ceilings even panels may produce an excessive directional heating effect if all the heat necessary in a cold climate is introduced from above. Similarly, if the floor alone is used, it may—in very cold weather—be necessary to make the floor too hot for comfort. Wall panels, or a combination of ceiling and floor panels, will perhaps produce the best results.

FUNDAMENTAL COMPUTATIONS

The mean surface temperature of an inert body, which will cause given rates of heat loss by radiation and by convection in a uniform environment, having a given air temperature and a given mean wall temperature, may be calculated from fundamental equations[4] for radiation and natural convection, with substitution of comparable cylinders for the irregular human body.

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

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

where

q_r = heat loss by radiation, Btu per square foot per hour.
q_c = heat loss by convection, Btu per square foot per hour.
T_s = absolute temperature of the body surface, degrees Fahrenheit.
T_w = absolute temperature of the walls, degrees Fahrenheit.
T_a = absolute temperature of the air, degrees Fahrenheit.
$T_m = \dfrac{T_s + T_a}{2}$
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 and 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 surface 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. When carefully designed, this method produces very comfortable results and great operating economy, but offers some slight obstacles when alterations or additions to the building are desirable. 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

[4]Surface Heat Transmission, by R. H. Heilman (*A.S.M.E. Transactions, Fuels and Steam Power Section*, Vol. 51, No. 22, September-December, 1929).

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.

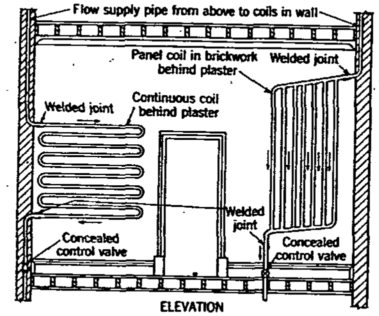

FIG. 1. COILS IN WALL SURFACES

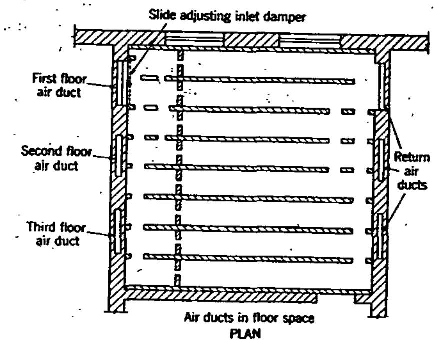

FIG. 2. AIR DUCTS FOR FLOOR HEATING

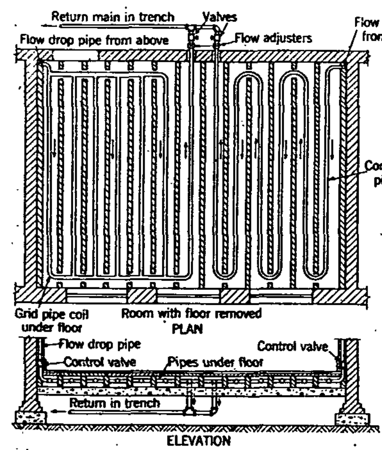

FIG. 3. CONTINUOUS COIL IN FLOOR

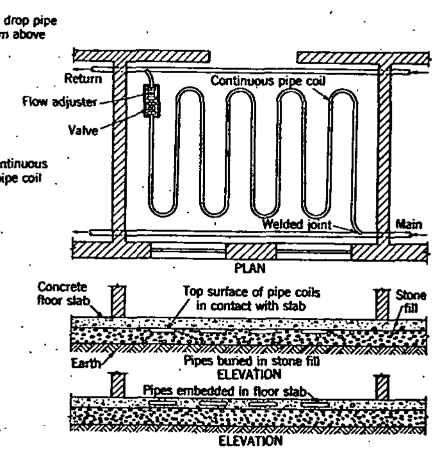

FIG. 4. COILS EMBEDDED IN FLOORS

To provide a uniform floor temperature, one should give special consideration 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 when pipes are actually imbedded in the floor. Pipes may be 1½ 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 ex-