

imbedded in the slab, a larger portion of the heat will flow into the ground, and a smaller portion into the space to be heated.

In the following example it is assumed that the insulation above the pipe coils is such that 90 per cent of the heat emitted by the pipe coils will flow into the room and 10 per cent into the space above.

Since the room is to receive 35,117 Btuh, and since the room is assumed to receive only 90 per cent of the heat emitted by the coils attached to the plastered ceiling, the coils must emit $35,117/0.9$ or 39,000 Btuh. If $\frac{1}{2}$ -in. pipe and a mean water temperature of 140 F are selected, the heat emitted, per foot of pipe, will be $0.9(140 - 68)$ or 65 Btuh. The quantity of pipe required will therefore be $39,000/65 = 600$ lineal feet.

The pipe coils can be arranged in any convenient manner, but should be arranged so that the temperature of the water in the pipe will vary only slightly; otherwise, the temperature distribution over the ceiling will not be uniform. Generally, it is best to arrange the pipes so as to form two-pipe reversed-return flow circuits in the separate panels. By using 33 runs of $\frac{1}{2}$ -in. pipe, welded to two $1\frac{1}{2}$ in. mains, sufficient pipe surface is secured; the $\frac{1}{2}$ -in. pipes will then be spaced about $8\frac{1}{2}$ in. on centers, which is satisfactory.

While coils can be designed with pipe and fitting resistances which will insure proper distribution to each coil, it is advantageous to provide adjustable flow control valves or resistances for final regulation of the water temperature or flow to the various coils. It is desirable to divide large heating systems into sections, and to install valves so that individual sections can be disconnected without interfering with the operation of the system as a whole.

Part II—Radiant Heating

The term *radiant heating* is applied in this chapter to a system in which only the heat radiated from the panel is effective, as in outdoor and semi-outdoor conditions.

The outstanding example of radiant heating is the transfer of heat from the sun to the earth. The sun radiates large quantities of energy of which a very small portion is intercepted by the earth. A part of the intercepted radiation is transformed into heat when it strikes the earth's surface. In this manner heat is received by the earth from the sun by *radiation*.

In industry, radiant heating is employed in manufacturing processes, particularly in drying, baking, and dehydrating operations; in agriculture, it is employed to improve living and growing conditions for young plants and young animals.

The heating engineer employs radiant heat primarily in the heating of open-air schools and open-air hospitals. When a surface radiates heat, and every surface does unless its temperature is absolute zero, every point of the surface radiates heat in all directions. The total quantity of heat radiated by a point or by an elementary area is π times the quantity of heat radiated at right angles to the surface.

Thus, if in an elementary cube the upper face is the heating panel, the lower face would receive only about 32 per cent of the radiated energy, and the four sides would receive each about 17 per cent.

For larger surfaces the conditions are different. If two parallel plane surfaces of considerable size are near each other, the rate of heat exchange between the two can be determined fairly accurately by means of the chart of Fig. 9. This is possible because the larger part of the heat radiated by one of the surfaces is intercepted by the other surface, and only a small portion is radiated in such directions that it will not impinge upon the opposite surface.

As the distance between the two surfaces is increased, the proportion of the heat radiated by one of the parallel plane surfaces and intercepted by the other, decreases almost as the square of the distance between the sur-

faces increases, because the intensity of heat radiation, like the intensity of light radiation, varies inversely as the square of the distance from the source of radiation.

For the purpose of designing radiant heating systems in which the heating panel is practically square and is radiating heat toward a parallel surface of equal size and shape, as shown in Fig. 10, the rate of heat exchange between the two surfaces will be equal to that shown in Fig. 9, multiplied by a factor, p , which depends upon the ratio of h to s (Fig. 10) as shown in the following table:

$h/s =$	1	2	3	4	5
$p =$	0.200	0.070	0.034	0.020	0.013

For example, if a panel 3 ft square is located parallel to, and 9 ft above, a bed in an open-air hospital, and if the temperature of the panel is 112 F and that of the bed is 70 F, the rate of heat transfer from the panel to a 9 sq ft section of the bed directly beneath the panel, will be 3.4 per cent of the rate shown in Fig. 9, or $0.034 \times 9 \times 44$, or 14 Btuh, approximately. The rate of heat transfer from the panel to a section of the bed other than the 9 sq ft directly beneath the panel, will be lower than 14/9 Btuh per square foot.

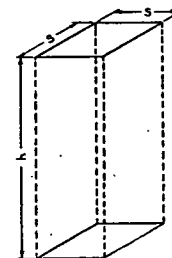


FIG. 10. EFFECT OF HEIGHT UPON RADIATION RECEIVED FROM A PANEL

This is a crude way of designing a radiant heating system for an open-air hospital, but it is sufficiently accurate, because the required temperature of the bed and the required rate of heat flow into it will vary with the temperature of the outdoor air, with the air movement over the bed, with the thickness and the character of the bedding, and with the physical condition of the patient.

A radiant heating system for an open-air school may be designed as described for the open-air hospital. The heating panel in such a case should be almost as large as the ceiling and, in order to keep the heat loss by radiation at a minimum, should be placed so that a maximum portion of the heat radiated by the panel will be directed toward the pupils, and a minimum toward the outside walls, and particularly the windows.

MEASUREMENT OF RADIANT HEATING

Radiant heating is intended to control the rate of radiant heat loss from the human body, and should be measured by calorimetric methods.

The apparatus for this purpose consists essentially of a cylinder, maintained at the accepted mean surface temperature of the human body, together with an accurate means (usually electrical) of measuring the varying rate of heat supply required to maintain this exact temperature. This instrument, the *eupatheoscope*, is readily adapted to function like a thermo-