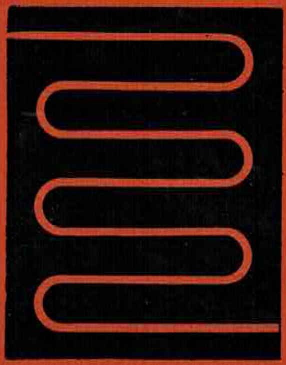
RADIANT PANEL HEATING

A Non-Technical Discussion



REVERE COPPER AND BRASS INCORPORATED

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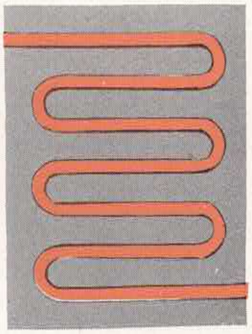

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Introduction to
RADIANT PANEL HEATING

A non-technical descriptive introduction to panel heating; intended primarily for architects, engineers, and heating contractors, who seek a background sufficient to enable them to compare radiant panel heating with other types of heating systems.

Answers the Questions:

1 What are the advantages, claimed and assured, of radiant panel heating?

2 What are the disadvantages, claimed and assured, of radiant panel heating?

3 What are the relative advantages of ceiling panels, wall panels, and floor panels?

4 What are the best methods of distributing the panel surface?

Prepared by

Research and Development Department, Staff and Consultants

of

REVERE COPPER AND BRASS INCORPORATED

Foreword

DURING the last five years there have been many evidences of a growing interest in the radiant panel type of space heating system. The technical literature contains innumerable articles detailing the intricacies and complexities of various design procedures while the semi-technical publications present a mass of often conflicting evidence to prove or disprove the merits of this system. Where in this confusion of claim and counter-claim does the truth lie?

In an attempt to provide an authoritative and impartial answer to the above question the staff of the Research and Development Department of REVERE COPPER AND BRASS INCORPORATED, assisted by technical Consultants, have prepared the material which appears in this booklet. As fabricators of a basic material which finds successful application in all types of heating systems REVERE COPPER AND BRASS INCORPORATED obviously has nothing to gain by advocating radiant panel heating or any other particular method of heating. We do feel, however, that in presenting the facts we can aid our customers and prospective customers in the field of panel heating just as we have, whenever possible in the past, presented facts which were of value to those of our customers and prospective customers whose interest lay in convector, radiator, or other types of heating systems.

The material which follows presents no conclusions and offers no recommendations. We have searched the literature for such unquestioned facts as are available on the subject of panel heating. These facts we have presented as disinterestedly as possible and with the thought only that they be made available, as evidence, from which the architect, heating contractor, and prospective home-owner can reach their own conclusions and make their own recommendations.

R. A. Wilkins

R. A. WILKINS, *Vice President*
REVERE COPPER AND BRASS INCORPORATED

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SUMMARY FOR BUSY READERS

The purpose of a heating system is not to heat the house, nor the occupant, but to prevent the occupant from losing body heat too rapidly. Radiant heating theoretically makes up by direct radiant transfer (such as is experienced when in the sun) the excess loss of body heat to cool air. An ideal radiant heating system — which is as yet impractical and probably will long remain so — would permit reducing heating costs of an average residence to approximately $1 per year.

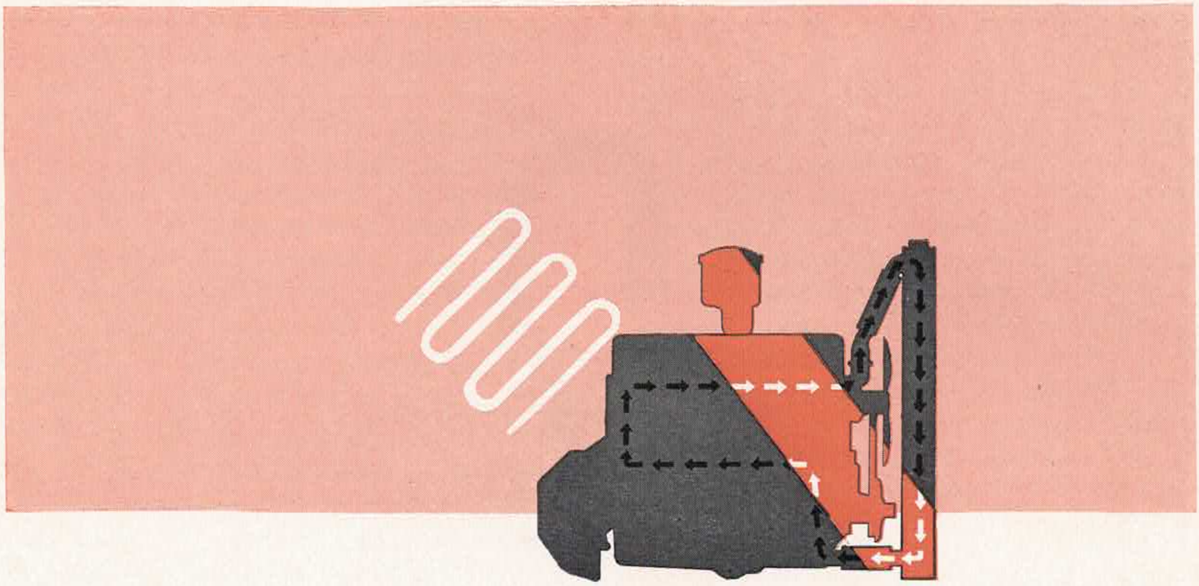
Panel heating is a first approximation — and not a close one — to radiant heating. A panel system consists of low temperature (100° F) heating tubes embedded in the ceiling, walls, or floor of the room. Accurate and dependable cost data are not available, but existing evidence suggests that an average panel installation is likely to have a 10% greater first cost than other comparable heating systems and a 10% lower operating cost. The required area of a heated panel in a ceiling is usually only one-half as great as a floor panel of equal capacity. The first cost of a ceiling installation will therefore be less except in cases where construction differences make the cost of unit area much greater for ceiling surface. When the required area of panel is only a fraction of room area, the heating surface should not be placed in a single panel, but broken up and distributed through the room.

The most significant advantage claimed for panel heating is that comfort can be obtained at a room air temperature less than 70°. This is frequently true, but is not a characteristic found in all installations. When it does exist the advantages are greater comfort, less drying effect, lower operating cost. A careful engineering analysis of any proposed installation will show whether or not reduced air temperature will be realized and, if so, how much.

Significant advantages found with all panel installations are the invisibility of the heating surface, cleanliness, saving in room space, warmer floors, and very uniform heating. Disadvantages found with all panel installations are difficulty of repair or alteration, necessity (in large buildings) of separate ventilation system, and requirement of more complex control. In addition, panels built into heavy masonry structures will have great heat storage capacity with constant lag in response of the heating system to changes in outside weather.

Panel heating has been used, in various forms, for hundreds of years. Within the last twenty years many thousands of panel systems have been installed in every major country in the world. The basic question to be answered, therefore, is not whether panel heating will successfully perform its function — that it will is known with certainty — but whether it is more or less desirable than other methods of heating. The answer to this question will vary with the particular conditions of the individual heating problem as well as with the opinion and the personal experience of the architect, the heating contractor and the home owner. No general answer is indicated. The evidence presented in the following pages is intended to assist, rather than to influence, the individual who must make a decision.

Fully comfortable in radiant sunshine despite sub-freezing air temperature, a skiier stripped to the waist skims down a slope at the world-famed Sun Valley winter resort in Idaho.



WHAT IS A HEATING SYSTEM?

Contrary to popular opinion the purpose of a comfort heating system is not to heat the house. Nor is it to heat the occupants. The fundamental purpose of a comfort system, whether for heating or for cooling, is to maintain an environment in which the occupant will continuously lose heat at a rate equal to that at which the human body produces excess heat.

The human body is a thermal machine comparable in its operation to an automobile engine. In the process of doing work it produces heat. So long as the work continues the production of heat likewise continues. But for a human being, even when seated and at rest, the requirement of doing work is unceasing. The "internal" work required to pump blood through the circulatory system and to operate the "bellows" which constitutes the human respiratory system must be provided at all times. As a consequence of this "internal" work the average adult continuously produces approximately 400 heat units (Btu) of energy per hour, all of which must be lost to the surroundings if the individual is to avoid a rise in body temperature with an associated hazard to health. Thus the human body, like the automobile engine, must be continuously cooled if it is to function properly; actually it need *never* be warmed.

The purpose of a heating or cooling system is therefore to regulate and control the rate of heat loss from the body, but it is never to establish a net heat transfer from the surroundings *to* the occupant. The heating of a house is intended not to warm the occupants but to prevent them from cooling too rapidly.

In air at 50 degrees Fahrenheit an average person would undergo excess loss of bodily heat to the amount of 100 heat units per hour. To prevent this excess loss (by raising the air temperature to 70 degrees) the average house would require an energy input of the order of 30,000 heat units. Thus if there are three persons in the house the heating system consumes *100* heat units for each *one* unit of excess heat loss that it prevents.

From the standpoint of simple arithmetic the above statement is very striking: To save $1 the conventional heating system spends $300. But what can be done about it? The first and most obvious answer would be to allow the air temperature to remain at 50° F and to increase by 100 units the waste heat available for disposal from the body. This could be accomplished if the occupant were to do a relatively small amount of useful, that is, "external," work. The accuracy of this statement can be readily verified since everyone has experienced the warming effect of exercise. But the occupant cannot be expected to work in order to keep warm so some other method must be found of providing the 100 excess heat units.

WHAT IS RADIANT HEATING?

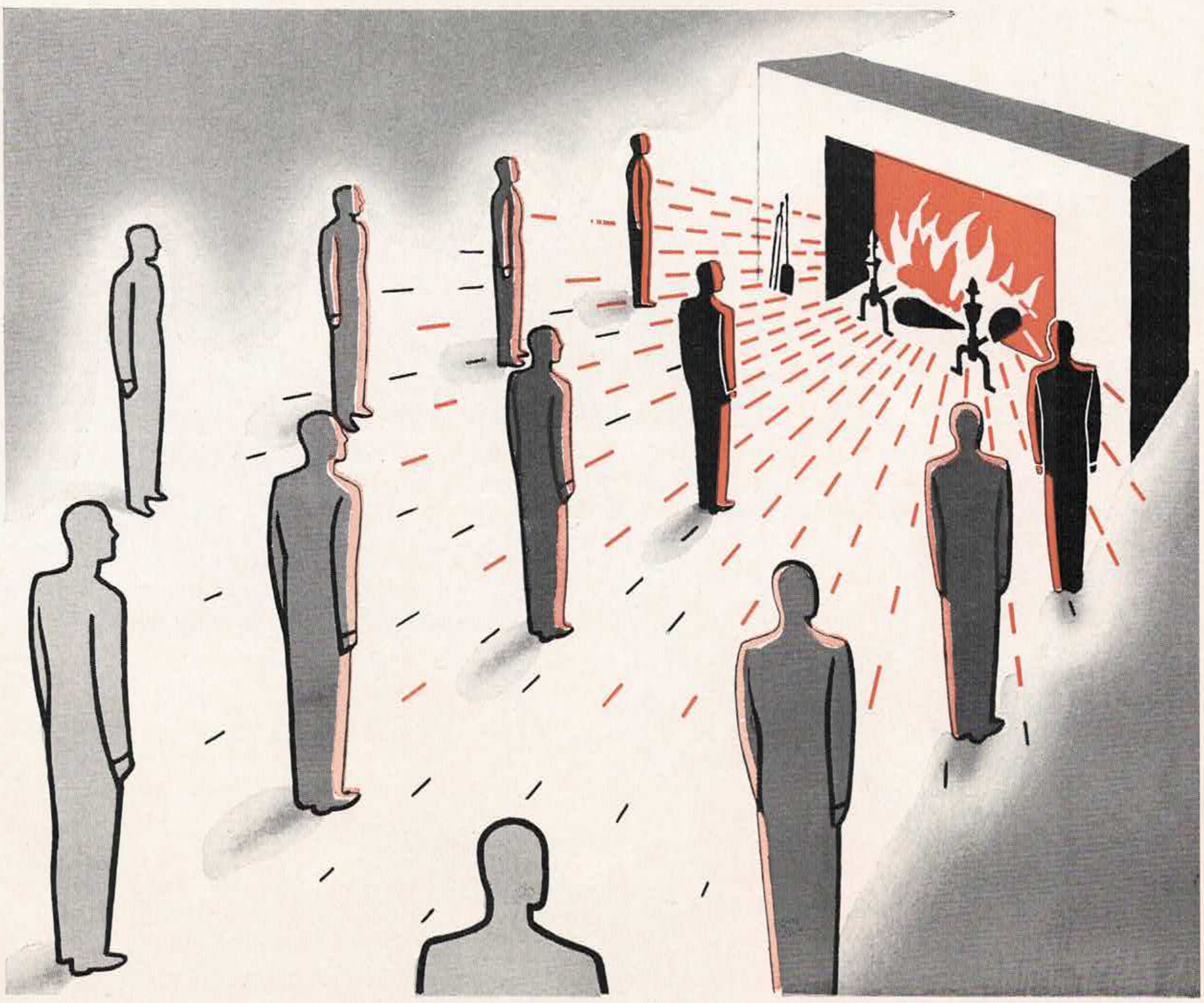
Another solution to the problem of excess body heat loss would be to make up, from an outside source, each excess heat unit lost by the occupant to the cool room air. But how can heat be supplied to the occupant without raising the temperature of the "sea" of air in which he is immersed? Common experience — as represented by the difference between walking on the sunny or the shady side of the street — provides an immediate answer: On a cold, clear day one is far warmer when in the sun than when in the shade, yet the actual air temperature is the same on both sides of the street. The difference is that — when on the sunny side — heat is supplied directly to the body from solar radiation.

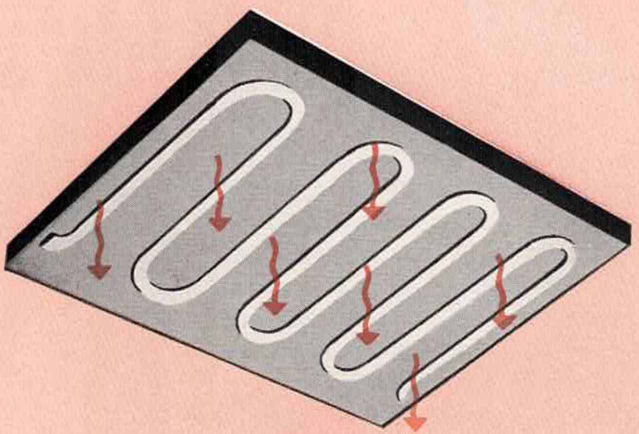
Any warm surface emits radiant energy at a rate dependent on its temperature; in a very crude sense such radiation can be visualized as consisting of a very large number of very small bullets, capsules of energy, which shoot off from the warm surface and travel at extremely high speed (186,000 miles per second) through intervening space; when these small "bullets" strike a solid object they release their energy in the form of heat which thereby serves to warm the object. A person walking or standing in the sun is thus subjected to a constant bombardment of radiant bullets each of which delivers a small quantity of heat.

A similar bombardment is experienced when standing in front of a fireplace and if the flames are high there is the definite possibility — again within the realm of common experience — that the intensity of the radiant bombardment will be so great as to be painful. In spite of the high intensity, a fireplace is a relatively inefficient radiant source since only a small fraction of the energy which it emits is actually received by the occupant. Bullets of radiant energy are being constantly discharged to all parts of the room and the percentage of the total number which actually strike the "target" — the occupant — is so small as to make the process a most wasteful one. The fireplace does not take aim; it discharges energy in all directions with a reasonable assurance that some fraction of it — though a small and wasteful fraction — must inevitably strike the occupant.

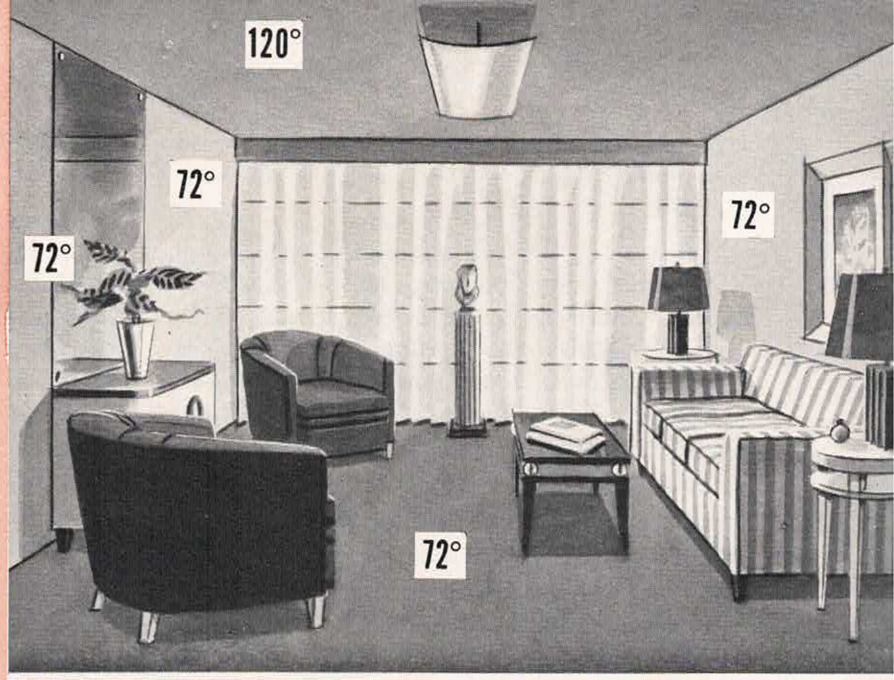
Suppose, now, that some means could be developed which would permit focusing radiation on the occupant in much the same manner that light can be focused. In this event the quantity of energy emitted by radiation could be very greatly reduced since all of it would now be effectively directed to the "target" and the wasteful bombardment of *all* parts of the room would no longer occur. If such a system were possible, and practical, the quantity of radiant energy required from the source would be exactly equal to the excess heat loss of the occupant; using the numbers of the preceding section we see that the heating system would be required to deliver a mere 100 heat units per hour in contrast with the 30,000 units now required to "heat the house." For each 300 pounds of coal now burned only one would be required; for each 300 gallons of fuel oil consumed only one would be needed; in place of a $300 per year heating bill, a home could be kept comfortable for $1 per year!

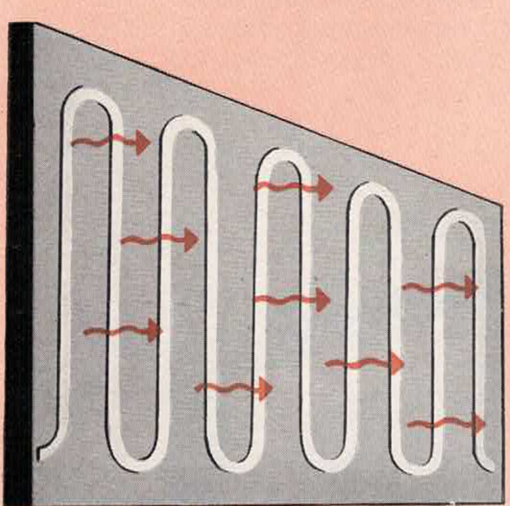
Unfortunately, a heating system such as that described above is not practical, nor is there any reason for thinking that it is likely to be soon perfected. An understanding of the theory of such a system is important, however, since it assists one in recognizing the fundamental advantage of radiant heating and in visualizing the tremendous potential saving which awaits the development of more effective radiant systems. Existing radiant systems do not even approach the potential savings which have been indicated; they are more important as expressions of intent than as examples of achievement. But with comparative operating costs of $1 a year for theoretical radiant heating and $300 a year for theoretical convection heating it is evident that even the most crude practical approach to a radiant system — inefficient and wasteful (as compared with the theoretical) though it may be — will still have an excellent chance of realizing some small fraction of the large potential saving which has been indicated.



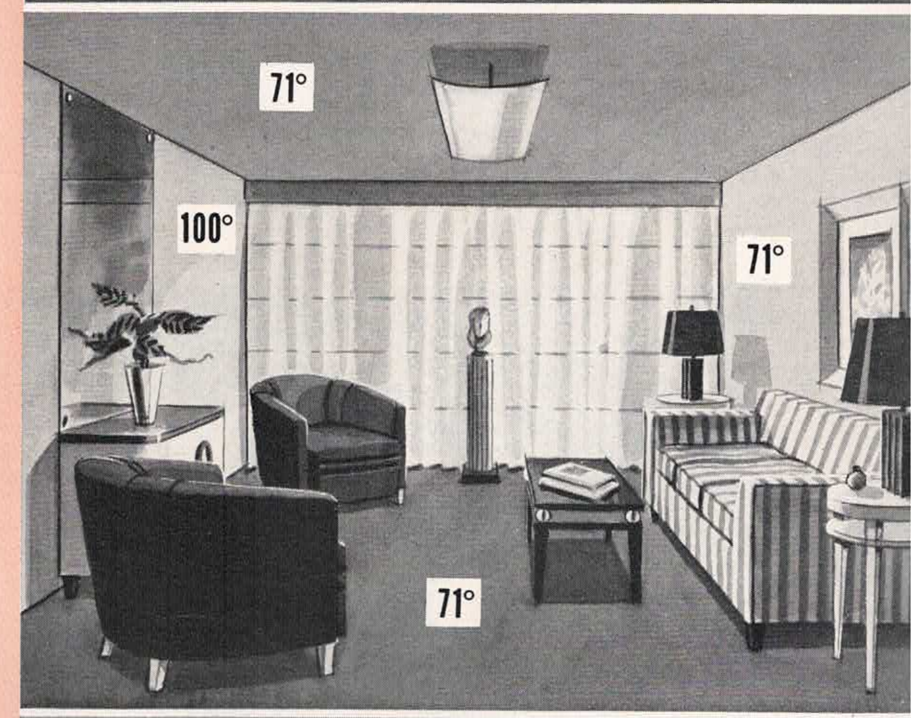


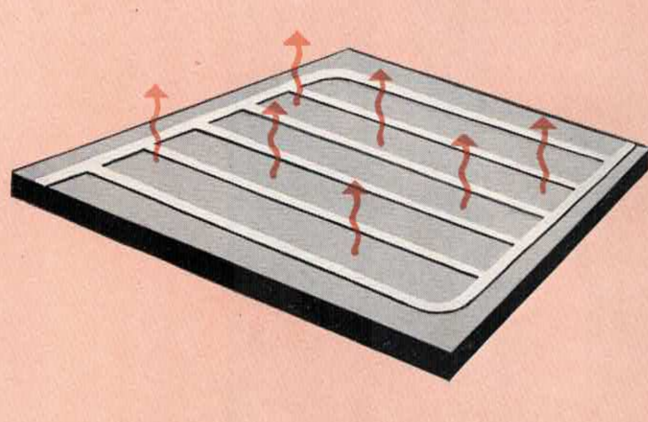
Heating Panel in Ceiling
With average surface temperatures as shown, room air temperature could be 68°.



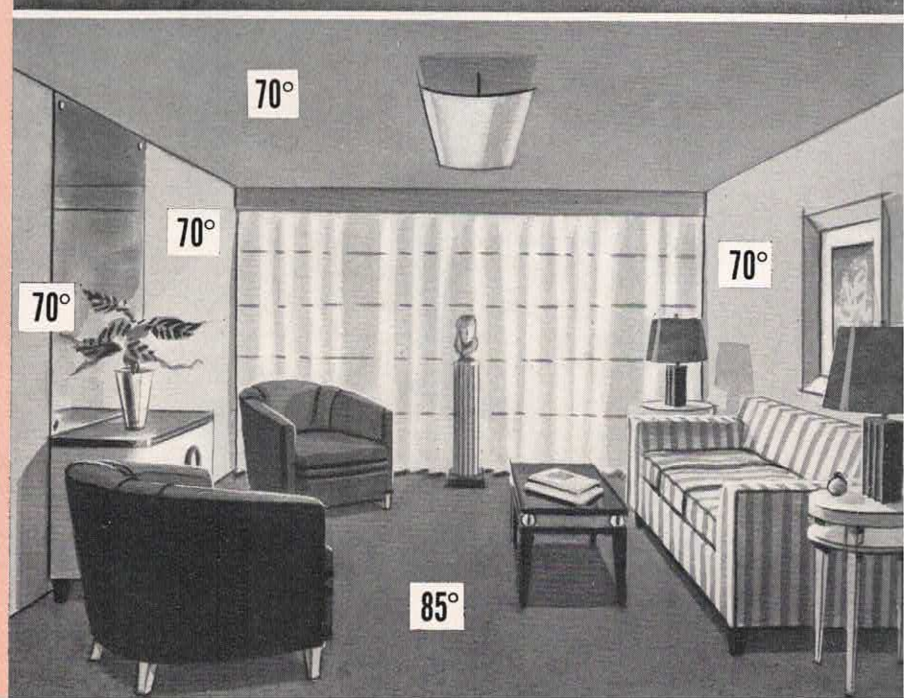


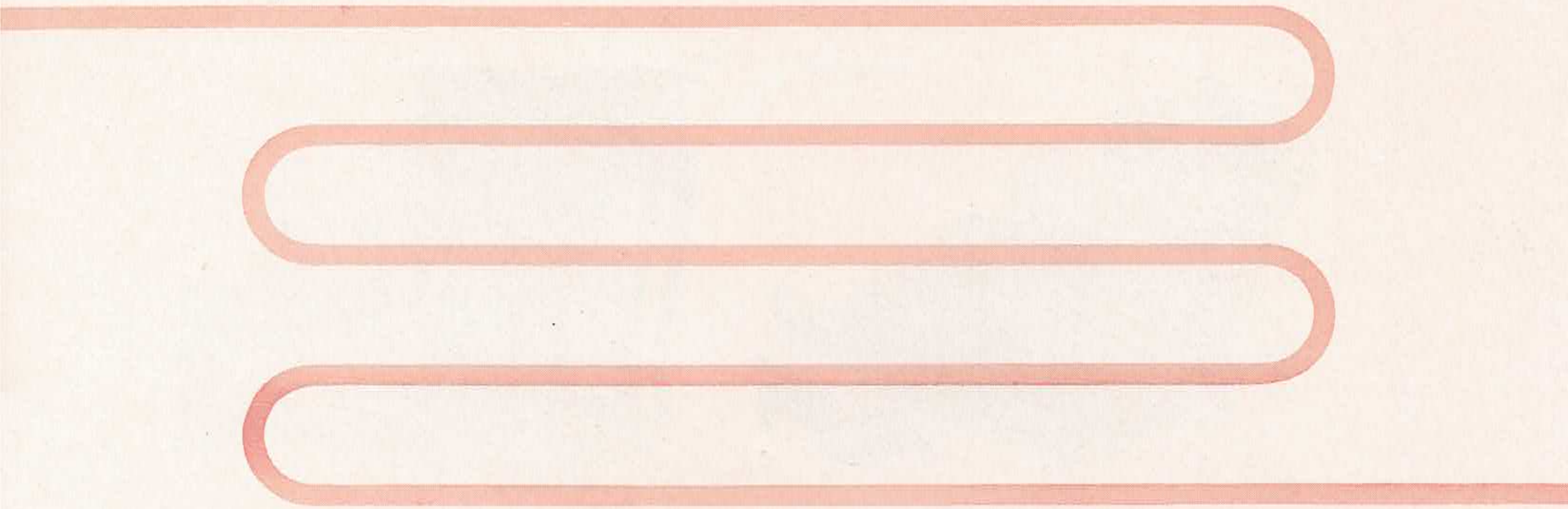
Heating Panel in Left Side Wall
With average surface temperatures as shown, room air temperature could be 69°.





Heating Panel in Floor
With average surface temperatures as shown, room air temperature could be 70°.





WHAT IS PANEL HEATING?

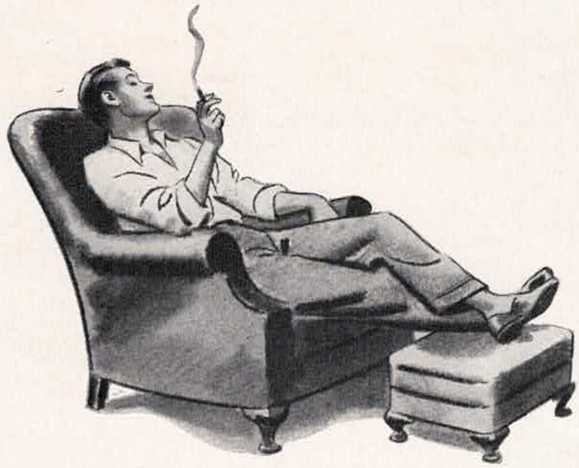
Panel heating is a first step — and a very small one — in the direction of radiant heating. All panel systems must be radiant systems but radiant heating can also be attained by other means. The problem of focusing or "aiming" radiation at the occupant is not solved by panel heating, but the disadvantage of intense and non-uniform bombardment (technically irradiation) such as is experienced in front of a fireplace is overcome by reducing the temperature and increasing the area of the radiant source. A heating panel is perhaps ten times as large and one-tenth as hot as a fireplace; hence the occupant is irradiated less severely and more uniformly than he would be if subjected to the high temperature radiation from an open flame.

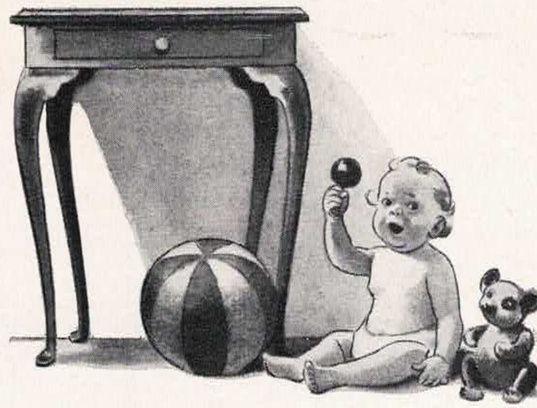
The object of a panel heating system is to provide sufficient heated surface at sufficient temperature so that the *average* surface temperature of the room will be above 70° F. Experience has shown that for each 1° F that the average surface temperature exceeds 70° F the air temperature can be reduced 1° F below 70° without altering the feeling of warmth experienced by the occupant. Thus in a room with air and walls at 70° the average person will be comfortably warm, but he will be equally warm in a room with air at 65° and walls at 75°, or in a room with air at 60° and walls at 80°. The difference between warmth and comfort must be understood; in the three rooms just described the feeling of warmth would be the same, but — as will be discussed in the next section — the sensation of comfort would be greatest in the room with 60° air and least in that with 70° air.

The first cost of heating *all* surfaces of a room would be prohibitive but the *average* surface temperature can be raised to any desired value by installing in one or more surfaces of the room, heated panels having a surface temperature higher than the desired average. Common practice in panel heating is to raise the temperature of floor panels to 85°, or of wall panels to 100°, or of ceiling panels to 120°; determination of the required area of any type of panel is a design problem which can be solved only in terms of the particular locality and the structural characteristics of the particular house. The technical procedure for designing a panel heating system is given in detail in the Revere publication, "A Graphical Design Procedure for Radiant Panel Heating."*

The "panel" in a panel heating system consists of a section of floor, wall, or ceiling — indistinguishable from other parts of the floor, wall, or ceiling — in which is embedded a coil of tubing through which hot water is circulated. Copper tubing possesses a number of characteristics which make it well suited for use in panel coils and there are many copper-coil panel installations which have been in service in the United States for a number of years. Fundamentally the heating system used with panels is a forced circulation hot-water system similar to that used with radiators or convectors. The significant difference is that the heating unit of a panel system is a large, flat, low-temperature indistinguishable section of the floor, wall, or ceiling in contrast with a small, higher temperature exposed radiator or convector.

* Distribution limited to architects, engineers, and heating contractors.





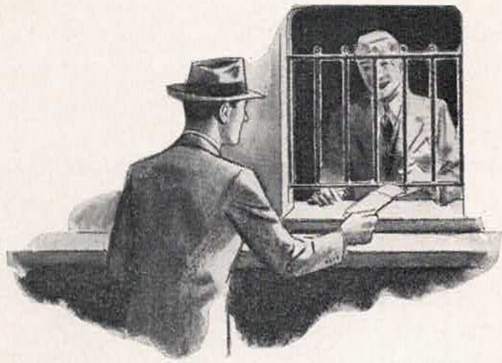
WHAT ARE THE CLAIMED ADVANTAGES OF PANEL HEATING?

In this and the following section a differentiation has been made between the *claimed* advantages and the *actual* advantages of panel heating. The difference is not intended to imply that the claims are false, but rather to separate those advantages which are definitely found in every installation from certain others which sometimes occur, but which are not inherent attributes of all installations. In the literature on this subject it is not uncommon for the enthusiasm of an advocate to lead him to unjustifiably generalize and credit "panel heating" with an advantage which actually can be realized only under certain special conditions. The same is true of disadvantages and in later sections these, also, will be separated into claimed and actual divisions.

1. *The Advantage of Reduced Air Temperature.*

The advantages of reduced air temperature are unquestioned. In terms of comfort and of health and of operating economy an air temperature of 60° is more satisfactory than one of 70°. Why, then, is this factor considered as a *claimed* rather than an *actual* advantage? The answer is very simple: The actual advantages do exist whenever an air temperature reduction is achieved, but in many panel installations conditions are such that there is not an appreciable air temperature reduction. Thus the cautious designer, or home-owner, must first determine whether or not the thermal characteristics of a given installation are such that reduced air temperature can be obtained, and if this is not the case he must either alter the design or forego the advantages which are associated with lower temperature.

The basis of the difficulty resides in the fact — already discussed — that only a very small fraction of the radiant energy emitted by a panel actually strikes the occupant. The far greater part — usually well over 95% of the total — misses the occupant and strikes the furniture or other room surfaces where it is absorbed and later lost to the room air by convection. In theory a room would be comfortable if the average surface temperature were 80° and the air temperature were 60°, but in practice the difficulty is not to raise the average surface tempera-



ture, but to do so without causing a corresponding rise in the room air temperature. If all room surfaces were 80° the air temperature would also necessarily rise to 80° unless heat were rapidly carried from the room by a continuous entering stream of cold outside ventilation air.

In large buildings a fan and duct system usually assures the introduction of fresh air for purposes of ventilation whereas in the average home, cracks around the windows and doors allow a leakage into the house (and also, of course, out of it) of some ventilation air. In general, the volume of air which enters a residence by this means is more than sufficient to meet the fresh air requirements of the occupants, but it very rarely is sufficient to permit maintenance of a comfort inside air temperature appreciably less than 70°. Thus for average residential installations of panel heating there will not be any marked reduction below 70° of the comfort air temperature and consequently the occupant will not obtain such advantages as are associated with lower temperatures.

There is not, at present, any technical evidence to substantiate the extreme claims which have been made that it will some day be possible to sit in an average size living room, in perfect and economical comfort, with the windows open and the inside air temperature not greatly different from that of the outside air. Scientifically such claims now seem absurd and there are no data to indicate that they will ever be otherwise.

Determination of the extent of air temperature reduction which can be realized in a particular installation is a technical design problem (refer to the Revere book, "A Graphical Design Procedure for Radiant Panel Heating"). As a first approximation, however, it can be considered that the magnitude of the possible reduction will increase as the ventilation rate is increased and will be greatest for a ceiling panel installation and least for a floor panel installation. This air temperature reduction is also affected by the extent to which the structure is insulated; a well insulated building will usually have a lesser air temperature reduction than a poorly insulated one, but it would obviously be uneconomical to achieve lower air temperature by reducing or removing insulation.

When the conditions of the particular installation are such that an appreciable air temperature reduction can be achieved, the following advantages will exist:

A. Comfort. The sensation of stuffiness so often associated with indoor winter atmospheres is largely eliminated if the same feeling of warmth is attained at an air temperature lower than 70°. Neither doctors nor engineers are able as yet to precisely define the quality of air which is commonly described as "freshness," but experiment has shown conclusively that the average subject considers an atmosphere more "fresh" and invigorating if — while maintaining comfortable warmth — the air temperature can be reduced to a value somewhat less than 70°. The tendency toward drowsiness is reduced and the average subject finds it both easier and pleasanter to remain mentally alert. (Refer, "Panel Heating and Cooling Performance Studies," Raber and Hutchinson, ASHVE Transactions, Volume 48, 1942). Obviously there is a limit to the reduction in air temperature for which comfort can be attained; even if an occupant were warm in a room with enclosure surfaces at 100° and air at 40° he would doubtless find it most unsatisfying to sit on a 40° chair or to hold a 40° book or magazine. Present limited evidence suggests that the minimum acceptable comfort air temperature in a home is in the range from 55° to 60°.

B. Health. Lower inside air temperature provides a more healthful atmosphere for two reasons. In the first place the "shock" effect experienced on passing from a heated interior to the cold outdoors is less severe because of the smaller temperature difference to which the mucous membranes of the respiratory passages are subjected. Secondly, the drying effect of an unhumidified inside atmosphere will be reduced because — for a constant absolute humidity — the relative humidity will be greater with the lower air temperature. Medical evidence is not yet complete on the influence of low humidity, but present data show that whenever the relative humidity of a 70° atmosphere drops below 60% (corresponding, technically, to a 55° dew-point temperature) the mucous membranes of the nose and throat will tend to dry out with a possible associated hazard of greater susceptibility to infection. The lower air temperature of a panel heated room may or may not be sufficient to prevent critical drying, but it will in any event increase the relative humidity and thereby reduce the rate at which drying occurs.

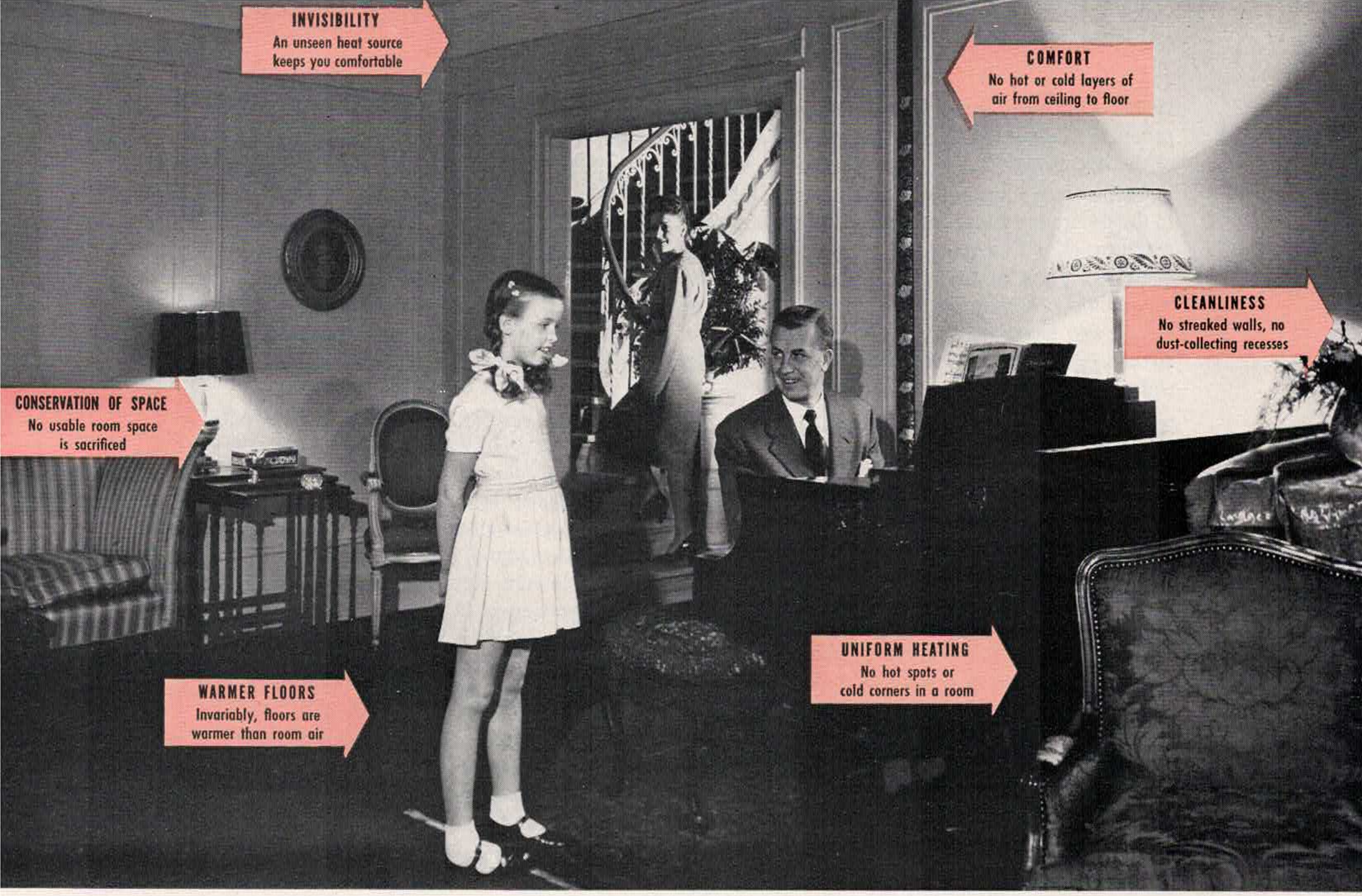
C. Drying of Furnishings. The drying experienced by furniture, rugs, draperies, books, etc., is almost entirely dependent on the relative moisture content of room air; hence the effect of lower air temperature will always be definitely beneficial in reducing the amount of drying that occurs in a home which is not artificially humidified. The material value of this advantage is difficult to evaluate, but that some advantage does exist is unquestioned.

D. Economy. Undoubtedly the most significant advantage of lower air temperature is in the consequent saving in heat requirement for the house. In many structures — particularly large buildings with mechanical ventilation — a substantial part of the total heat requirement is represented by the energy needed to heat ventilation air from the outside temperature to room temperature. In a locality where the *average* outside temperature during the heating season is 40° and in a structure where a 10° air temperature reduction is possible, the saving in heating of ventilation air would be $10/(70-40) = 33\%$; thus it is evident that whenever the ventilation load is significantly large the opportunity for making a very real saving is rather great.

2. *The Advantage of a 15% Reduced Operating Cost.*

Not infrequently the claim has been advanced that heating costs for a panel system will be less by 15% than for a non-panel system. There is much evidence to support the belief that operating costs for panel heating will usually be somewhat lower than for other systems, but the magnitude of the reduction will vary widely with the type of installation; it is therefore dangerous and erroneous to generalize and consider a 15% reduction assured. Unfortunately, there is very little dependable cost information available. Most of the claims which have been made are on the basis of differences between the actual heating cost of an existing panel heated house and the estimated cost of heating the same house by conventional means. When one considers that the estimated and actual costs for conventional systems frequently disagree, it becomes evident that a comparison of calculated costs for one system with actual costs for another is subject to more than casual suspicion. Acceptable comparative cost data can be obtained by three methods, but none of them has been extensively used. The first would be to erect two houses having identical heating requirements and compare costs for different heating systems. The second would be to compare corrected costs for one house when actually heated by different systems in different heating seasons. The third method would be to compare estimated costs for two different systems when used in one particular house. The third method is less desirable than the first two, but it is at least consistent within itself, which is more than can be said for a comparison of estimated costs for one system against actual costs for another. No one of these methods has as yet been widely used.

Summarizing, existing comparative cost data are meager and frequently untrustworthy. English claims of operating savings of the order of 50% are more noteworthy for optimism than for accuracy. The statement that a 15% saving is to be realized from a panel system cannot, with present data, be either proved or repudiated, but best existing evidence indicates that some saving will usually be associated with panels and that it will probably vary in the range from 2% to 20% depending on the conditions of the particular installation. Wherever a panel heating system is installed, the owner can reasonably expect his heating costs to be less than for any other system, but he cannot be certain — without careful engineering analysis — whether the difference will be great enough to merit consideration.



WHAT ARE THE ASSURED ADVANTAGES OF PANEL HEATING?

All panel heating systems, irrespective of the conditions of the particular installation, have certain inherent advantages that will always be obtained. The prospective home-owner can most effectively make his decision concerning type of system by first comparing the actual advantages and disadvantages, then tempering his opinion by reference to the claimed advantages and disadvantages. The first comparison is based on conditions which will definitely be associated with his system, whereas the second group contains factors whose importance depends on the special characteristics of the house or structure which is under consideration.

1. *The Advantage of Invisibility.*

Unlike all other types of heating systems, panel heating maintains comfort in a room without any visible evidence of the heating mechanism. The panels are embedded in and form an integral part of the structure; there is no evidence of their location either in the form of a protrusion or of a change in the decorative treatment. Because of the low temperature (120°F maximum) at which the panels operate they can be decoratively treated in the same way as the unheated portions of the wall, floor, or ceiling and hence do not possess the aesthetic disadvantage that is associated with visible heating equipments.

2. *The Advantage of Space Requirement.*

Unlike certain other methods of heating, panels do not occupy space in the room that could be used to architectural advantage, nor do they produce room areas which cannot comfortably be occupied because of the overheating effect of being too close to the heat source (as occurs when one sits too close to a radiator). This advantage is of particular importance in offices and industrial buildings where greater use can be made of the space adjacent to windows.

3. *The Advantage of Cleanliness.*

Because they form an integral part of the structure, invisible panels do not possess dust collecting characteristics. There are no spaces back of or under a panel which the housewife must clean. Further, hot, dust-carrying air currents do not exist with panels, hence streaking effects are not found when panel heating is used.

4. *The Advantage of Uniform Heating.*

Because of the relatively large area of low temperature panel surface a panel heated room will usually have a very uniform distribution of warmth. The "hot" spots which are found with some systems and the "cold" spots often found in room corners do not exist when panels are arranged in a recommended distribution pattern (see Pages 33 and 34).

5. *The Advantage of Flexibility.*

When installed in office or industrial buildings heating panels possess a decided advantage over other systems in that interior partitions can be shifted or installed with much less hazard of unbalanced heating. If one large office is separated into two, additional heating will not usually be required since the large area of low temperature panel will be divided by the partition into acceptable areas for heating the two smaller offices; if window radiators had been used, however, a shift of partition might require the addition of a new radiator.

6. *The Advantage of All-Year Adaptability.*

Summer cooling can be achieved by means of cool panel surfaces just as winter heating is realized by use of warm surfaces. Thus the panel system of heating possesses the advantage of being available for use as an all-year heating and cooling system. Further, because of the moderate temperatures at which the panel surface operates an all-year panel installation is better adapted for use with reverse cycle refrigeration than is any other heat distributing method. With summer use of panels care is needed to assure the maintenance of panel surface temperatures at a value greater than the dew-point of the room air, that is, the point at which the moisture in the air would become drops of water.

7. *The Advantage of Warmer Floors.*

Irrespective of the location of panels (whether in walls, floor, or ceiling) the radiant effect of the heating surface is such that the floor surface temperature will almost inevitably be raised to a value slightly higher than that of the room air. While this temperature difference may not be very great (of the order of a few degrees) it will at least serve to prevent the cold-floor drafts that are so annoying and troublesome, particularly in homes where small children may be playing on the floor.

8. *The Advantage of Reduced "Cold Wall" Effect.*

It is common experience that to maintain comfort during very cold weather the air temperature in a room heated by warm air or radiators must be raised to a value substantially greater than 70°. This need occurs because as the outside air temperature decreases the inside surface temperature of the room also decreases; this "cold wall" effect must be compensated for by raising the air temperature. With panel heating the average surface temperature of the room is maintained at a higher level so that an inside air temperature in excess of 70° would never, for the usual type of installation, be required. In an earlier section (Page 11) it was pointed out that with panel heating it is frequently possible to maintain comfort at air temperatures less than 70°, but that the magnitude of the reduction depends on the particular case. Note now, however, that even for those unusual installations which do not realize a reduced air temperature there still remains the very real advantage of not having to maintain a temperature in excess of 70°. Thus as a summary of the air temperature discussion one can visualize that panel installations usually have the positive advantage of reduced air temperature, but, at the most unfavorable, never possess the positive disadvantage of a comfort air temperature in excess of 70° F.

9. *The Advantage of Reduced Floor-to-Ceiling Temperature Difference.*

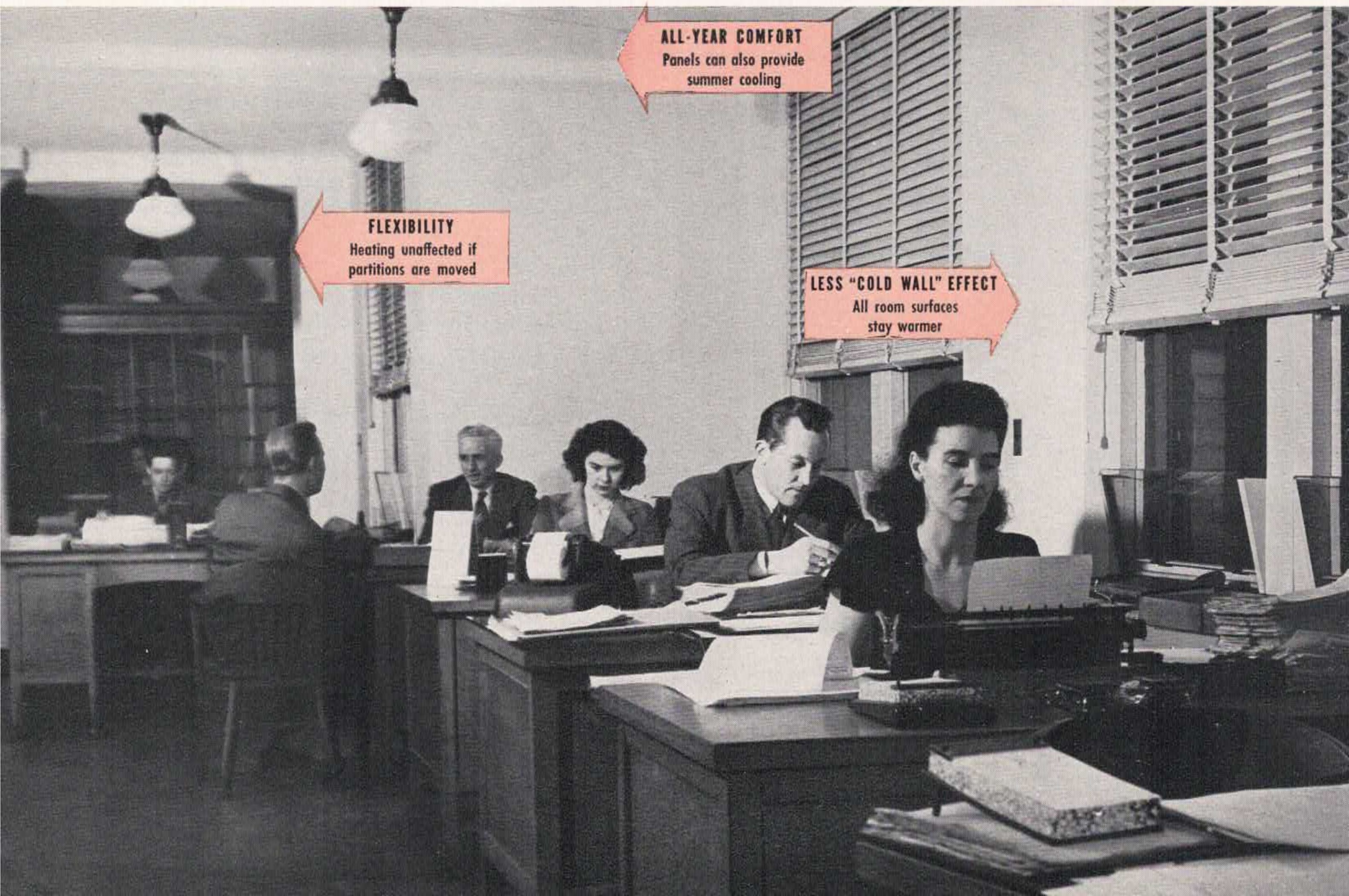
With many heating systems stratification of the heated air occurs and a large difference in air temperature is observed between the floor and the ceiling of the room. Such a condition is both uneconomical and uncomfortable. In rooms with high ceilings stratification requires maintenance of an average temperature higher than would otherwise be needed; without the higher average the air temperature at the breathing level would be uncomfortably low. Necessarily, therefore, the heat losses through the exposed walls and ceiling are much greater than they would otherwise be whereas the floor losses are slightly less. Further, the higher average temperature is reflected in greater heat requirements of the ventilation air.

From the standpoint of comfort, a floor-to-ceiling air temperature difference is highly undesirable since the feet of the occupant are likely to be too cool while his head is unpleasantly warm. Differences in the feeling of warmth will be experienced between the sitting and standing positions and the floors will be particularly cold for children.

All available evidence indicates that floor-to-ceiling air temperature differences are unusually small for all types of panel heating systems. Irrespective of panel location (wall, floor, or ceiling) reports of existing installations show that differences are less than for most convection type systems and are always so small as to constitute no hazard either to health or to economy.

Copper water tube is the ideal material for a radiant panel heating system:

- **It is light in weight.**
- **It conducts heat very rapidly.**
- **It is easily bent by the contractor installing it.**
- **Long lengths are available, resulting in fewer connections.**
- **It is highly resistant to corrosion attack from the water in the heating system, hence rust accumulation is eliminated.**
- **It has a gun-barrel interior finish which reduces frictional resistance to a minimum and thus permits water to circulate freely.**



WHAT ARE THE CLAIMED DISADVANTAGES OF PANEL HEATING?

As with the advantages, so too the disadvantages of panel heating can be separated into those which are associated with all panel systems, — the *assured* disadvantages — and those which may or may not be found depending on the conditions of the particular installation. The latter group — the *claimed* disadvantages — will receive first consideration.

1. *The Disadvantage of Greater First Cost.*

The first cost of panel heating has been said by some to average as much as 50% greater than other comparable heating methods; others say that the cost disadvantage is more nearly of the order of 5% while some heating contractors — based on competitive experience with a large number of installations — state that a well-designed panel heating system can be installed for 15% *less* than a comparable radiator or convector system. Undoubtedly most contractors have found panel installations somewhat more costly — probably 10% more so, on the average — but whether this greater cost is correctly attributed to the system or more correctly to the inexperience of the contractor with the system — is a question that cannot yet be answered with assurance. When one realizes that the modern concept of panel heating has only recently been revived and that the majority of American heating contractors have never made an installation it is evident that first cost analyses are not, as yet, likely to be entirely trustworthy. Within the next couple of years this situation will undoubtedly be clarified as panel heating installations are now going in at an accelerating rate and a large mass of cost data will soon be available.

2. *The Disadvantage of Greater Design Complexity.*

Many heating contractors have looked with disfavor on panel heating because of the complexity of the calculations which have been necessary to carry out a technically accurate design. This difficulty has now been completely overcome. A number of approximate and simplified computation procedures have recently appeared in the technical literature and Revere Copper and Brass Incorporated has published a book* which gives a graphical design procedure that can be used, with ease, by anyone who can do simple arithmetic and is capable of following a dotted example line on a chart. Literally, the time and effort needed to design a panel installation by the Revere graphical method is actually less than that required for designing a standard convection type heating system.

3. *The Disadvantage of Slow Response to Weather Changes.*

When a heating coil is embedded in a heavy concrete or masonry structure the quantity of heat which goes into storage in the heated slab is very great. Under such conditions there will inevitably be a pronounced lag in the response of the heated surface to changes in temperature of the heating fluid flowing within the tubing embedded in the slab. Thus if the weather becomes colder and the room thermostat calls for more heat there will be a definite time interval before the change is reflected in an increase of the surface temperature of the panel. This delayed action is said to be due to the "thermal capacity" of the slab. In panel systems where the coils are embedded in slabs of high thermal capacity a serious and unsatisfactory control† situation may exist. This will be particularly true in localities where abrupt and marked changes in temperature occur.

The above difficulty can be reduced to insignificance by designing a panel which does not possess great thermal capacity. By placing the heating tubes as near the surface as practicable and reducing the material on the rear side of the heating coil to a minimum, the thermal capacity can be reduced to a point such that control is excellent and response of the heated surface is almost immediate. Whenever the choice is left with the designer he should make every effort to use relatively thin, light panels in contrast to those of massive construction.

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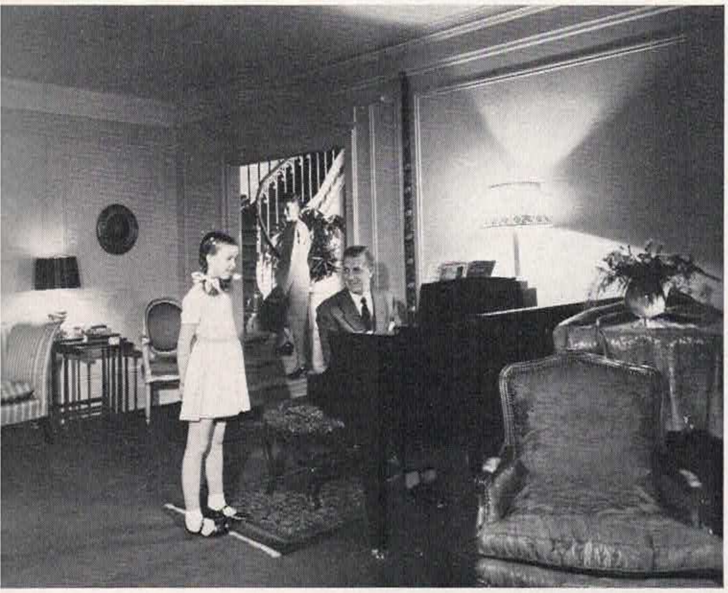
* "A Graphical Design Procedure for Radiant Panel Heating," Revere Copper and Brass Incorporated, available to architects, engineers, and heating contractors.

† Detailed information on proper controls is given in a booklet, "Automatic Control of Radiant Panel Heating", published by Minneapolis-Honeywell Regulator Company.

Some disadvantages that might result from the use of heavy piping materials can be overcome by using copper water tube.

WHAT ARE THE ASSURED DISADVANTAGES OF PANEL HEATING?



Like all other systems, panel heating has certain inherent characteristics, some good and some bad, which appear in every installation. The disadvantages which cannot be avoided are the following:

1. *The Disadvantage of No Ventilation.*

With conventional radiators, panel heating shares the marked disadvantage of providing a complete heating system without means for admitting, controlling, moving, or humidifying fresh outside air. In residential installations this disadvantage may not be serious since frequently no means are provided — irrespective of the heating method used—for supplying more fresh air than that which enters the house through door and window cracks. For large office buildings, however, some means of forced air circulation is essential and, when panel heating is used, a ventilation system must be installed in addition to the heating system.

2. *The Disadvantage of Difficult Alterations.*

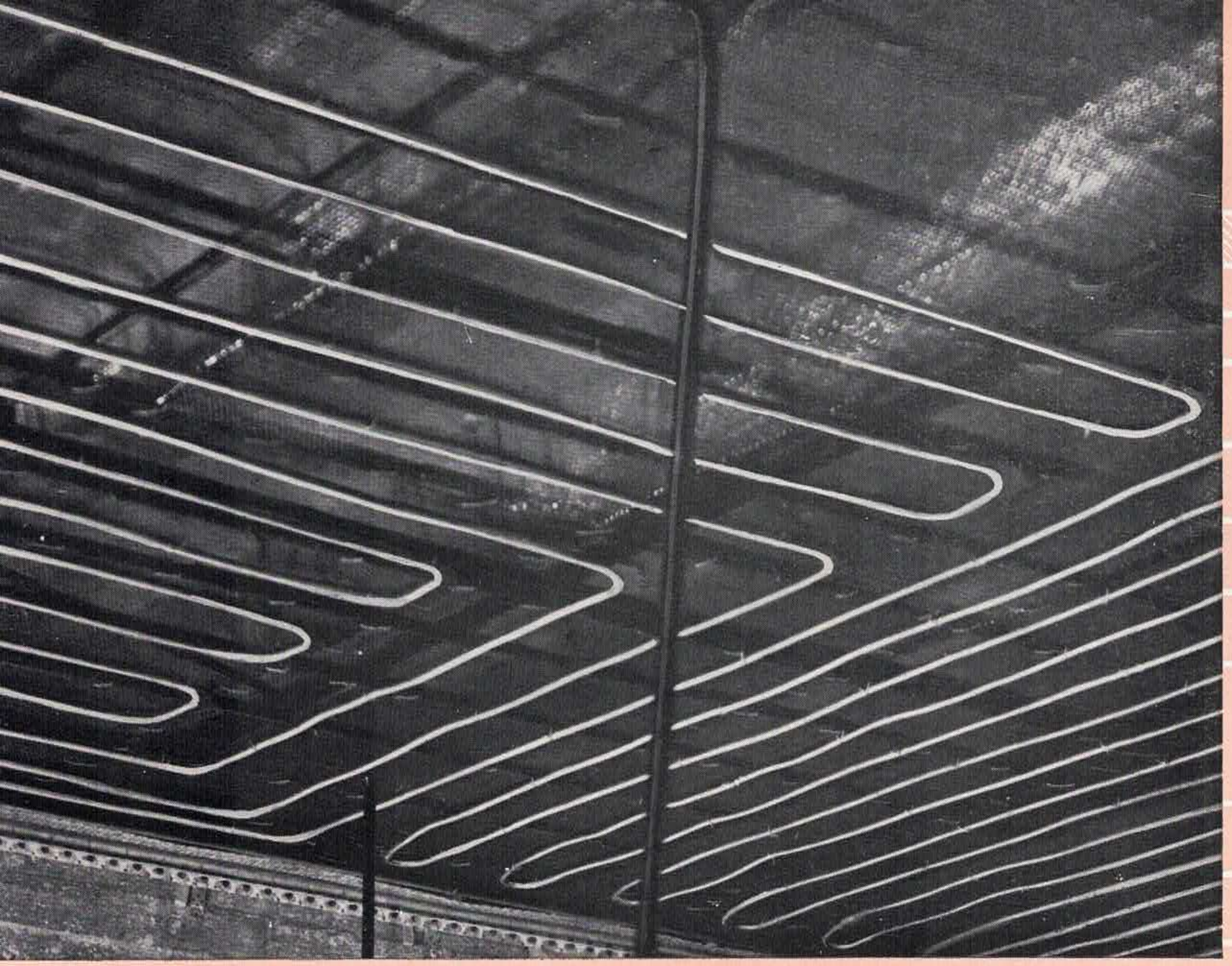
The design of a panel system must be reasonably correct because once the system has been installed it would be most difficult — if not economically impossible — to add additional surface. The coils of tubing are embedded in the structure and there they must remain. Accessibility for repairs and maintenance is practically impossible and it is therefore essential that the materials and workmanship be such as to insure permanence. There are many hundreds of embedded-coil panel heating systems that have been in service in England for close to twenty years — some for much longer — and experience shows that there is no reason to anticipate difficulty or the need for repair. If, however, a leak did occur, it would be most difficult to repair.

3. *The Disadvantage of Variable Air Temperature.*

The optimum inside air temperature in a panel heated structure varies from 70° at times when there is no heating load to some value less than this at maximum load. As already discussed (Page 11) the air temperature reduction in some installations is negligible and, for such cases, the variable control disadvantage does not exist. When the reduction is great, however, the control system must be designed to vary the air temperature inversely as a function of heating load; in severe weather the air temperature inside is low whereas in mild weather it approaches 70° F. This condition is a disadvantage in the sense that a more complex control arrangement is required, but the advantages gained from the lower temperature (in economy and in comfort) far more than offset the disadvantage.

4. *The Disadvantage of Limited Available Area.*

Because it operates at unusually low surface temperature a heating panel has a much lower heat output per unit area than do other heating units. For this reason a larger heating surface is required. But the maximum area of a floor, wall, or ceiling panel is obviously fixed by the size of the floor, wall, or ceiling; in poorly insulated houses located in cold climates it is not unusual to find that the required area of an adequate panel would be too large to fit in the house. In such cases it is always possible, of course, to split the required area into heating surface installed in two or even three locations, but in general such extensive use of surface will be found uneconomical and a less costly procedure will be to insulate the house sufficiently to reduce the necessary panel area.



Copper tube in position on the ceiling before being covered with plaster. It is better to place the copper tube above the metal lath.

Invisible beneath the surface of the plaster, radiant heating panels occupy no otherwise usable space in the completed room.

WHAT ARE THE RELATIVE MERITS OF FLOOR vs. WALL vs. CEILING PANELS?

One of the first decisions which must be made when planning a panel heating system is with respect to the location of the heating surface. Should it be installed in the ceiling, the wall, or the floor? On the correct answer to that question will depend in large measure the first cost and the operating cost of the system. There are in the United States at the present time many hundreds of installations including examples of all three panel locations and some combinations of two types of panel in one installation. Any type of panel, when properly designed, can be successfully used to establish effective and comfortable heating. The problem of choice is, therefore, not between workable and unworkable systems, but between adequate in contrast with superior installations. In cases where a decision among the three locations for the heating surface is difficult the home-owner need not fear that a faulty decision will be responsible for a faulty heating system. Wherever the panels are placed, provided they are sized properly, the resulting system can be expected to provide a degree of comfort not less than that which would be realized if a convector, radiator, or warm air installation had been used.

Thus the problem of choosing among wall, floor, and ceiling affords an opportunity for obtaining a "dividend" in more effective and less costly heating, but the choice is unattended by hazard; a faulty decision will still lead to a faultless heating system.

1. *Relative Sizes of Wall, Floor, and Ceiling Panels.*

The first cost of a panel heating system depends on the cost of installing one square foot of heating surface and increases directly with the number of square feet needed to provide the requisite size of panel. The first factor, cost of unit area, will vary widely, depending on building costs, wage levels, etc., in the locality under consideration; it will also depend on the type of structure in which the heating element is to be embedded. The cost of heating one square foot of concrete floor will not be the same as that of heating an equal area of plaster ceiling, or of wood-panelled wall; variations in types of panel are multitudinous and an adequate unit area cost estimate can only be obtained in terms of the specific conditions which are found to exist in a particular structure. No valid generalizations are possible and hence no direct comparison of the relative cost of unit area of wall, floor, or ceiling panel can be made.

The second cost factor, size of panel, does permit of more exact treatment. For any given installation the relative size of panel is determined by the rate at which heat is lost from unit area and this, in turn, depends essentially on two things: 1. The temperature of the panel surface; 2. The direction in which the surface is facing.

A. Effect of Panel Temperature on Capacity. In order to keep the first cost of an installation as low as possible the customary procedure is to design the panel so that its surface temperature will reach the highest permissible value at a time when the heating load on the structure (as determined from the outside air temperature) is a maximum. Thus in a locality where the design outside air temperature is −10° F, the panel would attain its maximum design surface temperature only in −10° weather; at all other times the panel would operate at some lower temperature. In terms of first cost it is obviously desirable to select the highest possible design panel temperature since by doing so the rate of heat transfer from the panel is maintained at a high value and the size of panel can therefore be decreased. But difficulties arise!

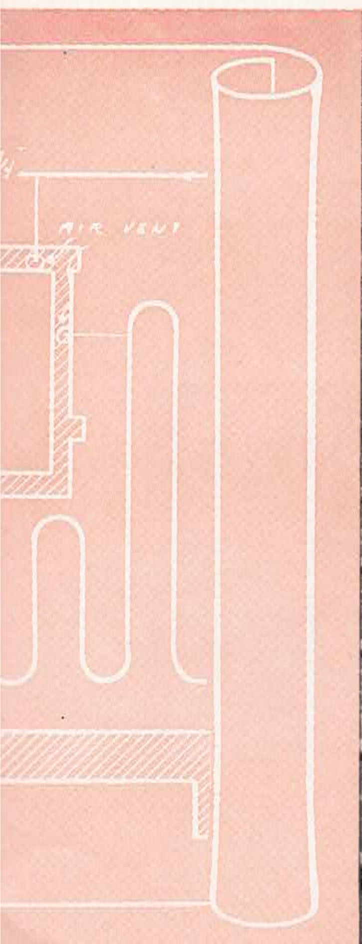
In order to provide effective and uniform distribution of radiation to all parts of the heated enclosure it is essential that the *intensity* of radiation (comparable to the intensity of light) be kept reasonably low and that the radiating source occupy a substantial fraction of the room surface. This situation is not unlike that represented by two identical rooms, one illuminated by means of a powerful, unshaded electric globe while the other — with an equal amount of light — has effectively distributed indirect lighting. In the first room there will be regions of glare and regions of pronounced shadow whereas the room with indirect lighting will be more uniformly illuminated and will be more satisfactory both from an

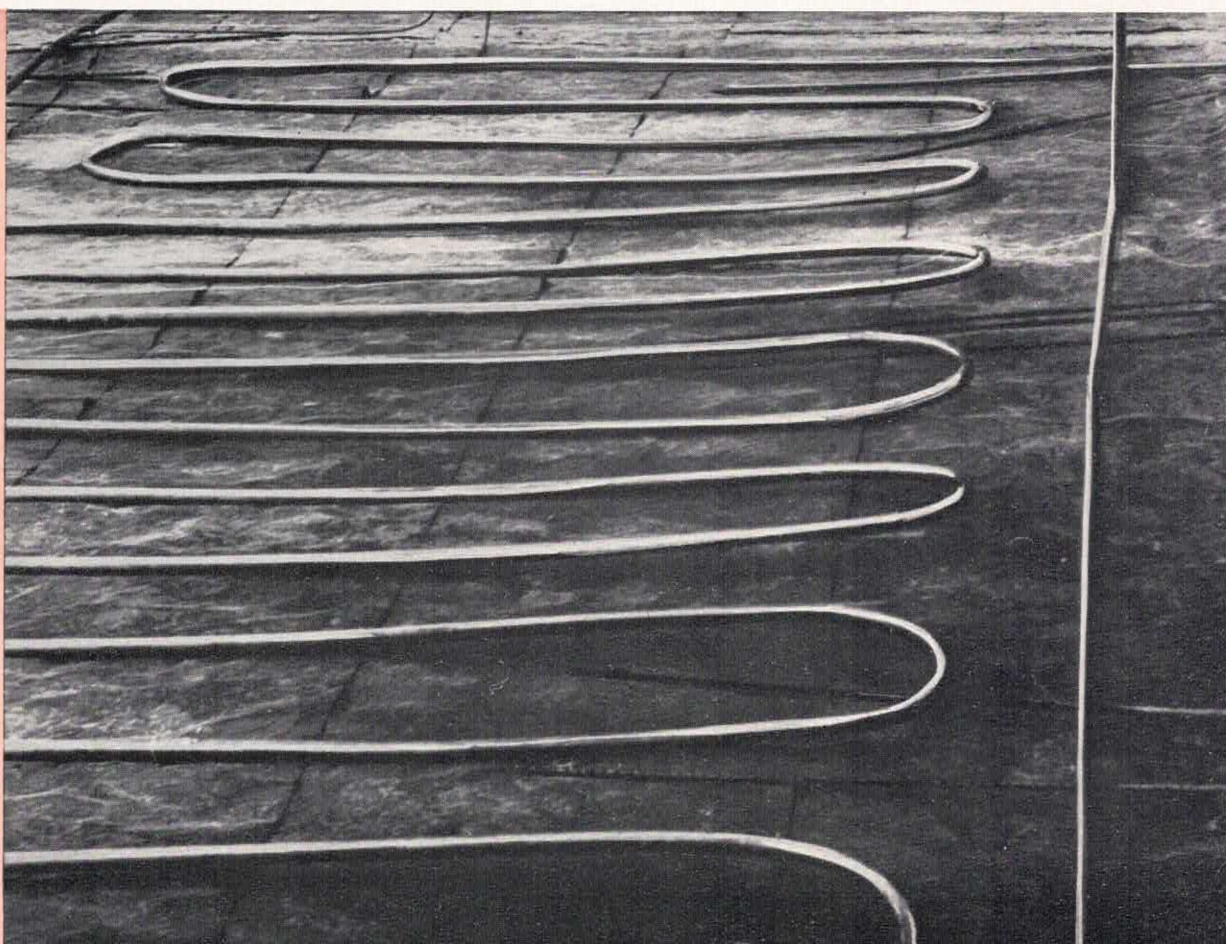
aesthetic standpoint and also in terms of the physiology of "seeing." An analogous situation exists with panel heating. Small high-intensity panels lead to wide variation in the degree of irradiation (corresponding to illumination) experienced by the occupant as he moves around in the room. Regions of glare and of shadow (though in the infra-red rather than of visible light) exist in the room with the consequent production of what have sometimes been described as "radiant drafts." In rooms of average size and ceiling height experience shows that panel temperatures greater than 160° F are likely to be responsible for uncomfortable conditions and that 140° F is probably a safe maximum.

Except in very unusual circumstances panel surface temperatures greater than 120° F are not used in modern installations. In order to maintain the surface of a panel at 120° F the temperature of the heating fluid embedded in the panel will usually be of the order of 150°—175° and most contractors and engineers are of the opinion that temperatures higher than this are undesirable. Particularly with plaster, concrete, wall board, or wood-veneer panels, surface temperatures in excess of 120° F would represent wide departure from current practice. Thus in terms of structural necessity as well as of uniform comfort it is customary to select 120° F as a maximum design value of the panel surface temperature for wall or ceiling installations. In many cases, particularly in mild climates where the problem of finding adequate space for the design area of panel is not serious, a maximum design temperature of 100° is used in preference to 120° F.

With floor panels, however, another comfort factor must be considered. Body temperature is 98.6° F, but the average surface temperature of the human feet is 85° F or less, and to walk on a floor which is hotter than this will lead to heating of the feet, perspiration, and development, literally, of "hot foot." Hence to establish comfort conditions with a floor panel installation, it is essential that the maximum design temperature be taken 85° F or less for all floor surfaces over which the occupant may walk; in art galleries, halls, and similar large rooms a heated band of floor surface near the walls can sometimes be raised to 100° F, but only when it is so located that the occupants will not normally walk or stand on it.

The point has already been made (Page 11) that the equivalent temperature in a comfortably heated room will be approximately 70° F, so the temperature difference available to produce a heat transfer from the panel to the room will be of the order of $120° - 70° = 50°$ F for a ceiling or wall panel; the maximum difference available with a floor installation will be $85° - 70° = 15°$. Temperature difference in a heat transfer system corresponds to potential or voltage in an electrical system, or difference of elevation in a gravitational system; the greater the

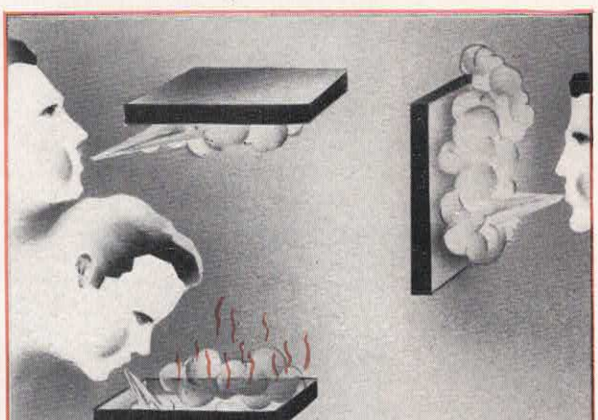


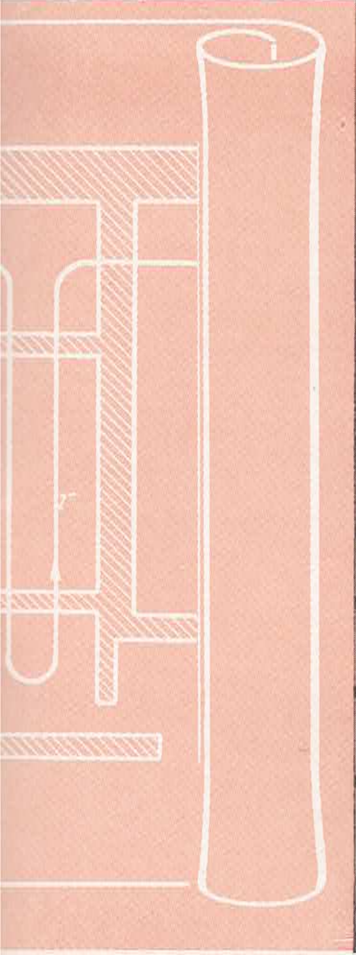


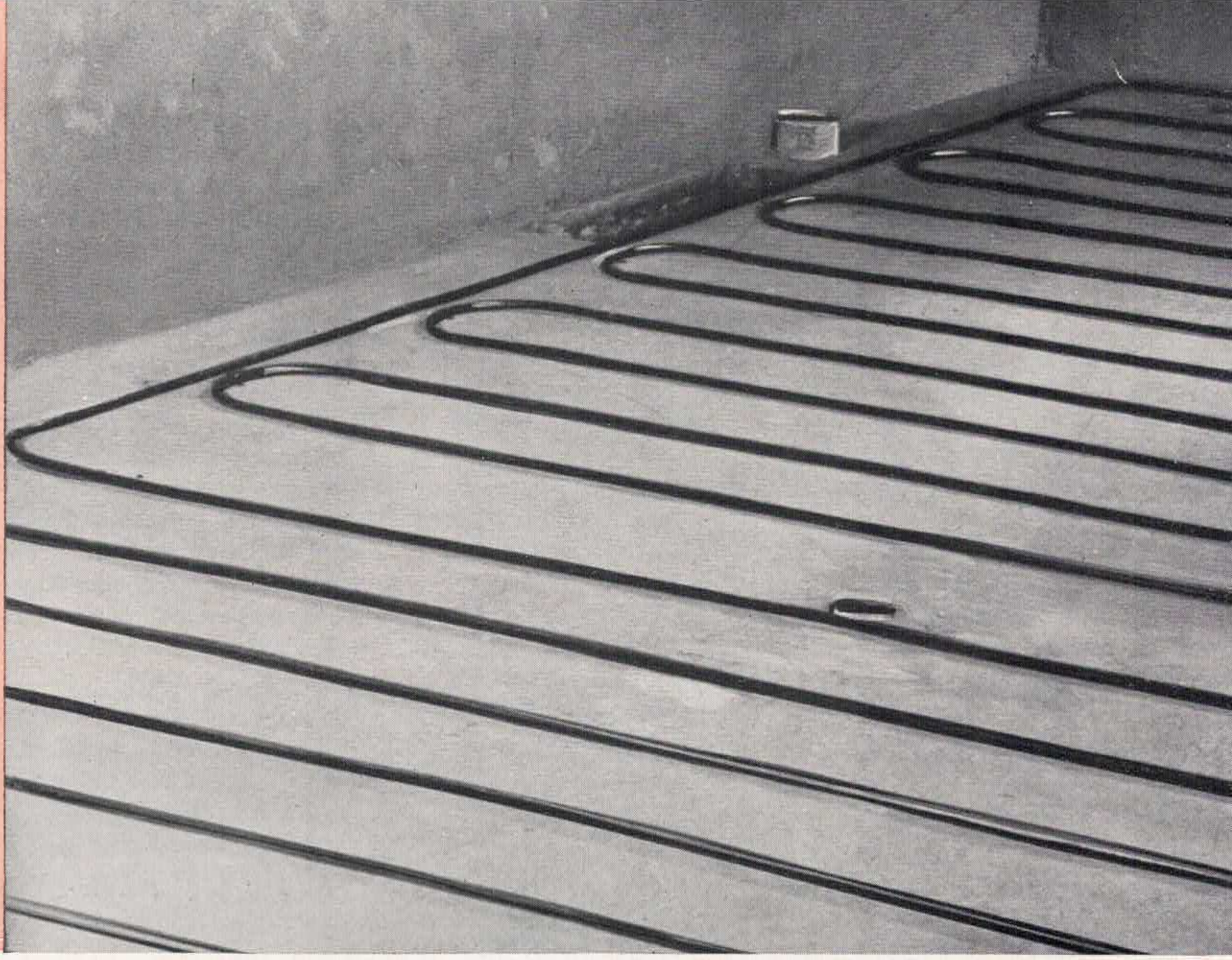
temperature difference the greater the rate of heat transfer, just as the greater the vertical distance between two tanks, the greater the rate of fluid transfer from the high one to the lower one if they are connected. Thus it is at once evident that wall or ceiling panels designed for a 120° F maximum surface temperature have a heat transfer potential, "voltage" if you prefer, more than three times as great as that of an 85° F floor panel.

Fortunately, the difference in capacity of floor and ceiling units is not nearly as great as the ratio of temperature differences would imply. The final capacities depend on surface characteristics as well as on temperature difference, and with respect to surface influence the floor unit possesses an advantage — as discussed in the next section — which partially offsets the disadvantage of smaller temperature difference.

B. Effect of Direction of Heated Surface on Capacity. Ceiling, wall, and floor panels correspond, respectively, to heated surfaces which are: 1. Horizontal and facing down; 2. Vertical; 3. Horizontal and facing up. The difference in heat dissipating characteristics of these three types of surfaces is very great and the reason for it can be readily visualized by means of a simple experiment: Obtain the cover of a cardboard box of moderate size (as a shoe box or hatbox) and heat it in front of a radiator or other available heat source to a temperature somewhat higher than that of the room air. Then hold the cover directly over your head with the cardboard rim facing down and slowly blow cigarette smoke into it. Hot air tends to rise and the warm smoke blown into the cover will tend to remain there until it is slowly dissipated by diffusion into the surrounding air. Repeat the experiment by holding the cover in a vertical position directly in front of you and again blowing smoke slowly into it; the tendency to rise now causes the smoke to move up over the vertical surface and escape around the rim at the top. Again repeat the experiment, this time with the cover held near the floor; now the smoke rises from all parts







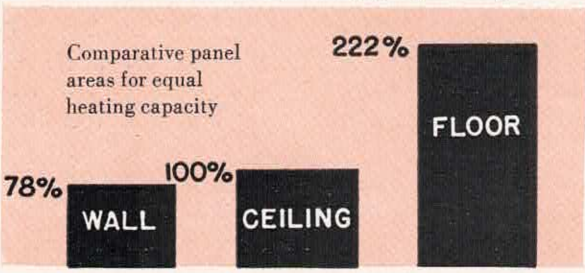
of the cover and is replaced by cold air which moves in, over the rim, from the sides.

The three simple experiments described above demonstrate convincingly that the movement of warm air across a heating panel will be least when the panel is located in the ceiling, somewhat more when it is in the wall, and greatest when the panel is located in the floor. Technically, the effect of the air movement is to increase the rate of heat transfer from 0.4 of a heat unit (per hour per square foot per 1° F temperature difference) for a ceiling panel to 0.8 units for a wall panel to 1.1 units for a floor panel. Thus the ratio of heat loss to room air for ceiling, wall, and floor panels is approximately of the order of 1 to 2 to 3. The greater transfer rate of a floor panel is an advantage in the sense that it increases the capacity and thereby partially offsets the influence of smaller temperature difference, but it is a disadvantage in that effective radiant heating requires reduction to a minimum of the air heating effect of the panel.

In addition to the heat loss to room air there is also a transfer of energy directly from the heating surface to the occupants or to unheated room surfaces by the mechanism of radiation. Radiant energy travels with the speed of light and for practical purposes can be considered as having negligible heating effect on the air through which it passes. The rate of radiant exchange depends on the temperatures of the emitting and receiving areas and on their surface characteristics, but the quantity emitted is completely independent of the position of the emitting surface. Experience shows that the radiant loss, over the range of temperatures found in panel heating installations, is approximately 1.0 heat unit (per hour per square foot of panel per 1° F temperature difference). This value is equally true for ceiling, wall, or floor panels.

Then adding the air-heating and the radiant fractions of heat loss for each type of panel gives: $0.4 + 1.0 = 1.4$ for a ceiling panel, $0.8 + 1.0 = 1.8$ for a wall panel and $1.1 + 1.0 = 2.1$ for a floor panel. The values are, in each case, the number of heat units transferred from one square foot of surface in one hour for each 1° F temperature difference. Examining these totals and considering the air-heating fraction in each case, it is evident that a ceiling panel transfers $1.0 \div 1.4 = 71\%$ of its energy by radiation whereas a wall panel transfers 56% by radiation and a floor panel transfers only one-half of its energy by radiation. Considered from another point of view the 50% greater heat transfer rate of a floor panel over a ceiling panel consists entirely of air-heating effect, hence in no way contributes to the attainment of those characteristics which are associated with *radiant* heating. Similarly, the 29% greater heat transfer of a wall over a ceiling panel consists entirely of air-heating. Both of these increases serve to add more heat to the room, but it is as though the extra energy were supplied from an auxiliary warm air system rather than from a radiant type panel surface.

C. Combined Effect of Temperature and Direction on Capacity. From the data of the two preceding sections it is now possible to determine the relative sizes of ceiling, wall, and floor panels of equal capacity. For a design surface temperature of 120° F a ceiling panel will have a temperature difference of 50° and a total heat transfer rate of 1.4, so its capacity will be $50 \times 1.4 = 70$ heat units per hour. A wall panel, operating at the same surface temperature, will have a capacity of $50 \times 1.8 = 90$ heat units per hour whereas a floor panel, with 85° F design surface temperature, will transfer only $15 \times 2.1 = 31.5$ heat units per hour. Assuming that the heating requirements of the structure were approximately the same irrespective of the panel location, a floor panel would then have to be 222% as large as a comparable ceiling panel, whereas a wall panel would need be only 78% as large as the ceiling unit. Thus in terms of panel size the wall installation would require least area, the ceiling somewhat more and the floor would need about 2⅞ as many square feet of heating surface as would the wall. The relative cost of ceiling, wall, and floor installations can therefore be determined by multiplying the respective



costs of unit area of each type of panel (as determined by local experience) by 1.00, 0.78, and 2.22 respectively. It is evident that low first cost would seldom be an attribute of a floor installation unless special circumstances reduced the cost per square foot of panel to substantially less than half of that for wall or ceiling units. A floor installation is the obvious recommendation of a supplier whose primary purpose is to sell a maximum quantity of pipe or tubing, but if he is desirous of providing a recommendation of greatest advantage to the customer he will in many cases suggest either a wall or ceiling installation.

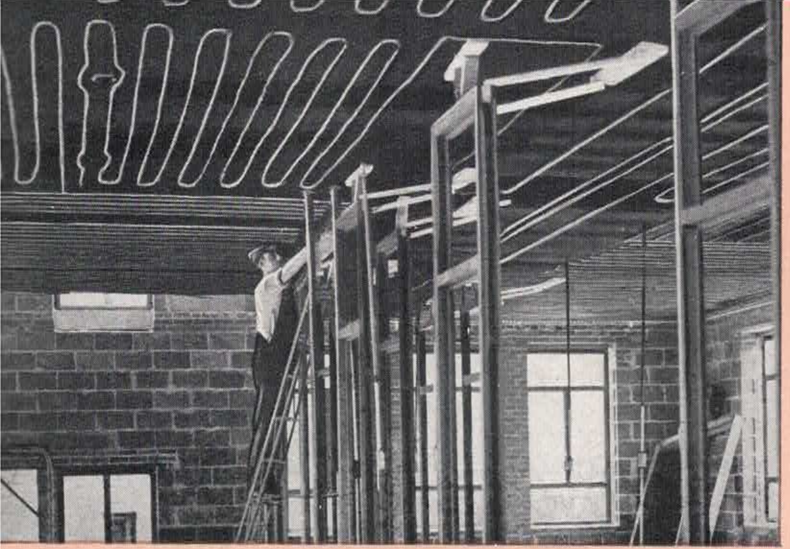
In addition to the inherent size advantage possessed by a wall panel, this type of installation offers another very significant first cost advantage in that wall panels can frequently be installed in inside partitions where a single panel can effectively heat two rooms. Such installations are subject to special problems of control, as discussed in the next section, but where these difficulties can be overcome a panel of this type has two very great advantages over all others: 1. There are no heat losses to the outside; 2. The area — and hence the first cost — is reduced by approximately one-half.

2. *Energy Losses from Rear of Panels.*

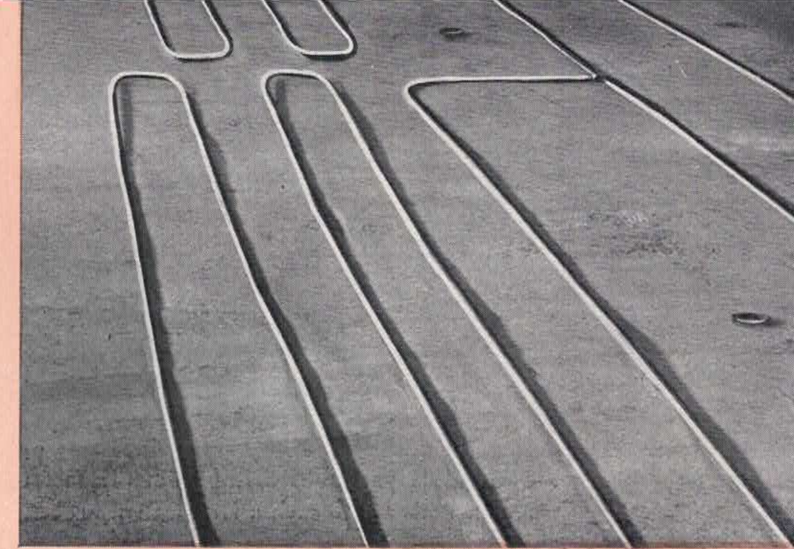
The purpose of a heating panel is to dissipate heat from the surface facing the room. Obviously, however, the heat supplied to the coils embedded in the panel will tend to flow out not only through the front heating surface, but also through the rear of the panel and thence through the floor, ceiling, or exterior wall to the outside air. In order to maintain low operating costs, it is essential to conserve the heat supplied to the panel for use within the room; this is done by providing insulation at the rear of the panel. From the standpoint of first cost, a panel location for which minimum insulation is required will have obvious advantages.

A. Inside Partitions. In structures where inside partitions can be used for heating purposes a simple, non-insulated installation is possible. Since the two sides of the panel each face rooms to which heat is to be supplied, *all* heat lost by the panel is usefully supplied to the heated enclosures. Two special problems require consideration when using inside partitions as heating panels: 1. The heat requirements of the two rooms adjoining the inside partition probably will not be the same. Consequently, the rooms will either require panels of different size, or panels which — though of the same area — operate at different surface temperatures. The latter arrangement can be easily obtained by designing the partition panel with the heating coil closer to one surface so that more heat will be supplied to one room than to the other. Such an arrangement would adequately solve the problem if the ratio of heat loads for the two rooms remained constant, but in general, this ratio will change. Occasions will arise on which there will be need of increasing the heat supply to one of the rooms while maintaining constant energy input to the other; control of this kind cannot be achieved if the panel surfaces of the two rooms are an integral part of one another.

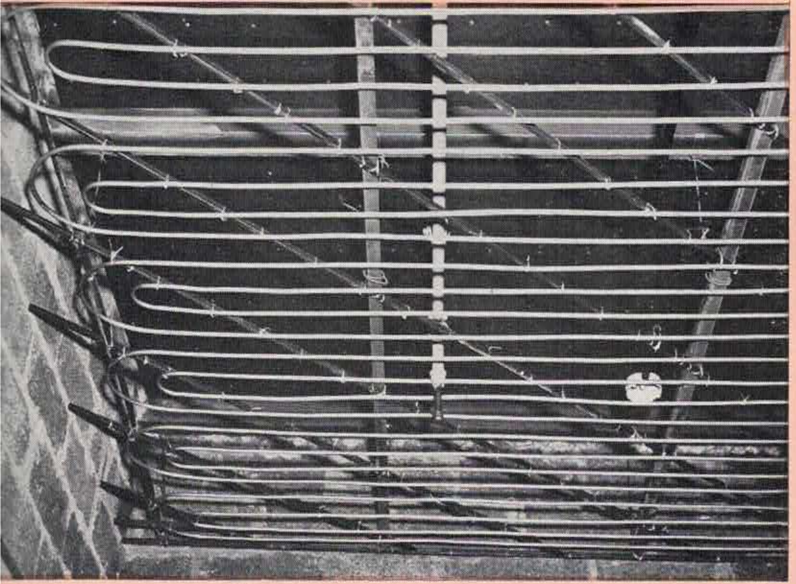
A partial solution to the above problem which allows retention of the advantages of the non-insulated partition panel while avoiding the difficulties of individual room control can be realized by using the inside partitions to carry the major part of the load and installing auxiliary panels in the outside wall surface (or in non-common parts of another inside partition) to take care of minor load fluctua-



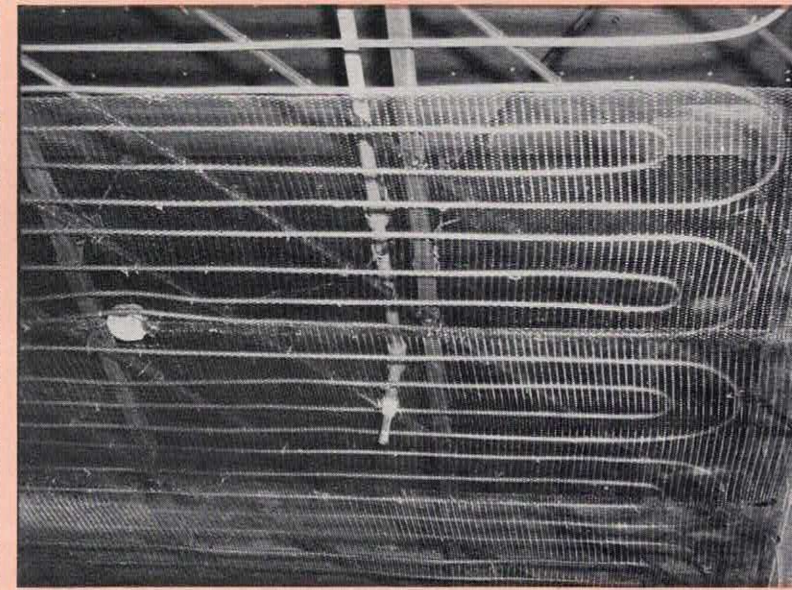
To warm the surface of a relatively large ceiling, wall or floor area, warm water is circulated through copper tubes coiled in a serpentine pattern.



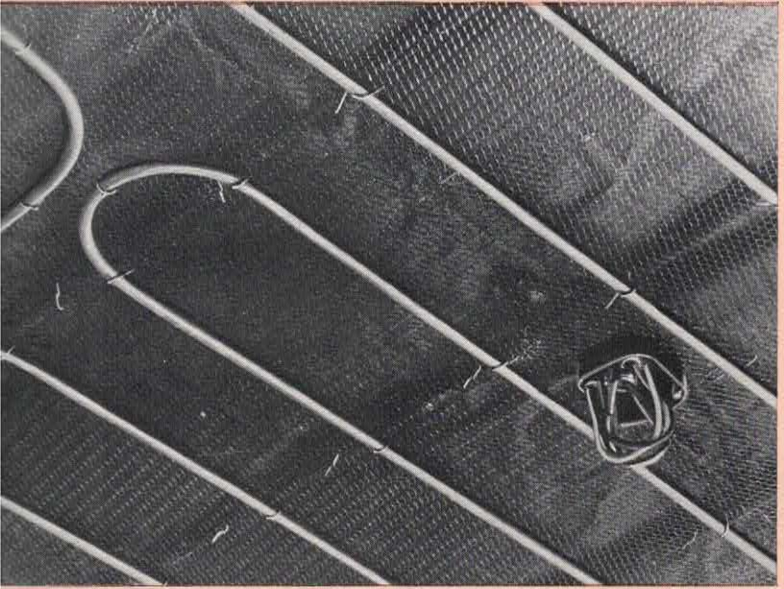
These copper tubes lying on the rough concrete slab will be imbedded as near the finished floor surface as practicable when the final layer of concrete is poured.



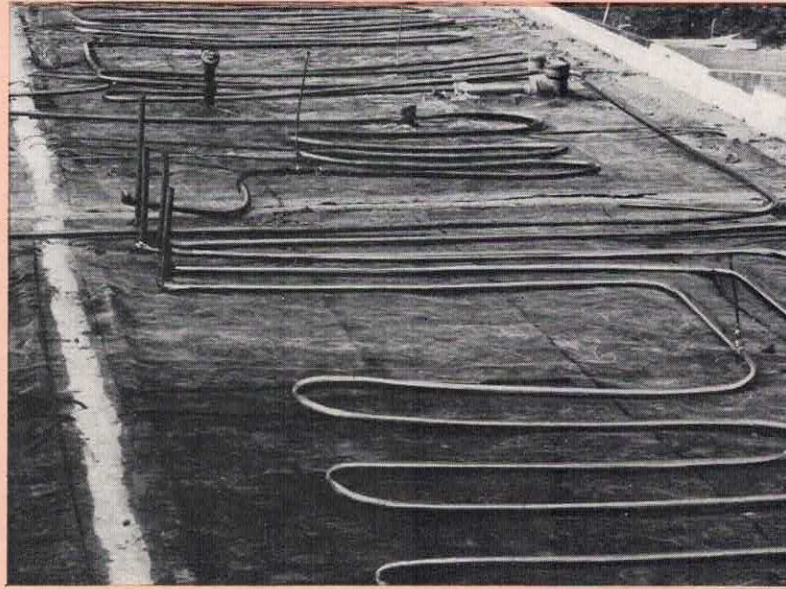
Light steel channels, to which the copper water tube is wired, are installed diagonally to support lengthwise or crosswise heating coils.



Metal lath is applied below the copper tube and is attached to supporting members. The plaster penetrates lath and partially surrounds the tube.



To provide the smoothest flow of warm water throughout a panel heating system, all bends and curves of the copper tube are made as generous as possible.



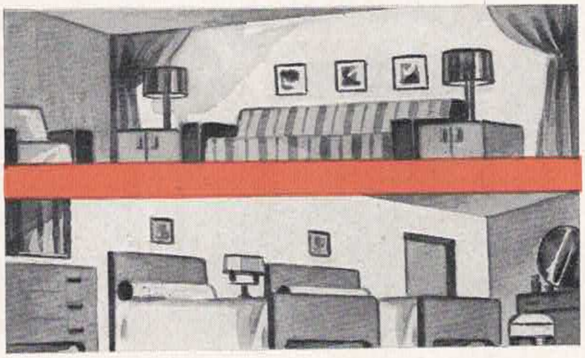
Heating surfaces should be distributed to conform to requirements of each room. Minor irregularities in alignment of the tube are relatively unimportant.

tions. In this event the auxiliary panels do not represent added area as they permit reduction in size of the common panel. Another method is to install sufficient partition panel to carry the entire load of the room having least exposure, then place this surface under direct control of the thermostatic element in that room; auxiliary panels are then used in the room on the other side of the partition and these are controlled by the thermostatic element in that room.

The greatest obstacle in the way of more general use of inside partitions arises from the fact that common walls are to such a large extent broken up by doors and closet space; in many cases there is not sufficient available partition space to permit the installation of adequate panel area. Other objections are that interior panels localize the heat source in that part of the room which is farthest from the cold exterior walls, hence tend to produce radiant drafts and make for non-uniform heating effect.

B. Exterior Walls. Panels located in exterior walls are likely to have a greater heat loss to the outside than those installed in any other location. A given thickness of insulation will usually be least effective — if effectiveness is measured in terms of the absolute quantity of heat which is lost rather than the per cent reduction in losses — when installed in a wall. This is true because the wall is exposed directly to the outside air, whereas the floor and ceiling exteriors are usually exposed to basement (or earth) and to attic space respectively. Additional insulation can be used with exterior wall panels to reduce their losses to a value consistent with that which would be found if the panels were located elsewhere, but the cost of such added material would have to be charged to the wall system.

C. Ceiling Panels. Losses from the rear of ceiling panels will in general be less — for the same amount of insulation — than from exterior wall panels. The difference, however, is not likely to be very great and probably will be more than offset by other factors. One point, however, which is particularly worthy of attention is that there are no losses from the rear of a ceiling panel when it is installed in a room below a room to which heat must be supplied. Thus in a two-story residence, the energy lost from the top side of ceiling panels for first floor rooms will serve to meet the heating requirements of rooms on the second floor. In general, installations of this kind are designed so that first floor ceiling panels will supply something less than the minimum heat needs of the room overhead. In other cases, the heating element is located near the mid-point of the between-floor structure so that what is a design ceiling panel for one of the rooms is also a design floor panel for the other; this latter arrangement is economical in terms of first cost, but requires precision design for the panel and will lead to serious control difficulties unless the ratio of loads for the two rooms remains practically constant.

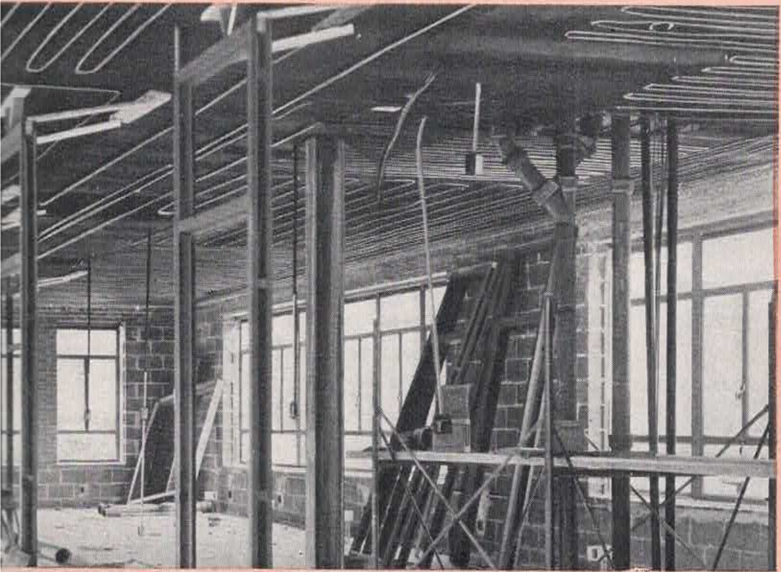


D. Floor Panels. The statements of the above paragraph relative to combined ceiling-floor installations also apply to combined floor-ceiling installations. For floor panels from which rear side exposure is to the ground, the outside air, or to an unheated basement space, the insulation needs are similar to those of ceiling units. One special type of floor panel which is widely used does require separate consideration: In many cases the floor slab, when concrete flooring is used, is poured directly on the earth, or on some type of fill which, in turn, is placed directly on the earth. Many installations of this kind are in service for which no insulating material of any kind has been used under the floor slab. The principle underlying such construction is that the earth constitutes a semi-infinite solid which will eventually reach an equilibrium temperature distribution — out from the slab — such that the resistance to heat flow from the slab out around its edges to the ouside air will be very small. The accuracy of such an assumption depends on the locality and on the slab construction, and it should be carefully investigated before proceeding with any contemplated installation. Unless calculation clearly demonstrates that the particular system is one for which losses will be negligible, the safer design will be one in which insulation is provided for the underside of the floor slab.

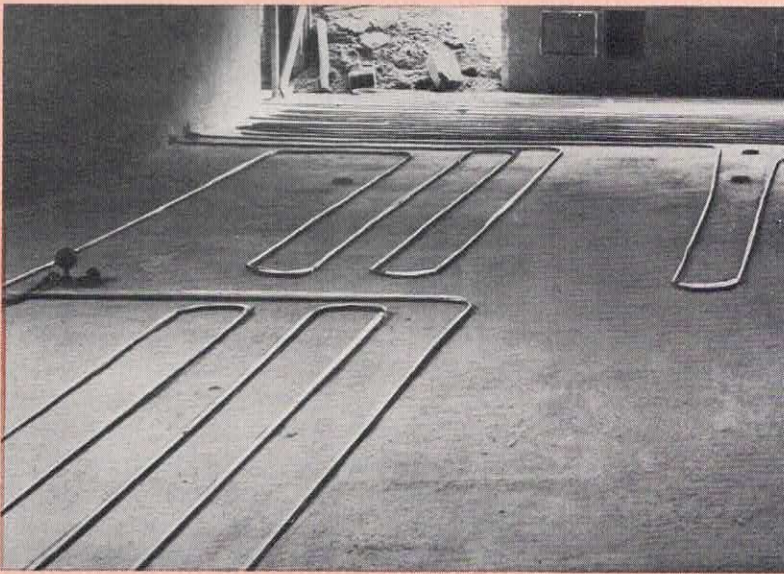
E. General. The importance of providing adequate insulation behind a heating panel — irrespective of the location of the panel — cannot be overemphasized. If losses from the rear of a panel are excessive the effect will be not only to increase the operating cost of the system, but also to place in hazard the entire design; excess losses require excess temperature drops of the hot water passing through the panel and consequently necessitate maintenance of a substantially higher temperature of water from the boiler than would otherwise be required; both

An efficient radiant panel heating system must not only be carefully designed, but should be installed exactly in accordance with the calculations.

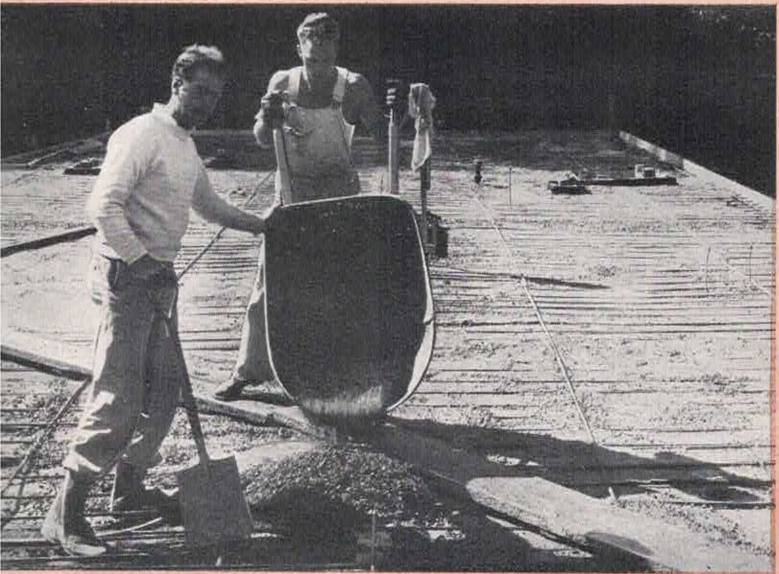
For most installations, the copper tube used need not be large in diameter; hence the plaster covering in a ceiling or wall panel will not be excessive.



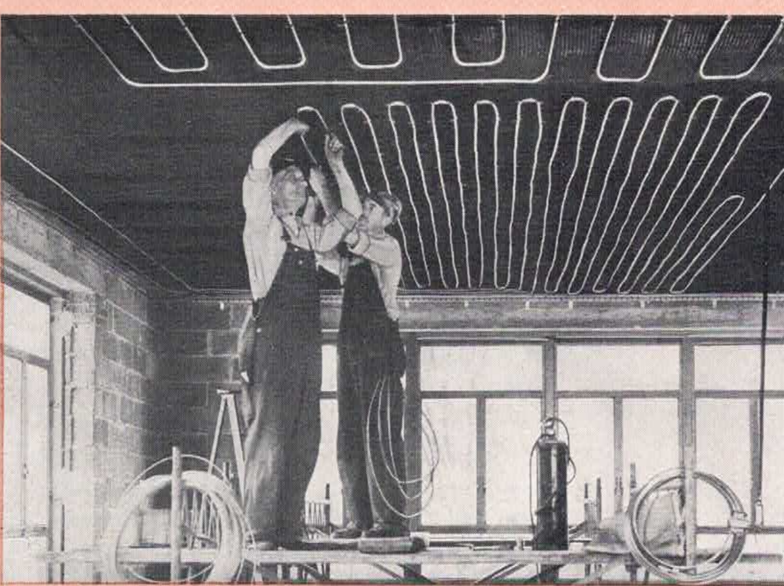
Panel heating places few restrictions on the position of partitions, windows or doors, and does not prevent moving of partitions if changes are desired.



In some cases greatest effectiveness is attained by distributing two or more small panels over the desired area rather than by using one large panel.



A drawback of panel heating is that alterations in the system, if needed, are difficult and costly, making correctness of original design doubly important.



General experience has been that panel systems may cost as much as 10% more to install but may save approximately 10% in their cost of operation.

of these factors can lead to structural difficulties as they necessarily increase the thermal stresses to which the panel is subjected.

Lacking other data, the designer will be adequately conservative if he provides sufficient insulation to insure reduction of the heat loss from the rear of any panel to not greater than 5% of the design heat loss from its face.

3. *Relative Comfort Characteristics of Ceiling, Wall, and Floor Panels.*

The preceding discussion relative to various panel locations has been in terms of size and first cost. Also of importance is some knowledge of the differences in performance characteristics associated with these different types of installations. Recognizing that the purpose of a radiant heating system is to raise the mean radiant temperature while not directly affecting the room air temperature, it is at once evident that the type of panel which will most closely approach this objective will be one which has a maximum ratio of radiant to total heat transfer. Any panel, irrespective of type or location, will necessarily perform in large measure as an air heating device.

Even if a panel were to be developed from which all heat transfer were by radiation, the room would necessarily have a heating characteristic not radically different from that of convection heating because most of the energy dissipated by radiation from the panel would eventually be transferred to the room air by convection from the unheated room surfaces. Thus the matter of selecting a panel location for which the radiant fraction is high rather than low does not represent the difference between a true radiant heating system and a convective one, but rather determines the magnitude of the approach which the actual installation will attain to the characteristics of a radiant system. No panel system does more than provide an approach to radiant heating, but the difference in degree of approach which is realized with different types of panels is very great.

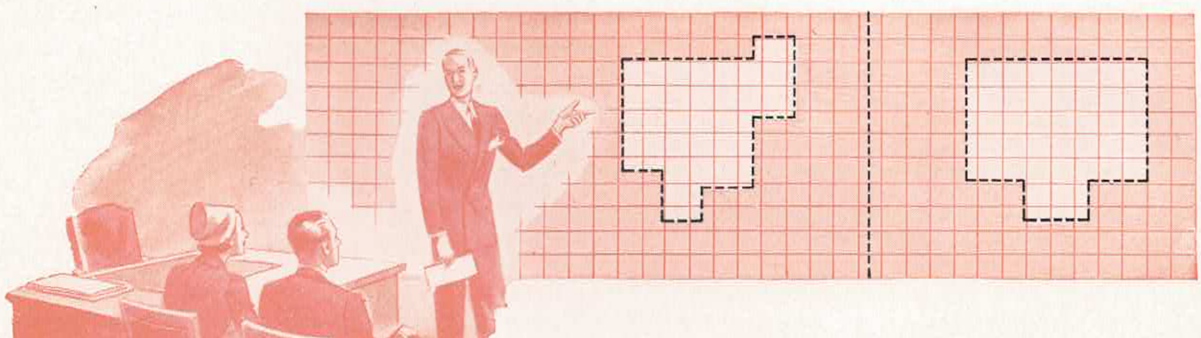
As discussed in the section on size, a ceiling panel transfers substantially more heat by radiation, for a given total output, than do either wall or floor surfaces. Almost three-fourths of the heat leaving a ceiling panel is in the form of radiant energy, whereas less than two-thirds of that from a wall panel is in radiant form and only one-half from a floor panel is transferred as radiation. The effect on performance of these differences is to make it more difficult to maintain room air temperature at a value depressed below the average surface temperature; as the air heating fraction increases the comfort air temperature tends to rise until, in the extreme case, comfort would be experienced with room air and average surface temperature both at 70° F. This latter condition would not be unsatisfactory and, in fact, would be considerably more desirable than the results achieved in some 100% convection systems where cold-wall effect reduces the average surface temperature to a value *below* that of the air temperature. But if the system is to retain, in any measure, the advantages of cooler "fresher" air which are claimed for radiant heating, then it is essential that the air heating effect of the panel be minimized. This would indicate that the ceiling is the most preferable location for panels and the floor the least desirable location.

In certain structures and under particular load conditions exceptions to the generalization of the preceding paragraph will occur, but for the average installation the comfort air temperature will be highest for floor panels and lowest for ceiling panels. The most important exception is that of a room with unusually high ceiling. In this case, the much greater proximity of the occupant to the floor rather than to the ceiling increases greatly the effectiveness of the floor surface as a means of raising the equivalent surface temperature. This can be visualized by considering an occupant standing in the center of the floor of a room 20′ long by 20′ wide. Irrespective of ceiling height the quantity of radiant energy which reaches the occupant from the floor remains constant since the position of occupant and floor do not change with respect to one another. If, however, the panel were in the ceiling, the quantity of radiant energy received by the occupant would decrease as the ceiling height increased (since the distance from panel to occupant would become greater). Note that this effect has nothing to do with the required panel size, but does influence the performance characteristics of the system; as ceiling height increases a ceiling panel has a constantly decreasing equivalent fraction of radiant transfer and hence it provides, to an ever-lessening degree, the radiant characteristic which is to be desired in panel heating.

Another exception occurs in the case of small rooms with high ceilings. In this case the reasoning of the preceding paragraph applies except that the influence of wall panels on the equivalent average surface temperature is even greater than that of floor panels. This is true because the geometrical relationship between an occupant and a vertical surface gives more effective radiant transfer than will occur between an occupant and a horizontal surface.

Summarizing, ceiling panels give system characteristics which more closely approach those of true radiant heating than do any other type of panel. Exceptions to this statement occur in the case of rooms with high ceilings: If the rooms are small, wall panels are to be preferred, but if large, floor panels will lead to best results.

WHAT IS THE BEST METHOD OF DISTRIBUTING THE HEATING SURFACE?



The installation of a panel sufficiently large to provide the requisite heat supply is not in itself a guarantee of satisfactory performance. In addition, attention must be given to the distribution of the panel area in such a manner as to provide reasonable uniformity of heating effect throughout the entire room. This same problem has already been briefly discussed (Page 24) in establishing a comparison between indirect lighting and panel heating. The same analogy can be extended to the case of a large room in which only a relatively small fraction of the ceiling need be heated. If a single panel of the required area is centered at room center the system will be comparable to that represented by a single lighting fixture located at the mid-point of the room. More effective and uniform lighting would be obtained by using a number of smaller fixtures distributed through the room and, similarly, more effective and uniform heating would be attained by distributing the total required panel area either in a number of small panels, or as a border, or as a continuous heating strip in the room ceiling.

The problem of selecting the most effective pattern for distributing panel surface is a complicated one and depends on room size, shape, and ceiling height. For the case of ceiling panels certain generalized patterns have been developed and presented in a paper which is available in the Transactions of the American Society of Heating and Ventilating Engineers*; the recommended patterns can be summarized as follows:

1. *In a Room with 8′ Ceiling.*

A single panel in the center of the ceiling will give poor distribution. The preferable arrangement is to use a pattern consisting of strips of panel running parallel to both wall directions and centered 10′ apart in both directions. The correct width of strip can be readily determined by measuring — on a floor plan of the room — the indicated length of panel center line, then dividing this number into the required panel area. The result will be the requisite width of panel, though subject to slight increase to take account of the number of places where the normal strips cross over one another. Although 10′ spacing is said to give *optimum* distribution, any spacing between 9′ and 14′ will be satisfactory, but spacings outside of this range should be avoided. Thus if the room were 18′ square a satisfactory panel distribution would be one having three strips running in each of the two directions, one down the center of the room along each axis and the other four over against the walls. If the room were 16′ by 16′ the preferred arrangement would be to have four strips parallel to the four walls, each strip centered 3′ out from the respective wall (parallel strips thereby being centered 10′ apart).

* "Optimum Surface Distribution in Panel Heating and Cooling Systems", Raber and Hutchinson, ASHVE Transactions, Vol. 50, 1944.

2. *In a Room with 10′ Ceiling.*

For this case a square strip pattern similar to that described for an 8′ ceiling should be used, but with the strips centered 14′ apart for optimum distribution or in the range from 10′ to 15′ spacing for less than optimum, but satisfactory, results.

3. *In a Room with 12′ Ceiling.*

When the ceiling height is equal to or greater than 12′ the distribution problem becomes less important and almost any reasonably symmetrical panel will give satisfactory uniformity of heating effect. For optimum results, however, a squared strip spacing similar to that recommended for 8′ and 10′ ceilings should be used with the strips on 20′ spacing, though any spacing in the range from 17′ to 21′ will closely approach the performance of a 20′ spacing. For rooms smaller than 14′ an effective pattern is obtained by centering two strips of panel along the room axes.

4. *Modifications of Basic Pattern.*

The distribution arrangements suggested in the preceding paragraphs will require modification, in the light of the designer's experience, to meet such special conditions as will inevitably be associated with different installations. For rooms with large window areas, excess cooling will tend to occur in the region near the glass surfaces and this will have to be offset by shifting more of the heating surface to the region near the exterior walls than to that beside inside partitions. Similar adjustments will be necessary near outside doors, etc. No fixed general rules have been established for arranging special panel areas of this type, but adequate distribution can usually be obtained by simple common sense adjustments.

Those who wish to obtain technical data on which material in this booklet is based are referred to the following original sources:

Panel Heating and Cooling Analysis, by *Raber and Hutchinson*, ASHVE† Transactions, Vol. 47, 1941.

Panel Heating and Cooling Performance Studies, by *Raber and Hutchinson*, ASHVE† Transactions, Vol. 48, 1942.

Optimum Surface Distribution in Panel Heating and Cooling Systems, by *Raber and Hutchinson*, ASHVE† Transactions, Vol. 50, 1944.

Radiant Energy Exchange as a Factor in Airplane Cabin Heating, by *Raber and Hutchinson*, Journal of the Aeronautical Sciences, Vol. II, 1944.

Radiant Heating: Floor, Wall or Ceiling?, by *F. W. Hutchinson*, Heating, Piping and Air Conditioning, March, 1946.

Response and Lag in the Control of Panel Heating Systems, by *F. W. Hutchinson*, ASHVE† Transactions, Vol. 53, 1947.

†*ASHVE: American Society of Heating and Ventilating Engineers,* 51 *Madison Avenue, New York* 10, *N. Y.*

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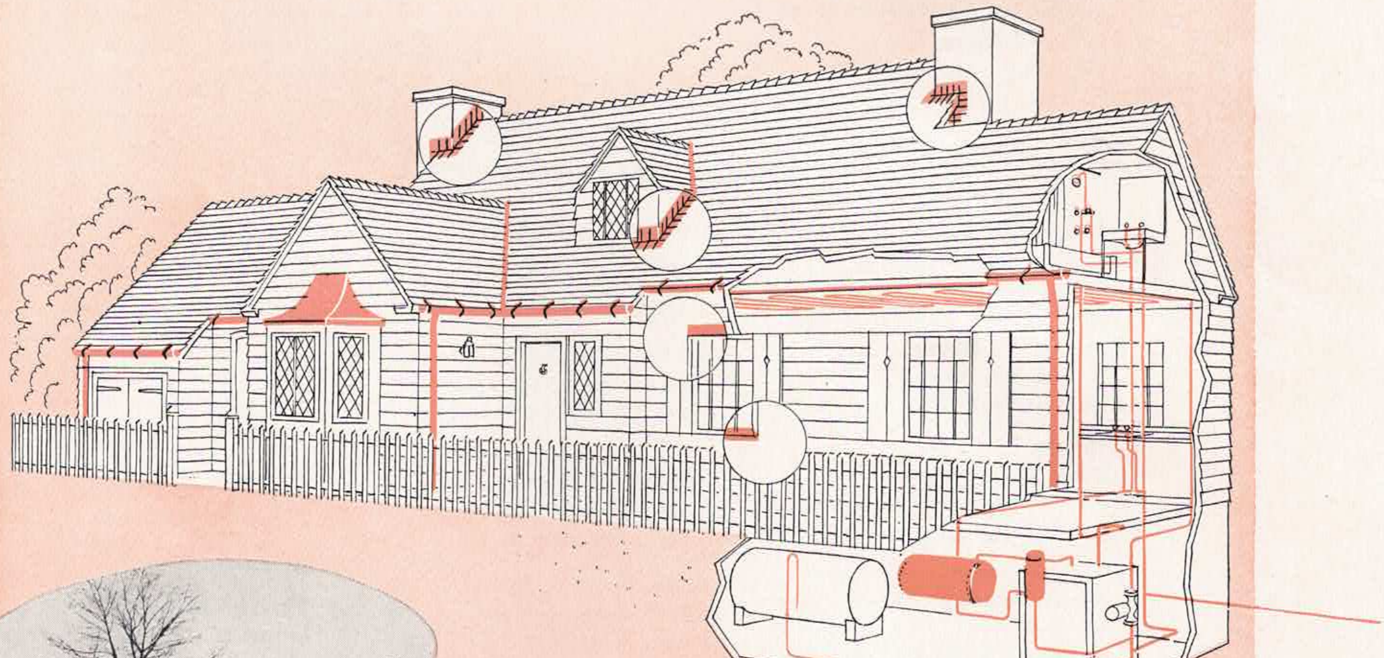

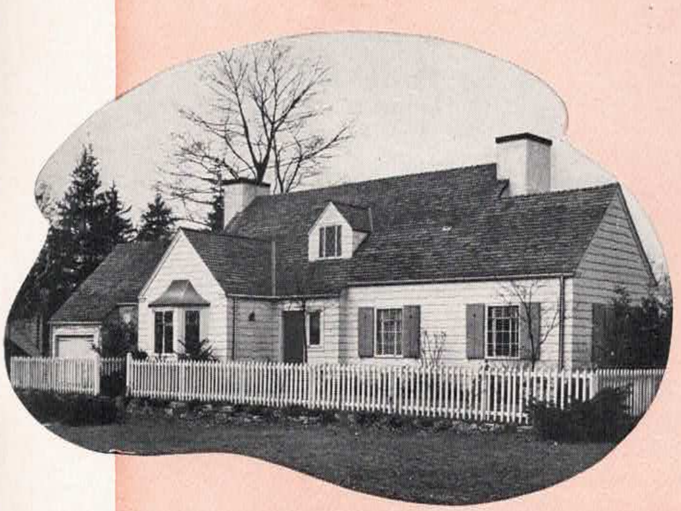

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