sand-blasted or frosted and can be painted or left unpainted. A $\frac{3}{8}$-inch layer of gypsum board is mounted on the back of the panel and aluminum foil backing is optional. The complete panel is about $\frac{5}{8}$ inch in thickness. The panel units are framed by metal borders which serve to hold the unit assembled as well as to provide means for mounting the panels. Terminal connections are provided for wiring the panels. These panels are made in various sizes, all of them being 16 inches in width and in lengths varying from 16 inches to 48 inches. All panels are designed for a heating capacity of 72 watts per square foot of panel area at 220 v and for surface temperatures of 180 F when mounted horizontally and 160 F when mounted vertically in an ambient temperature of 70 F.

This type of panel is not designed for overall surface coverage, but for border installation. For ceiling installations the manufacturer proposes that the panels be mounted close to the intersection of the walls and ceilings. If the heat requirements of the particular room in which the panels are to be mounted are such that the ceiling border of panels is not required all around the room, then the panels may be placed only along the outside walls.

The use of these panels is of course not restricted to ceiling mounting. They may be placed on walls in any location where they are required. There would be some advantage, when so used, in mounting them adjacent to windows or outside doors. Neither is it necessary that the panels be arranged as a border around the ceiling. They may be staggered checker-board fashion over the entire ceiling surface, that is, with only a part of the ceiling area covered by panels, with the panels distributed over the whole ceiling.

The principal advantage of this particular panel is that it can be installed in old or new construction. The panel has a good appearance except for the metal frame and mounting strips which could be improved. The high rating of the panels might be of some advantage but, on the other hand, this might in many cases be an objectionable feature. Probably the most satisfactory condition for radiant heating is to have the entire ceiling act as the radiant panel in order to insure the best heat and temperature distribution in the room. The use of panels of high unit area energy capacity requires extremely careful study in order to insure satisfactory heat distribution. Otherwise, the danger of an installation of panels of this kind resulting in one part of the room being cold and another part hot is quite apparent.

Another type of prefabricated panel that is now in experimental production by a reputable manufacturer in this country is of somewhat different design than the glass panels just described. This panel consists of a layer of electrically conducting material laminated between a top layer of fabric and a back layer of ¼-inch asbestos and cement board. Terminal boxes and conduit are mounted on the back of the panel.

These panels have a capacity of about 25 watts per operating square foot of panel area. Being made in 4′ x 4′ and 4′ x 3′ sizes, the capacities are 335 watts and 295 watts, respectively, at 220 volts.

Like the glass panels, these panels are designed for use in either old or new constructions. The fabric surface covering is intended as an anchor for plaster, although the panels may be used plastered or unplastered. To avoid the use of molding strips or channels for covering the joints between panels an over-all coat of finishing plaster is recommended. When installed in new construction the panels may be mounted on joists or studs, and when used in old construction the panels may be mounted on furring strips nailed to the plaster or other wall or ceiling material. Both this type of panels and the glass panels may be controlled by ordinary room thermostats. Such control would, of course, be off-and-on control.

Radiant panel surface temperatures, in the case of ceiling or wall panels, are generally in the range of from 80 to 110 F. Floor panels probably should not exceed 80 F, as temperatures higher than this in floor panels might result in discomfort to the occupants. Assuming surface temperatures in these ranges, using hot water as the heating medium, water in the temperature range of from 95 to 130 F for wall and ceiling panels and from 90 to 105 F for floor panels would be expected.

The advantages of radiant heating as compared to convection heating may be summarized as follows: The radiant panels may be and usually are a part of the ceiling, walls, or floor surface of the room. In the sense that no heating fixtures are visible, the heating system is completely hidden. In addition to the fact that there are no radiators or convectors which take up room space, there are practically no limitations whatever with respect to furniture arrangements caused by the heating system. The range of materials suitable for radiant panels is quite wide, so that there is very little restriction on decorative materials or schemes on this account.

When hot water coils are used in the radiant heating system, these same coils can be used for cooling in the summer.

Very low air temperature gradients between floor and ceiling zones are obtained with radiant heating. This means very uniform air temperature throughout the room, with a possible 3 to 4 degree difference between any two places in the room, as compared with 10 to 15 degrees difference commonly obtained in some convection systems. This means warmed floors and higher air temperatures near the floor with radiant heat.

With radiant heating, particularly with electric panel heating, the house can be divided into as many zones as desired and each zone can be separately controlled. This, of course, means individual room control, with any desired condition being maintained in each individual room.

Room air may be maintained at lower temperatures, resulting in better physiological conditions. Since the air is not in contact at any time with surfaces at high temperatures, the air is not "baked" or "burned," and the ion content of the air is not disturbed, resulting in an effect of freshness and an invigorating atmosphere. This condition results in two distinct economies. One is that due to the "fresh" condition of the air, less ventilation is required; the other is that due to the lower air temperatures, a lower heat loss is involved, resulting in decreased heating costs.

Since the radiant system does not depend on convection currents in the air, drafts are very likely to be materially reduced. This results not only in better comfort conditions, but also reduces the streaking of walls and ceilings by dust and dirt-laden air passing over the surfaces or by precipitation of dirt in the air on cool wall or ceiling surfaces.

One word of caution should be inserted here for the benefit of those who have and those who will become enthusiastic about electric panel heat. Experiences in several localities have indicated that building codes, at least those in some localities, are not written to cover embedded wire panels. Not having been written to cover this particular phase of construction, these codes have no provision for coping with embedded wire panels and, consequently, considerable trouble may be involved in getting such an installation approved by the local building inspectors. It is the National Electric Code which to date has prohibited this type of wiring; the local codes naturally have been guided by the National Code.

There are at least two possible means of correcting this situation. One is that building codes be modified to recognize and provide for this type of heating system; the other is the possibility of prefabricated panels, which are approved by insurance underwriters, being available and meeting the building code requirements. The possibility of building code requirements being a real and serious obstacle in the way of embedded wire electric panel heating should by no means be minimized.

One inherent feature of radiant panel systems that might be considered a disadvantage is the fact that changes in or repairs to the system are very difficult once the system is installed. This is, of course, because the coils or the electric resistance elements are embedded or at least concealed and are, consequently, not at all easily accessible. This does not necessarily apply to prefabricated panels. As more panels of this type are brought out and as further development is made in installation methods and application of radiant heating systems, possibly this one objection may be completely eliminated.

One other disadvantage of radiant heating systems is that separate heating and ventilating or air conditioning systems are required. The objection is not particularly serious, however, for at least two reasons. One of these is that less

ventilating or air conditioning is required for radiant heat. The second reason is that the radiant systems and the convection systems are quite comparable in that the convection systems require separate ventilating and air conditioning equipment also.

IV. A DISCUSSION OF FUELS AND FUEL ECONOMY

While it is not the purpose of this bulletin to go into a detailed discussion of the various aspects of fuels used for heating purposes, it is felt that some discussion should be given to this phase of heating economics.

A great amount of work has been done in determining the efficiencies of various types of furnaces using various fuels. However, a considerable amount of data on this subject is misleading to some extent due to the fact that these data and the efficiencies are arrived at under certain particular operating conditions, and usually the most favorable conditions. In other words the efficiencies usually given are the best efficiencies obtainable in laboratory tests from the particular type of furnace and fuel. Such data do not give a true picture since most home-heating devices operate under varying conditions, sometimes at low load, sometimes at high, and almost always for varying lengths of time. These varying conditions affect not only the efficiency of combustion but the efficiency of the entire heating plant.

A much more informative method of arriving at heating costs for various types of systems and various fuels is based on total costs for a heating season. Such a basis takes into account all conditions encountered during the season. Since seasons and heating requirements vary from one locality to another, some provision accounting for these differences is required.

For this purpose the degree-day method of measuring efficiencies is of some value. This method accounts for the outdoor temperatures and consequently gives a more comparable degree of measurement. However, even this method does not give a direct measure of the efficiency of the heating plants. Since the heat losses of the houses being heated are involved, and vary with the type of construction, a real measure of the heating plants themselves cannot be obtained by this method.

In addition to the cost of fuel, there are a number of other factors which are involved in determining the individual's choice of fuel and heating systems. A number of the advantages and disadvantages of various fuels are here tabulated. These are some of the factors, other than cost, which should be considered in the selection of any fuel.

In addition to the cost of the fuel itself as well as the cost of the heating system, the costs of other facilities necessary for the operation of the system are involved. These costs include the initial cost of the required storage spaces and the chimney or chimneys if required. These are factors which are often overlooked in determining the true costs of heating systems, but they often amount to as much as the heating plant itself.

Storage of sawdust, for example, usually requires a large space. This space is often in the basement, and being in the basement it requires relatively expensive construction. Regardless of where or what kind the storage space is, the cost of this space is chargeable to the cost of fuel or to the cost of the heating plant.

The cost of ash or refuse disposal is chargeable to the cost of fuel or to the cost of operating the heating plant. There are a number of other items which, since they are often a result of the functioning of the heating system, should be considered when a selection of the system and the fuel to be used is

Table 1. ADVANTAGES AND DISADVANTAGES OF VARIOUS FUELS AND OF ELECTRICITY FOR DOMESTIC HEATING*

Heat source	*Advantages*	*Disadvantages*
Wood	(a) Cheerful fire, (b) quick increase in heat.	(a) Low heat value, (b) large storage space required, (c) necessary labor in preparation, (d) does not hold fire long, (e) unsteady fire, (f) fire requires very frequent attention.
Sawdust	(a) Cleanliness, (b) responds quickly to opening of drafts.	(a) Low heat value, (b) large storage space required, (c) necessary handling to and from storage, (d) uncertain supply in some localities.
Anthracite coal	(a) Cleanliness, (b) easy control of fire, (c) easier to realize heat in coal than in the case with other coals, (d) steady heat.	(a) Difficulty of obtaining (b) slower response to change of drafts.
Bituminous coal	(a) Availability, (b) high heat value (in the best grades), (c) low percentage of inert matter (in the best grades).	(a) Dirty, (b) smoke-producing, (c) more attention to fire and to furnace necessary than with anthracite.
Sub-bituminous coal and lignite	(a) Availability (in some regions), (b) responds quickly to opening of drafts.	(a) Slakes and deteriorates on exposure to air, (b) takes fire spontaneously in piles, (c) heat value generally low, (d) heat in fuel difficult to realize, (e) fires do not keep well, (f) gases generated over fire pot sometimes burn in smoke pipe, causing excessive heating in the pipe.
Peat	(a) In general the same as for wood.	(a) Low heat value, (b) bulkiness.
Coke	(a) Cleanliness, (b) responds quickly to opening of drafts, (c) fairly high heat values.	(a) Bulkiness, (b) liability of fire going out if not properly handled, (e) fire requires rather frequent attention unless fire pot is deep.
Oil	(a) High heat value, (b) immediate increase in heat, (c) cleanliness, (d) small storage space necessary, (e) fuel does not require handling.	(a) Unavailability, (b) difficulty or cost of safe storage.
Gas	(a) Ease of control, (b) cleanliness, (c) convenience, (d) immediate increase of heat on demand.	(a) Unavailability, some localities.
Electricity	(a) Every major advantage.	(a) Some systems not approved by current building codes, (b) generally suitable only for new construction.

* U. S. Bureau of Mines Technical Paper 97, with some modifications.

made. The soiling of curtains, drapes, wallpaper, and woodwork by the air circulated by the heating system is a point to be considered. This soiling of the interior of the house may be due to the heating system itself or it may be partly due to the characteristics of the fuel. Cleaning and decorating expense may be a considerable item. Naturally, the system and the fuel that cause the least soiling of the house and its furnishings are the more desirable.

From the standpoint of cleanliness, there is no question that electricity and electric heating systems rank first; next in order of cleanliness is gas, and then oil. None of these fuels causes any dust or ash that might be circulated through

the house, and a well-designed and efficiently-operated oil-burning system would give very little trouble from the standpoint of smoke.

Assuming that the cost of electric energy is such that its use is justifiable from that standpoint, it is unquestionably the most desirable source of heat obtainable. Electricity offers convenience, flexibility, and ease of control that have been obtained to the same degree with any other source of heat. No labor is required for handling fuel either to or from storage, no storage facilities are required, no handling of ash or refuse is involved. The oxygen content of the air is not disturbed; obnoxious gases are not produced; there is no danger from open flames or unburned gases. In regions where electric power rates are low, electricity is rapidly becoming the accepted source of heat for domestic use. A brief discussion of the use of electricity for domestic heating in several localities is contained in the following section.

V. HEATING WITH ELECTRICITY IN THE UNITED STATES

The use of electric energy for heating houses will probably never become predominant or even generally established throughout the country. The use of electricity for heating purposes will probably always be confined to those regions where the power rates are low. This does not mean that electricity is not being used or will not be used unless it can be obtained as cheaply as other fuels. Electricity is being used and will be used wherever it can be obtained at a rate which makes its cost comparable with other fuels when both its direct cost and its advantages are compared with those of other fuels.

There are two regions in this country where electric energy is being used extensively for domestic heating and its use for this purpose is rapidly increasing. These two regions are those in the southeastern part of the country served by The Tennessee Valley Authority and local private utility companies, and the northwestern part of the country served by the Bonneville Power Administration and by private and municipally owned utility companies.

In both of these regions electricity is competing not only with the more costly imported fuels but also with fuels indigenous to the respective regions: coal in Tennessee and adjoining states, and wood and sawdust in the Pacific Northwest. Both regions have an abundance of hydroelectric power; both regions have moderate winter weather conditions.

The implication that these two regions are the only ones in which electric heat is used to any extent is not intended, as there are other regions in which electricity is being used for heating purposes. In the San Francisco Bay region of California, for example, where relatively cheap fuel oil as well as natural gas are both available, electric heating is definitely increasing. More data are available, however, pertaining to the experience with electric heating in the Tennessee region and the Pacific Northwest than in any other localities.

A study was made, for example, of the electrical requirements of 14 small houses in Knoxville, Tennessee, covering the heating seasons of 1942-43, 1943-44, and 1944-45. The average degree-day deficiency per year in this locality is 3665.

These 14 houses were rather small, the average floor space being 788 square feet and the average volume being 6304 cubic feet. These houses were well insulated and weather-stripped all around.

The total electric energy supplied to these houses for all purposes was metered. All purposes include heat, lights, water heating, cooking, and all other

electric appliances. The average total electric energy used by these houses, per year, and averaged over the three-year period was 13,655 kw-hr; the average annual electric bill was $121.83. While power rates varied depending on amount of electricity used for all purposes per month, the average rate was 8.82 mills per kw-hr.

Inasmuch as there are more than 1000 houses in the Tennessee Valley that are equipped for complete electric heating, these data pertaining to the 14 houses give a far from complete picture of the electric heating installations in this region. However, for small houses that were designed, built, and insulated for electric heating, the data probably give a reasonably fair picture.

A considerable amount of data on electric space heating has been obtained from the Pacific Northwest. In Richland, Washington, for example, 1820 houses were electrically heated during the war. These houses were built to house employees of the Manhattan Project's Hanford Plant and were small, prefabricated structures, well insulated. Electricity was used for heating, cooking, water heating, lights, etc. Since the cost of all of the electricity furnished to these houses was included in the rent, the houses were unmetered. However, test meters were installed on a feeder line serving 250 houses.

The maximum demands for electricity in these houses occurred in December and January and were approximately 6 kw per house. The minimum demands occurred in July and August and were approximately 1 kw per house. The minimum kw-hr consumption was 17 kw-hr per house per day; the maximum was 100 kw-hr per house per day. The heating load then varied from approximately 85 kw-hr per day per house to zero. These houses were equipped with 2 kw portable radiant-convection thermostatically-controlled unit heaters.

Here, again, the data are inconclusive and incomplete. Without specific knowledge as to the sizes of these houses, something about the occupancy, etc., these data are of only limited value.

Data that are probably more representative and more informative are available from the Public Utility District No. 1 of Cowlitz County, Washington. In the city of Longview, which is served by this Public Utility District, there are at least 60 houses using electric heat. A rather thorough study has been made of the performance and of the electrical requirements of these heating systems as well as all other electric services in a number of these houses.

An analysis of the electric services of 38 of these houses for the entire year of 1944 reveals a considerable amount of information which is both interesting and reliable.

The houses included in this study are all fairly small, the number of rooms varying from five to seven, the average being six. The average volume per house is 8,232 cubic feet. All houses were designed for using electric heat; every house was well insulated and weather stripped.

For the year 1944, with 4996 degree days, the average total electric consumption was 17,976 kw-hr; average total billing, $145.21. The average cost of this electricity was about 8.1 mills per kw-hr.

Of this total billing of $145.21, the amount of $68.59 was chargeable to electric heat; the balance to other domestic uses which include cooking, lights, water heating, etc. This amounts to an annual consumption of 1.27 kw-hr per cubic foot for heating, or an average annual cost of 8.3 mills per cubic foot.

All heaters used in the installations are radiant-convection, thermostatically-controlled unit heater type. These are not portable heaters, but are built-in heaters, placed in the studding space and mounted flush with the wall surface, or protruding slightly.

The electric consumption chargeable to heating for the year 1944 varied

quite widely for individual houses; these charges varying from 0.46 kw-hr per cubic foot for one six-room house to 1.97 kw-hr per cubic foot for another six-room house. Inasmuch as the construction of all of these houses is quite similar, at least as far as insulation and weather stripping is concerned, this wide variation in heating demand can be accounted for only by the number or habits of the occupants. Usually where there are older people or small children, the room temperatures are kept higher. The extent to which outside doors are left open affects the heat requirements. Some people do not heat their bedrooms at all, while others heat their bedrooms regularly. All of these conditions are factors which affect the over-all heating requirements.

Since the average consumption of electric energy chargeable to heating amounts to 0.283 kw-hr per thousand cubic feet per degree day, based on a deficiency of about 5100 degree days per year for Longview, this allocation of electricity for heating purposes appears to be quite reasonable and indicates about what can be expected in a house properly constructed and insulated, and using electric unit heaters.

A study has also been made of a number of electric heating installations in Portland, Oregon. In 1943, a 4244 degree-day year, the study covered 20 electrically-heated houses. These houses varied in size from three to eight rooms, the average being five rooms, and nearly all of the houses were insulated in walls and ceilings and were weather stripped. The average volume per house was 7,971 cubic feet. The average total electric service, per year, was 15,673 kw-hr, the average total electric billing was $166.41. The average service chargeable to heating was 8,809 kw-hr and the average billing chargeable to heating was $75.54. These data from Longview and Portland are for typical years and have been consistently repeated.

Based on these figures, the average cost per kw-hr for all purposes was 1.06 cents; the average cost per kw-hr for heating only was 8.6 mills. The average electric consumption in kw-hr per cubic foot of house was 1.11; the average annual heating cost per cubic foot was 9.5 mills. Based on the total average figures, the annual consumption of electricity per 1000 cubic feet per degree-day was 0.252 kw-hr.

The annual consumption of electricity in kw-hr per cubic foot varied from 0.52 for one seven-room house to 1.83 for a five-room house. This spread in kw-hr per cubic foot of space was in all probability not due directly to the difference in the sizes of the two houses, but was much more probably due to the living habits of the occupants. One three-room house included in this study also had a consumption of 1.83 kw-hr per cubic foot. This is the only house in the group that had only ceiling insulation and no weather stripping. The annual cost of heating per cubic foot of this house was 1.48 cents, while that for the five-room house was 1.59 cents and that for the seven-room house was 0.43 cent.

One other rather extensive installation of electric heating which has provided considerable data in the field of domestic heating is that at Mason City at Grand Coulee Dam in Washington. The original system here included 286 residences and 61 bunk houses, all of which were heated 100 per cent electrically.

As has already been indicated, there is a definite trend toward the use of electricity for heating purposes in those regions of the country where power rates are low enough to justify its use for this purpose. However, a word of warning in this connection is warranted.

Electricity is relatively expensive for heating purposes. On a basis of cost per energy unit alone, electricity probably competes in very, very few places. Because of its advantages of convenience, cleanliness, flexibility, etc., many

people are, and more will be willing to pay the higher cost of electricity. To bring the cost of electric heating down far enough to make its use attractive, even with its many advantages, certain precautions must be taken.

First, heat losses of the house to be electrically heated must be reduced to an economic limit. This is done by insulating, weather stripping, and double glazing to an extent beyond which further heat loss reduction would not be compensated for by the resulting saving in electricity. This limit can be determined for any house. Next, correctly-designed and correctly-installed heating systems must be selected. This rapid trend toward electric heating has brought on the market a great number of heaters and furnaces of all kinds. Some of these are good and some are bound to prove decidedly disappointing to their users. While the efficiency of all electric heaters is very close to 100 per cent, that is, all of the electric energy is converted to heat, unless that heat is distributed where it is needed and when it is needed, the heater installation cannot be said to be 100 per cent efficient. The real efficiency of any heating system is based upon the ratio of the heat supplied by it to the heat or energy supplied to it. The heat supplied by a furnace may not all be usable heat. The heat convected or radiated to a basement space by a central heating furnace, for example, may not be useful heat, particularly if it is more than is required to heat the basement space to the desired extent.

It should be remembered that control devices of some kind, usually thermostatic, are almost always required for proper heat control and heat or energy conservation.

No matter what type of heating system is desired, or what kind of fuel is to be used, there is no doubt that improved models are already designed and will be available within a reasonable length of time. The public as a whole is becoming more conscious of the desirability of good heating, ventilating and air-conditioning systems, and the proper house construction that is required to make these things possible. Indications are that they are going to get them.

VI. SAFETY

Probably any discussion of house heating and house heating systems would not be even reasonably complete without some discussion of the hazards involved in these systems and means of eliminating or avoiding these hazards.

Probably every type of heating system as yet devised has some characteristic or factor connected with it which can be hazardous if proper precautions are not taken.

The possibility of explosion is present with practically every fuel-burning system. For example, under certain conditions which are usually brought about by insufficient air being supplied to the combustion chamber, an accumulation of combustible but unburned gases may be present. In an oil or gas burner this accumulation may be due to improper ignition; in a coal-burning furnace or a sawdust burner this is usually due to the dampers being closed too far to allow enough air into the combustion chamber to burn the fuel, or the gases that are formed. These unburned gases then fill the combustion chamber and in many cases move on up into the flue pipe. When they are ignited they are likely to explode with resultant damage to the furnace and flue pipes and the consequent possibility of fire. In the case of a sawdust burner, such an explosion, aside from the damage done to the furnace, may scatter smoldering sawdust out of the burner.

In the case of a gas furnace, this hazard can be avoided by being sure that the pilot is functioning properly and that sufficient venting facilities are pro-

vided to assure the removal of all burned or unburned gases. Most modern gas furnaces are so designed that the gas will not be supplied to the furnace unless the pilot is burning. However, should gas be so furnished to the furnace without the pilot igniting it, due to some mal-functioning of the pilot, this condition is not too dangerous providing the vents are large enough to carry off the unburned gases and provided that no igniting element or flame is brought into the furnace before the gas has been vented off.

Practically the same remarks which have been made pertaining to gas furnaces also apply to oil burners.

In coal-burning furnaces, the explosion hazard can be avoided by always providing sufficient draft either to carry away unburned gases or to provide sufficient air for combustion; or by being sure that a flame or hot coal is always present or exposed in the furnace. This explosive condition in a coal furnace is often brought about when the fire is being banked. In these cases coal is piled on top of the hot coals and the dampers and drafts are closed. The hot coals then heat the coal, driving off gases which may not burn either because there is not sufficient air to oxidize the gases or because there is no flame to ignite the gases. When banking a furnace fire, this situation can be avoided by piling the coal to one side of the fire bed, leaving some of the live coals exposed. These coals will then ignite the gases as they are formed and will not allow any to accumulate.

When not operated correctly, sawdust burners, particularly, are apt to explode or backfire. This can be avoided by leaving the lower draft open just enough to supply sufficient air to the grate to burn the sawdust instead of letting it smolder to form gases that would not burn without sufficient air.

Another hazard common to nearly all combustion systems is that resulting from leaky or defective flues. The hazard here is not only that of fire but also the possibility of the flues leaking obnoxious gases to the house. Care should be taken to make certain that all flue pipes are in good condition, that all joints in the pipe are tight and that the connection between flue pipe and chimney is well made. The chimney itself should be sound and free from cracks, loose bricks, or loose mortar. With all of these things taken care of, not only would the system be safer, but the result would be a better performance of the furnace due to better draft.

It is also imperative, particularly in warm air systems, that the fire pot or combustion chamber be air tight and free from leaks of any kind. Otherwise, there is always the danger that combustion gases will leak into the warm air space and be carried to the rooms being heated. For this reason it is advisable, in the case of forced circulation systems, to place the fan on the cold air side of the furnace rather than on the warm air side. Such an arrangement tends to force the combustion gases back into the combustion chamber rather than to draw them into the warm air being circulated as would be the tendency if the fan were on the warm side of the furnace.

There is some danger in steam heating systems and, to a less degree in hot water systems, of boiler explosion. This hazard can be avoided entirely by providing the system with a sufficient supply of water at all times and by providing a safety valve on the water heater or boiler. Safety valves should be kept in working order at all times.

Limit controls are effective in preventing overheating of the furnace. In some installations, however, there is danger due to the overheating of flue pipes which are too close to partitions, joists, or other inflammable material. The most dependable means of eliminating this danger is either to be sure that the flue pipe is not too close to any inflammable material or to insulate the flue

pipe. When it is necessary to run flue pipes through partitions, at least wooden partitions or those made of any other inflammable material, the opening in the partition should be amply large to assure sufficient clearance between the flue pipe and the partition. Placing a good insulator around the flue pipe where it passes through the partition is also effective in reducing the fire hazard.

While wood and coal stoves do not have any inherent characteristics that result in hazardous conditions other than those already mentioned, the methods employed by many people in building and maintaining fires in heating devices of this kind are extremely dangerous. The methods referred to are principally the practice of starting and maintaining fires with the use of kerosene, and in some cases, even gasoline.

Putting kerosene on cold kindling in a cold stove is not especially dangerous. Because of its explosive characteristics, gasoline should never be used for this purpose, however. Neither kerosene nor gasoline should ever be thrown on live coals or on embers. Many explosions, severe burns, fires, and fatalities have resulted from both kerosene and gasoline being thrown into stoves containing live coals or going fires. This is one extremely serious hazard that can be avoided by the application of a little common sense.

Some of the hazards of unit gas heaters have already been mentioned. Being high temperature, open flame heaters, units of this type must be used with precaution. It is important that nothing be placed too close to these heaters while they are operating, as the high temperatures may easily set something on fire. These heaters should never be used in a tightly closed room as they can very rapidly exhaust the oxygen in the air. There is the additional possibility that the flame may be blown out or otherwise extinguished with the gas still turned on. Such a possibility is extremely hazardous not only because the gas may cause asphyxiation of the occupants, but also because of the danger of explosion caused by the gas becoming ignited. To avoid the situation, care must be taken to keep heaters of this kind out of drafts that might blow out the flame, and to see that sufficient air is supplied to the room to keep the gas burning. Should the flame be extinguished, however, it is extremely important that the room or house be thoroughly aired to remove all gas from the enclosure before the heater is lighted again.

The possibility of fire hazard in connection with the high temperature radiant-convection unit electric heaters seems quite apparent. As with the unit gas heaters, objects should never be placed too close to these heaters. Since this type of heater consists in part of a glowing or high temperature resistance element which is exposed to the air, inflammable liquids or gases should never be used in a room or closed space where a heater of this kind is operating.

There is one inherently hazardous characteristic of electric heaters and electric appliances of all kinds which is not common to any other type of system; that is the danger of shock and even electrocution itself.

Properly designed, properly maintained, and correctly operated, an electric circuit offers only remote possibility of danger due to shock. Too many people, however, do not realize the danger of poorly maintained or unrepaired electrical equipment, or the potential danger of shock which may result from improperly operating that equipment.

No electrical appliance should be turned on or off by a person with wet hands or by a person standing in water if the switch used is not of the pull-cord type and the cord dry. No electric socket, switch or appliance of any kind should be touched by a person in a bath tub. No person should turn an electric switch off or on while holding onto a connected water pipe or

faucet or any other metal which is grounded. These are all simple, common sense precautions, but a strict observance of them would save many lives.

No attempt has been made here to magnify the hazards or dangerous possibilities of various types of heating systems. All of the hazards cited here are quite possible unless sufficient precautions are taken to prevent them. With the required safeguards provided and the necessary precautions taken, all of the various types of heating systems described herein can be operated without danger. This is substantiated by the safe operation of thousands of heating plants of all kinds throughout the country.

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