A WORKING METHOD FOR CALCULATING A FLOOR TYPE RADIANT HEATING SYSTEM

WITH the rapid development of radiant heating there has arisen a need for a simplified and readily applied method of design of floor type radiant heating projects. In this discussion, in order to reduce the problem to its simplest terms, comments will deal mainly with the design of residences or commercial buildings built directly on the ground without basements and heated by wrought iron pipe coils imbedded in or under the concrete floor slab.

The problem of design will be approached in four steps as follows:

1. *Calculation of the amount of heat to be supplied to the building, which is, of course, equal to the heat loss.*
2. *Selection of the necessary floor temperature and the mechanical design of the floor.*
3. *Selection of water temperature, pipe size, spacing, and connections.*
4. *Selection of pump, boiler, and auxiliary equipment.*

It is desirable to approach these topics in their logical sequence, in order that the data necessary for the handling of each successive step of the design problem may be available when the time comes to deal with it.

I. Calculation of Heat Loss from the Building

In the design of a radiant heating system just as in the design of a radiator system, it is necessary to know just how much heat must be supplied before a system for introducing it into the room can be intelligently designed.

The system must be designed to supply enough heat to balance the heat loss from the room during the coldest weather commonly encountered, and this is usually taken to mean about 15 degrees higher temperature than the coldest day ever recorded in the locality where the building is to be erected.

Heat must be supplied to balance three major losses:

- *A. Heat loss through walls, floors, and ceiling.*
- *B. Heat loss through glass areas and doors.*
- *C. Heat loss required to warm cold air which leaks into the room around windows and doors.*

These three major methods of heat loss from buildings will be discussed separately.

A. Heat Loss Through Walls.

A great deal of research work has been done in recent years to determine the amount of heat which will be lost through walls of various constructions per degree temperature difference between inside and outside air, and the results of these studies have been published and are quite readily available.

Heat loss through well insulated walls commonly runs from about .06 to .20 BTU per square foot of wall surface, per hour, per degree temperature difference between inside and outside air. Walls with no insulation between the studding, but with rigid insulation sheathing may run from about .15 to .20 BTU per square foot, per hour, per degree temperature difference. With wood sheathing, a coefficient of 0.30 may be encountered. For a typical construction consisting of clapboard, sheathing, studs, and plaster on plaster board interior finish, with no insulation between the studs, the coefficient of heat transfer would be about 0.19 BTU per square foot of wall area, per hour, per degree temperature difference between the inside and outside air. The same wall with brick veneer substituted for the wood siding would have a coefficient of 0.21 BTU per square foot of wall area, per hour, per degree temperature difference.

To find the heat loss per square foot of surface, it is only necessary to select the proper coefficient, multiply it by the difference between the inside temperature and the selected outside temperature, say zero degrees F., and multiply the product by the area of exposed wall. For example, if a certain room has 150 square feet of exposed wall area and the wall has a heat transfer coefficient of 0.20, when the outside air temperature is zero and the inside air is 70 degrees, there would be a heat loss of 14 BTU per square foot, per hour, or a temperature loss through the walls of 2100 BTU per hour.

B. Heat Loss Through Glass Areas and Doors.

Heat is conducted through glass just as through walls but the rate of transfer is so much greater that it is customary to deal with this item separately. For single glazed windows about 1.13 BTU per hour will escape through every square foot of window area per degree temperature difference. Double glazing will cut this loss to 0.45 BTU per square foot, per hour, per degree temperature difference. Thus, with the air in a room at 70 degrees and an outside temperature of about zero, approximately 79 BTU will escape through each square foot of single glazed window and only about 31.5 BTU per hour will pass through one square foot of double glazed window.

C. Heat Loss Through Leakage of Air Around Windows and Doors.

When cold air leaks in around windows, heat must be supplied to warm it to room temperature. Even in the best of weather-stripped rooms, considerable leakage occurs; thus, infiltration loss should be given careful consideration by the heating engineer or contractor if a properly balanced and adequately designed system is to be installed.

To warm one cubic foot of air from zero to 70* degrees, requires the addition of 1.26 BTU and since infiltration often causes all the air in a room to change one or even two times per hour, it is apparent that considerable heat must be supplied to warm this volume of cold air. While rule of thumb methods are sometimes used to estimate the amount of air leakage, time required for a more accurate determination, is usually well spent.

Experiments with various types of windows more or less accurately fitted would indicate that with a typical wind velocity of about 15 miles per hour, the average non-weather-stripped window will have a leakage of about 40 cubic feet of air per hour, per foot of crack. Since the crack around a double hung window equals twice its height, plus three times its width, (including the crack between the upper and lower sash) it is a simple matter to calculate the leakage per window.

Weather-stripping reduces the leakage per foot of crack to about 24 cubic feet per hour and, if the window is poorly fitted and is not weather-stripped, about 110 cubic feet of air per hour, may be expected to enter through every foot of crack.

Of course, if a room is exposed on all four sides and half the windows are on each of two opposite sides, the air which leaks in through the windows on one wall will leak out through the windows on the opposite wall, and for rooms with three or four exposed sides, it is customary to compute the amount of air which would leak in through all the windows and divide it by two to find the amount of air which must be warmed. If the room is exposed on only one side, the other three walls being interior partitions, then all the air that leaks in must be warmed if that room happens to be on the windward side of the building. If a room has two walls exposed, air leakage should be taken as equal to the flow through the windows on the wall where the greatest crack is found. For example, for a room with three windows and two exposed walls, the leakage would be taken as the infiltration through the two windows because leakage through the one wall is more than half the total. In no case should the amount of air to be heated be taken as less than half the leakage which would occur through all the cracks.

Outside doors may be treated as poorly fitted windows and the leakage figured at about 110 cubic feet per hour, per foot of crack, and if they are weather-stripped, about half the figure can be considered typical.

To summarize the leakage through windows and doors, it may be computed by figuring the length of crack around all openings, multiplying this length of

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** Seventy degrees was selected as a basis for these calculations because it is slightly higher than the temperature most owners maintain when floor coils are used. One user finds a 60 degree thermostat setting comfortable in the coldest weather; others prefer the air at 65, 68 or 70. To be conservative in this article, the highest of those temperatures was selected.*

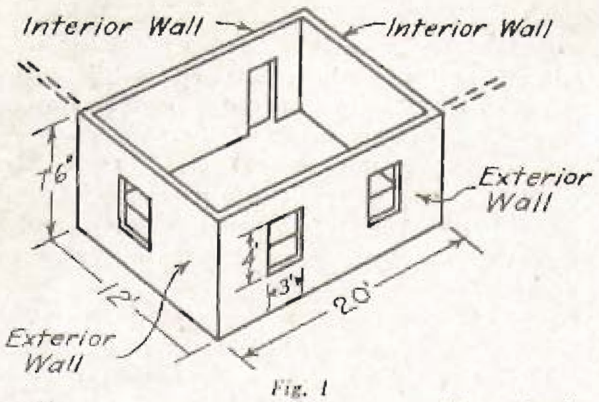


Fig. 1
Sketch showing typical corner room, ceiling omitted

crack by the amount of air which will leak in through each linear foot, and then taking a portion of this total depending on the number of exposed walls and the location of the openings. Having found the cubic feet of air to be warmed, the volume should be multiplied by 1.26 BTU per cubic foot to find the necessary heat input. The value 1.26 applies only when the inside-outside temperature difference is 70 degrees. For other temperature differences the following formula applies:

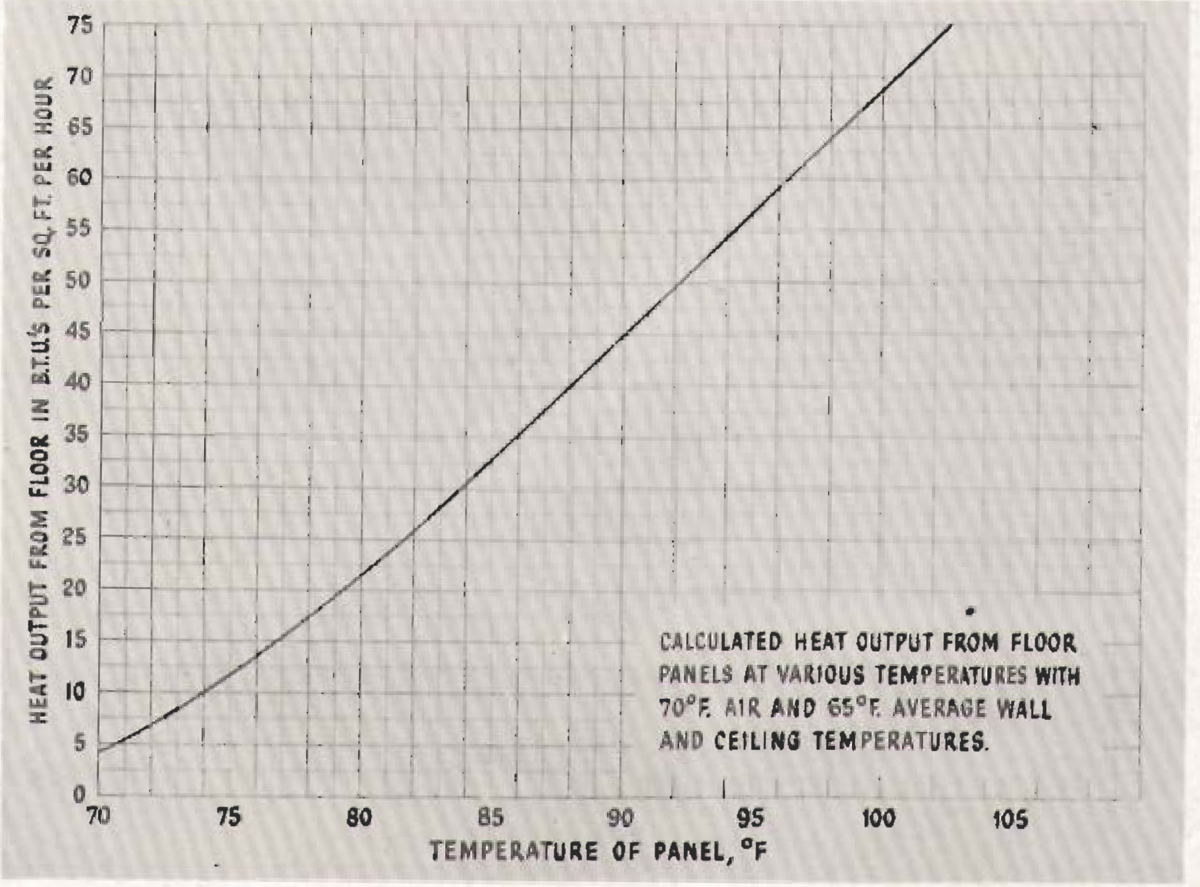
$$\text{Heat required equals } \frac{1.26}{70} \times (\text{Inside Temperature} - \text{Outside Temperature}) \times \text{Volume of air.}$$

In order to crystallize the method of applying the calculating principles just outlined, a typical installation follows:

Figure 1 shows in perspective a typical corner room 20 feet long, 12 feet wide, with a 7 foot 6 inch ceiling. It has three double hung windows, weather-stripped, and each window is three feet wide and four feet high. The outside walls are of brick veneer construction without insulation and have a coefficient of conductivity of 0.21 BTU per square foot, per hour, per degree temperature difference between the inside and outside air. Heat loss through the floor will be neglected since it is planned to use this surface as a warm panel. Furthermore, it will be assumed that heat loss through the ceiling is zero or, in other words, the room above is to be heated to the same temperature and, therefore, no heat will flow through the ceiling. Similarly, heat flow through interior partitions separating rooms at the same temperature will be zero.

The first step is, of course, to compute the area of the various surfaces. These are tabulated as:

Fig. 2



CALCULATED HEAT OUTPUT FROM FLOOR PANELS AT VARIOUS TEMPERATURES WITH 70°F. AIR AND 65°F. AVERAGE WALL AND CEILING TEMPERATURES.

Surface	*Area in Sq. Ft.*
Outside Wall (Exclusive of glass)	*204*
Glass	*36*
Floor	*240*

With radiant heating, it is customary to maintain slightly lower air temperature than with a radiator system, and in this example an air temperature of 70 degrees will be assumed with an outside temperature of zero. Heat loss through the outer wall will thus be (70 degrees temperature difference) × (0.21 BTU per square foot, per hour, per degree temperature difference) × 204 square feet or 2999 BTU per hour.

Heat loss through the glass is found by a formula similar to that just mentioned. Heat loss through the glass equals (70 degrees temperature difference) × (1.13 BTU per square foot, per hour, per degree of temperature difference) × (36 square feet) equals 2848 BTU per hour.

Before calculating infiltration loss, the length of crack around the windows must be figured. Including the cracks between the upper and lower sash, there would be 17 feet of crack per window, or a total of 34 linear ft. of crack for one wall and 17 for the other. In a previous paragraph, it was stated that for a room of this description, the volume of air to be heated should be taken as equal to the leakage through two windows. Using 24 cu. ft. per hour as the infiltration per foot of crack, we find that it will be necessary to heat 816 cu. ft. of air per hour. To warm one cu. ft. of air from zero to 70 degrees requires 1.26 BTU, so that to warm 816 cu. ft. of air per hour requires 1028 BTU per hour. Thus, the "infiltration loss" is 1028 BTU per hour.

To summarize, the total heat loss would be:

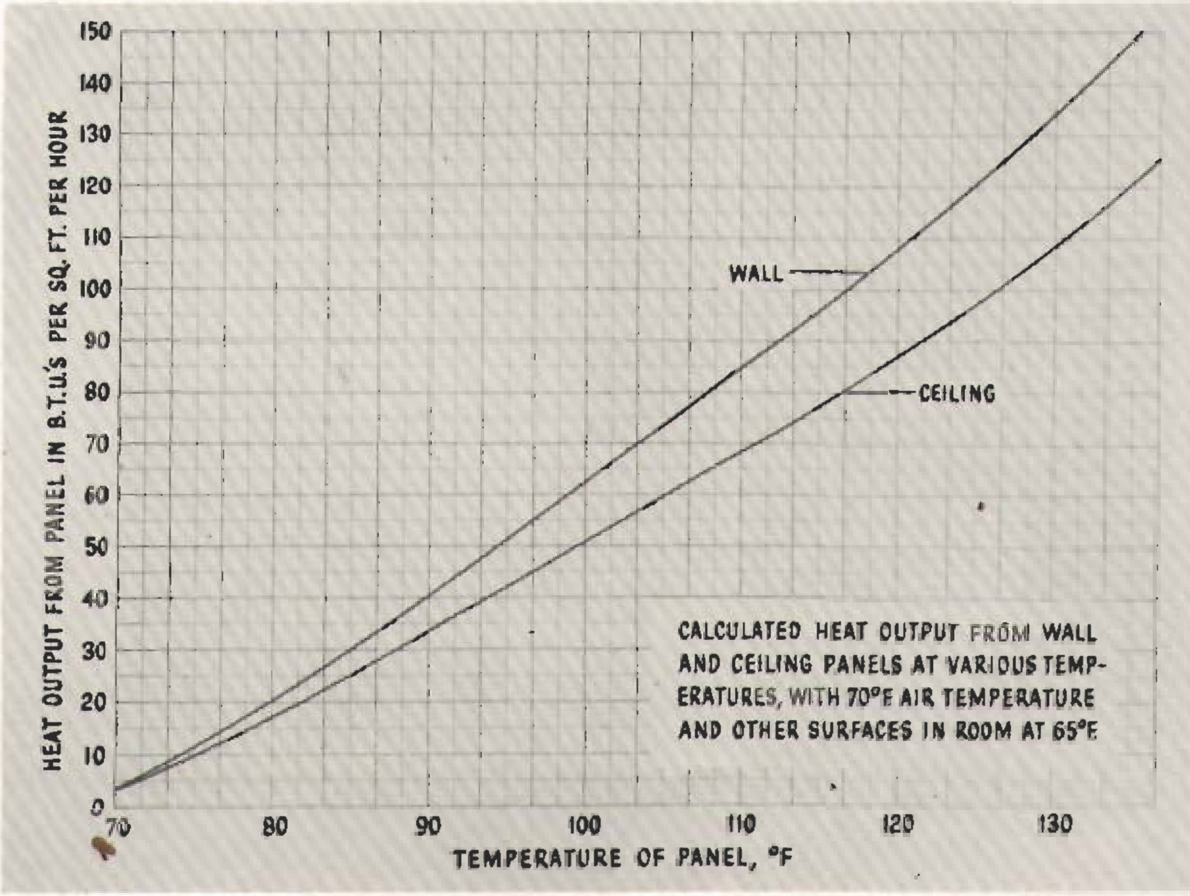
Through Outside Walls	*2999 BTU per hr.*
Through Glass	*2848 BTU per hr.*
Due to infiltration	*1028 BTU per hr.*
TOTAL	*6875 BTU per hr.*

We may now proceed to select the necessary floor temperature and to consider the floor slab.

II. Floor Temperature and Mechanical Design of the Floor

Figure 2 shows the amount of heat expressed in BTU per sq. ft. per hour, which will be given off by a warm floor at various temperatures. After the heat loss in the room has been computed, it should be divided by the floor area to find the necessary heat output per square foot of floor surface. Knowing the necessary heat output, it is a simple matter to select from

Fig. 3



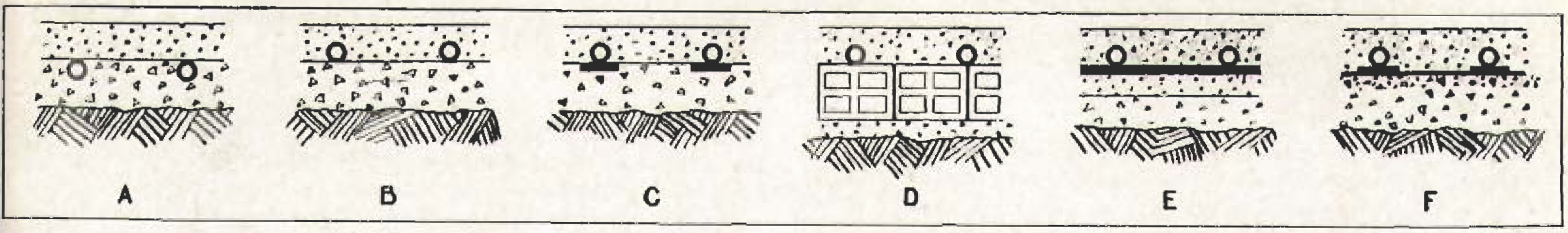


Fig. 4

Figure 2 the necessary floor surface temperature. In the illustration just cited, the heat loss was 6875 BTU per hour and the floor area was 240 sq. ft. Thus, the heat loss per square foot of floor surface would be 28.6 BTU per hour and from Figure 2 it is apparent that in order to balance the heat loss, the floor would have to be at a temperature of between 83 and 84 degrees F. Authorities agree that a floor temperature of 85 degrees is not excessive.

A few words might be said about special cases such as rooms with excessively large heat loss. For example, entrance halls often require more heat than other rooms because of their relatively small floor area in comparison to the outside wall area and the large amount of air leakage at the door. This higher heat loss may be balanced by installing extra capacity in adjacent rooms so that normal air circulation through the house will supply the deficiency.

Another method is to place a warm panel in the ceiling or in a wall. Figure 3 shows the rate at which these panels will give off heat when maintained at different temperatures. Depending on the ceiling height, ceiling panels can be operated at between 105 and 130 degrees F. and wall panels are usually held to a temperature of 100 degrees or less. It will be seen by an inspection of these curves that ceiling panels operated at relatively high temperatures may be used as effective supplements to the floor coils.

Then too, combination systems in which convectors or radiators are used in conjunction with radiant heating have also been successful when unusual requirements were to be met. To calculate the required size of radiator necessary to supplement the floor coils, it is suggested that the location of the radiator be selected, but the size be deferred until after necessary water temperature in the radiant heating coils has been chosen. Then after the operating temperature of the water has been figured, a radiator size may be readily calculated to supply the difference between the heat given off by the radiant panels and the heat requirement for the room.

After the panel temperatures have been chosen and the amount of heat which they must dissipate is known, the designer may proceed to consider various means for maintaining the floor at this chosen temperature.

Figure 4 shows some of the methods of floor construction which may be used. Drawing "A" of this figure illustrates the system most commonly employed to date in residential projects. Over the compacted soil a layer of gravel or broken rock 4 to 6 inches deep is placed and the wrought iron pipe coils are laid out so that the gravel just covers them. Cinders should never be used in place of the gravel because they contain a large amount of sulphur and will cause no end of trouble due to corrosion. Of all the available fill materials, limestone is to be preferred, but coarse gravel may be used.

Over the coils and gravel a concrete slab is poured. Heat is conducted from the pipe through the concrete.

Some designers prefer to embed the pipe directly in the concrete and since wrought iron and concrete expand at the same rate, this is a perfectly satisfactory procedure. The broken stone or gravel is spread and tamped before the coils are laid out on top of the gravel and the concrete is then poured. Since the pipe is surrounded by solid masonry, heat transfer is facilitated, quicker response to changes in temperature is achieved, and some reduction in heat loss downward may be expected.

In order to achieve further reduction of the downward heat loss, strips of rigid insulation board are sometimes bedded into the gravel under the pipe as shown in drawing "C" of Figure 4.

Another method of installing the wrought iron coils consists of placing them on hollow tile which not only retards heat flow to the ground but eliminates any possibility of moisture seepage as well. This construction is shown in sketch "D."

In certain places where structural concrete slabs have been laid on the ground, rigid insulation has been placed on the lower slab, wrought iron pipe coils placed on the insulation, and the concrete slab to be warmed poured over the coils. This was recently done in remodeling an old residence and changing it into a doctor's offices; the only difference being that the thin slab of concrete containing the coils was poured on the original wood floor, instead of on a concrete structural slab.

Sketch "F" shows a modification of this plan. The broken stone fill is spread and compacted, then a thin grout of sand and cement is poured over the stone and allowed to harden. Only enough cement is used to form a crust firm enough to permit the gravel to be walked upon. Then a membrane type water proofing is applied consisting of one or more layers of roofing paper mopped in pitch or asphalt. Over this water proofing, strips of insulating material may be used and the wrought iron coils laid on these strips. Pouring of the concrete floor completes the job. For locations where moisture seepage is anticipated, this method of construction seems to have possibilities.

Having selected a method of constructing the floor, the designer may now proceed to choose pipe sizes and estimate the water temperature required.

III. Selection of Water Temperature, Pipe Sizes, Spacing, and Design of the Coils

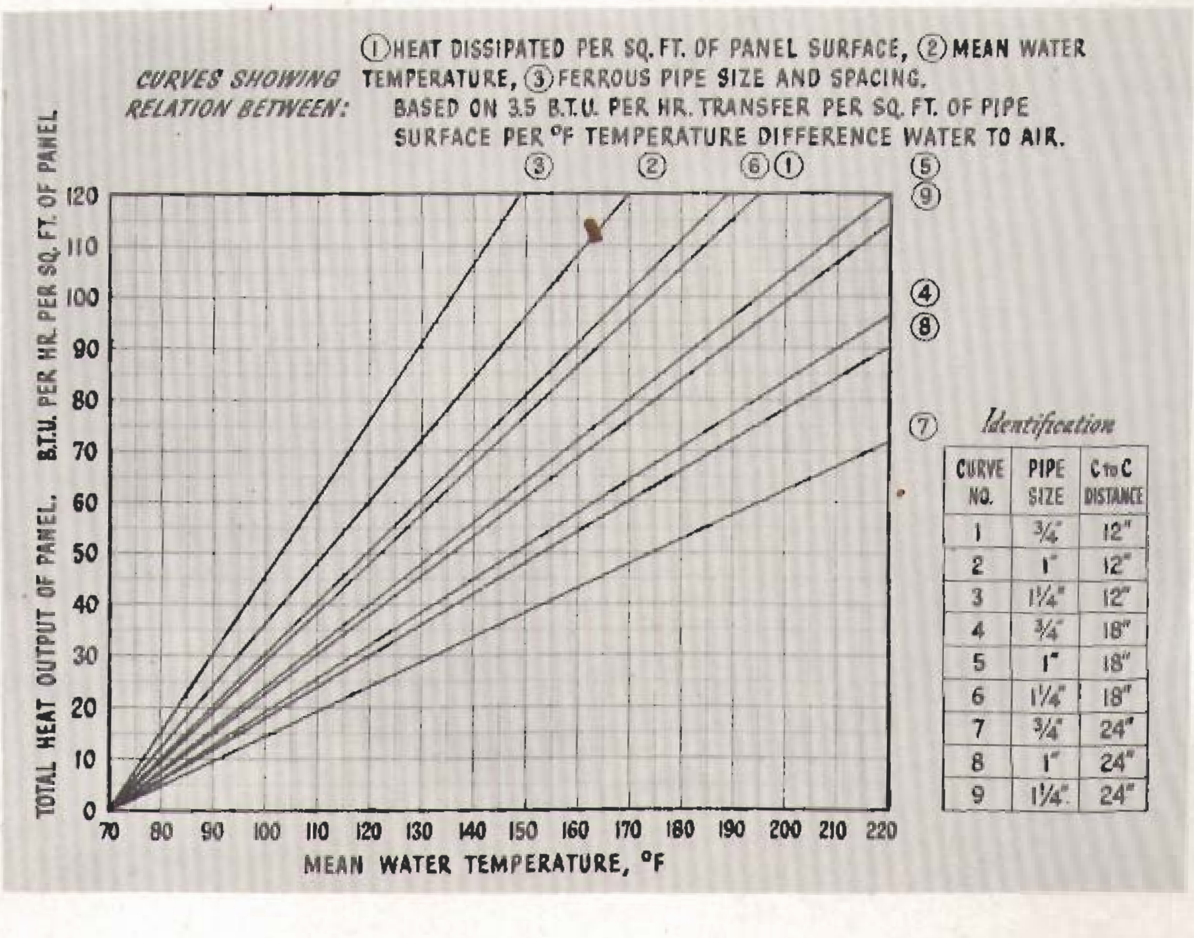
(Steam has been used for radiant heating in some cases, but most recent projects have used hot water as the heating medium. Therefore, this article does not include methods used in steam radiant heating installation work.

(One reason steam has appeared little in residential radiant heating is that some means must be provided to control the temperature of the slab. For example, if live steam were turned into the coils, the slab would immediately begin to heat up and it might easily become too hot before the thermostat was affected. To use steam with the types of floor construction shown in Figure 4 would necessitate either special control equipment and unusually thick concrete slabs, or equipment to supply the steam to the coils at sub-atmospheric pressure. The latter was used in the Johnson Wax building.)

The first step in the determination of the proper pipe size and necessary water temperature is to estimate the total amount of heat which must be supplied per square foot of floor area. This total includes, of course, the downward as well as the upward heat flow and, depending on the method of floor construction employed, downward flow may vary considerably. Moreover, with soils of various descriptions and in the absence of accurate means of determining the thermal conductivity of these soils, an approximation is the nearest to an accurate solution which can be suggested at present. For the uninsulated floor types, a 30% allowance may be sufficiently accurate and for the floor system employing insulation under the coils, 20% may be allowed for downward flow. It should be pointed out, however, that after the soil under the coils has been heated, actual heat loss may be expected to be very small, but during the warming up period, it is necessary to have enough capacity and, therefore, these rather generous allowances have been suggested.

Adding on to the upward heat flow previously determined as necessary, the arbitrary allowance for downward flow, we find the amount of heat which must be

Fig. 5


CURVES SHOWING RELATION BETWEEN: ① HEAT DISSIPATED PER SQ. FT. OF PANEL SURFACE, ② MEAN WATER TEMPERATURE, ③ FERROUS PIPE SIZE AND SPACING. BASED ON 3.5 B.T.U. PER HR. TRANSFER PER SQ. FT. OF PIPE SURFACE PER °F TEMPERATURE DIFFERENCE WATER TO AIR.

Identification

CURVE NO.	PIPE SIZE	C to C DISTANCE
1	¾"	12"
2	1"	12"
3	1¼"	12"
4	¾"	18"
5	1"	18"
6	1¼"	18"
7	¾"	24"
8	1"	24"
9	1¼"	24"

supplied by the pipe coils and can proceed to inspect Figure 5 which is based on experiments which indicate that when wrought iron pipe is embedded in concrete, about 3.5 BTU will flow from the pipe to the concrete for every degree temperature difference between the circulating water and the air in the room. This, of course, makes no allowance for floor coverings and the figure of 3.5 is affected to some degree by the space between the coils, the thickness of the concrete, etc. However, it is considered fairly conservative for coils surrounded by solid masonry.

Figure 5 shows that the designer has a considerable number of possible combinations of pipe spacing and water temperature from which to choose. Thus, he may use small pipe spacing relatively close together or larger pipe farther apart. He may use small pipe and high water temperature or larger pipe on the same centers with lower temperature. Small pipe, close together, gives uniform heating but, of course, means higher frictional resistance in the coils, more pipe to handle, and more joints to weld. Somewhere between the extremes of very large pipe and very small pipe, the most economical and generally satisfactory system will be found.

Coils are very rarely made of smaller than ½" wrought iron pipe and while on rare occasions, 2½" wrought iron has been used, 1¼" to 2" seem to be the maximum sizes commonly selected. These curves apply most accurately to installations in which the pipe is surrounded completely by the concrete and, if it is embedded in gravel or loose fill, more pipe surface should be installed. For example, about the same heating effect seems to be obtained with 2" wrought iron pipe laid in gravel as with 1¼" pipe surrounded by the concrete; the centers being the same in both instances.

Another consideration is the desired uniformity of heating. If temperature variations from point to point are to be kept at a minimum, this means close spacing of the pipe and the use of lower water temperature. If on the other hand, even floor temperatures are deemed less important than the ultimate in lower first cost, then smaller pipe, wider spacing, and high water temperature will be chosen. Again a compromise must usually be made but it has been found in practice that if the coils are spaced more than about 24" apart, it is difficult to maintain satisfactory uniform temperature distribution and owners seem to prefer spacing of about 18" or less.

Floor coverings also have their effect and in estimating water temperature for a concrete floor covered with a thin felt pad and carpet, it is suggested that about a 40 degree increase in water temperature be anticipated. This figure is again only a rough approximation but it may indicate the order of magnitude of the change to be made.

Linoleum has relatively less effect and perhaps 20 degrees allowance would be reasonable.

Thus, to summarize, let us assume that in the typical room previously discussed having a heat requirement of 28.6 BTU per square foot, per hour, the floor section shown in Figure 4-B is to be used. Since there is no insulation, the heat flow allowance of about 30% would be reasonable and the coils would have to supply nearly 40 BTU per hour, per square foot of floor surface. Figure 5 shows that various coils would supply 40 BTU per hour, per square foot of surface, and, a coil spacing of about 18" would be a reasonable compromise between uniformity of heating and low cost.

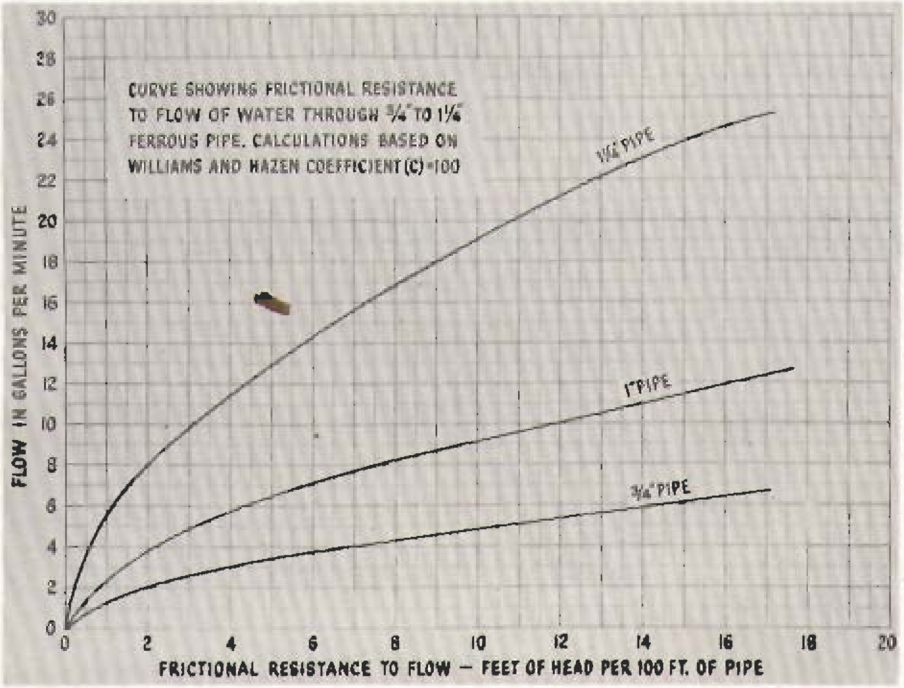
The last problem is which size pipe to use. If ¾" is selected, the water temperature would have to be about 132 degrees F. With one inch pipe the water would only have to be 120 degrees F. and with 1¼" pipe, a still lower water temperature of 109 degrees F. could be anticipated. If the floors were to be covered with linoleum, then the necessary temperatures might be estimated to be about 152, 140, and 129 degrees F. respectively. With carpeting, the temperatures would have to be in the neighborhood of 172, 160, and 149 degrees F. for the three pipe sizes originally mentioned.

Since there may possibly be inaccuracies or local variation necessitating the carrying of higher temperature than would be expected for these calculations, let us assume that the designer chose the 1¼" pipe, placing it on 18" centers. In order to have an average water temperature of 149 degrees temperature in the coil with a temperature drop through the coil from start to finish of about 10 degrees (which is generally considered satisfactory), the water would have to enter at 154 degrees and leave at 144 degrees.

All that remains now to complete the coil design is to make some layout that enables the pipe to be placed on about 18" centers with a minimum number of bends. This usually involves running the pipe the length, or the 20 foot direction, of the room with return bends at each end. Inch-and-a-quarter wrought iron pipe can be bent cold to as close as 5½" centers so that no difficulty would be encountered in making "U" shaped bends 18" center to center. Likewise 1" and ¾" pipe could easily be bent cold to centers far smaller than those commonly required in radiant heating systems.

The final step in the design procedure centers around the selection of auxiliary equipment such as a pump, boiler, and controls.

Fig. 6



IV. Selection of Pump, Boiler, and Auxiliary Equipment

By definition, if a pound of water (one pint) is cooled one degree it will give off one BTU of heat, and since one gallon of water weighs approximately 8 pounds, the cooling of one gallon of water will make available 8 BTU per degree temperature change. If this gallon of water is cooled 10 degrees in passing through the pipe coils, it will release 80 BTU. It is therefore obvious that in order to find the number of gallons per hour which must be circulated through the coils, it is only necessary to divide the total amount of heat which the coils will dissipate by 80.

In the room previously discussed the floor area was 240 square feet and we estimated that the upward plus the downward loss would be about 40 BTU per square foot of surface making the heat input requirement of the coil 9600 BTU per hour. Dividing 9600 by 80 we find that a rate of flow of water of 120 gallons per hour or 2 gallons per minute would be necessary. A pump must, therefore, be selected which will circulate 2 gallons per minute against the frictional resistance of the coil. In the example chosen there would be about 160 feet of pipe in this coil and the frictional drop through each return bend would be about equal to the frictional drop through a length of pipe equal to 25 times the nominal pipe diameter. For 1¼" pipe, about 2.5 feet should thus be allowed for each bend, making the effective length of the coil as far as frictional drop is concerned about 160 feet, plus 8 bends at 2.5 feet each, or a total of 180 feet.

Figure 6 shows that with a flow of 2 gallons per minute through 1¼" pipe, the frictional resistance expressed in feet of head would be about 0.2 feet per 100 feet of pipe. With the effective length of pipe coil 180 feet, the pipe would have to circulate 2 gallons per minute against a frictional head of about 0.36 feet. There is no difficulty at all in obtaining low cost pumps of this capacity. Any of the manufacturers of pumps can recommend the proper size.

Similarly, the selection of boiler need cause no concern since a boiler which will have sufficient capacity to heat the house using radiators would be of ample capacity for a properly designed radiant heating installation.

Response to changing weather conditions is rapid with a floor type radiant heating system. Owners seem to have had little or no difficulty using just the ordinary wall thermostat, though in the more elaborate projects designers have preferred the indoor-outdoor type of control device.

Initial response at the start of the heating season is obviously delayed. When the heating system is first started up in the fall, it might conceivably take all night before the slab is heated through. But thereafter, the slab does not cool off again until spring.

Summary

In the preceding discussion, the steps in the design of a radiant heating system have been briefly outlined. It was shown that beginning with a calculation of heat loss, the designer selects a type of floor construction and determines the necessary floor temperature. He then proceeds to choose a coil which will maintain the floor at the proper temperature. The amount of water to be circulated is then determined and the frictional resistance of the pipe to this rate of flow is estimated. A pump can then be selected and a boiler chosen just as for a radiator system. Proper controls are also selected in the manner suggested by radiator practice.

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