having a given air temperature and a given mean wall temperature, may be calculated from fundamental equations[3] for radiation and natural convection, with substitution of comparable cylinders for the irregular human body.

$$q_r = 0.1730e\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_w}{100}\right)^4\right] \quad (1)$$

$$q_c = 1.235\left(\frac{1}{D}\right)^{0.2} \times \left(\frac{1}{T_m}\right)^{0.181} \times (T_s - T_a)^{1.266} \quad (2)$$

where

q_r = heat loss by radiation, Btu per (square foot) (hour.)
q_c = heat loss by convection, Btu per (square foot) (hour.)
T_s = absolute temperature of the body surface, Fahrenheit degrees
T_w = absolute temperature of the walls, Fahrenheit degrees.
T_a = absolute temperature of the air, Fahrenheit degrees.
$T_m = \frac{T_s + T_a}{2}$
D = diameter of cylinder, inches.
e = the ratio of actual emission to black body emission.

If it is assumed that an average adult has a height of 5 ft 8 in., a body surface of 19.5 sq ft for convection, and 15.5 sq ft for radiation, an equivalent effect can be worked out for two cylinders, 5 ft 8 in. high by 13.15 in. diameter and 10.45 in. diameter, respectively. However, while the effects on a cylinder, of a particular size and shape may be used to estimate average similar effects on the human body, it should be remembered that the heat loss from the body varies greatly. Every movement alters not only its shape, but also the heat generated by the body, the velocity of the air passing over it and the surface exposed to radiation. This fact renders the results of any such computation only approximate.

APPLICATION METHODS

The several methods of applying panel and radiant heating to a structure are:

1. *By warming the interior wall and ceiling surfaces of the building.* Pipe coils are imbedded in the concrete or plaster of the walls or ceilings, the heating medium being hot water circulating through the pipe coils. These coils are generally constructed of small pipe ½ or ¾ in. I.D. and spaced about 6 to 9 in. apart. See Fig. 1. This has the effect of warming the entire concrete or plaster surface in which the pipes are imbedded. Since the temperature of the heating medium should never exceed about 130 F, due to the possibility of cracking the plaster the area of the warmed surface must be sufficient to supply the requisite quantity of heat at this low temperature. Normally the hot water circulation is maintained by means of a circulating pump and facilities have to be provided to eliminate all air at the top of the system. All coils and circulating pipes are welded together and tested after erection to a hydraulic pressure of 300 psi.

2. *By circulating warm air through shallow ducts under the floor.* In this design the entire floor surface of a room is heated as in Fig. 2. This method was used 2000 years ago in many parts of the Roman Empire. While this method is more expensive in construction, it is effective and quite suitable for cathedrals and large public buildings. To provide a uniform floor temperature, special consideration should be given to the design of the air ducts so that equal heat distribution is obtained.

3. *By placing hot water pipes in or under the floor.* With this arrangement the whole floor surface of a room is raised to a temperature sufficient to give comfortable conditions. Floor heating is recommended for schools and hospitals where large quantities

of outside air are desirable. The floor surface may be of concrete, wood blocks, marble or any other material unaffected by heat, and while it is true that heat will be conducted through all materials used in floor construction, it is important that due consideration be given to the emissivity of the floor. In some cases where pipe coils are installed in the air space under the floor, special floors are constructed in sections so that the whole floor can be lifted to examine the coils. See Fig. 3. Pipes supported thus may be larger and the heating medium maintained at a higher temperature than

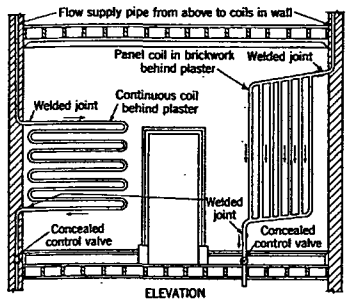


FIG. 1. COILS IN WALL SURFACES

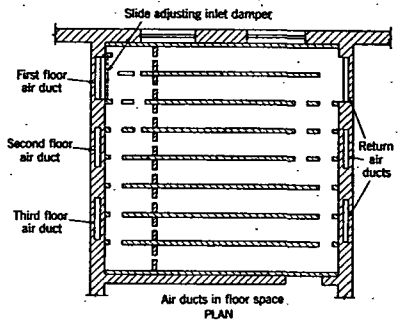


FIG. 2. AIR DUCTS FOR FLOOR HEATING

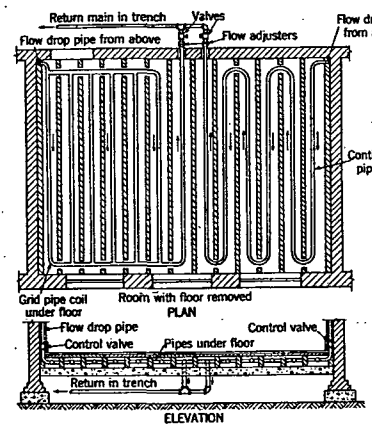


FIG. 3. CONTINUOUS COIL IN FLOOR

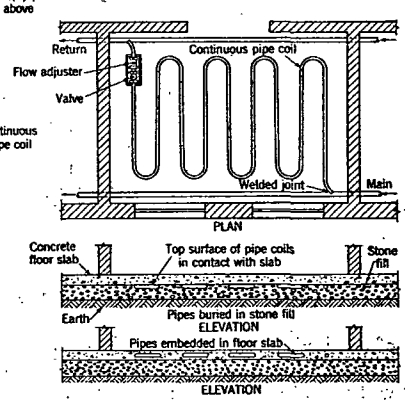


FIG. 4. COILS IMBEDDED IN FLOORS

when pipes are actually imbedded in the floor. Pipes may be 1¼ or 2 in. in the former, but for the latter ¾ or 1 in. pipes are recommended. See Fig. 4. Where the heat losses from a room are exceptionally high it may be necessary to supplement the warm floor by either adding some coils in the ceiling or forming heated panels in the side walls.

4. *By attaching separate heated metal plates or panels to the interior surfaces.* These plates or panels are placed either in an insulated recess so that the surface of the panel is flush with the surface of the walls or ceilings, or they may be secured to the face of the wall. They may be covered with wood veneers and decorated to harmonize with other parts of the room, or they may be cast into panels to imitate oak or other wood designs. With flat plate panels it is common practice to use a frame of plaster, wood, metal or composition to allow for expansion. These plates may be heated with either