it is assumed that the total heat losses are proportional to the temperature differences, inside and outside, the total heat loss will be 1.52 *R* (210 − 70) or 212.8 *R*. In this calculation, 1.52 is the value of *k* for a 38-in., 3-col. radiator. When the maximum water temperature is 180 deg., the total heat loss will be 1.34 *R* (170 − 70) or 134 *R*. Similarly, when the maximum water temperature is 140 deg. the total heat loss will be 69.6 *R*. Since a heat loss of 212.8 *R* corresponds to a temperature difference, inside to outside, of 80 deg., heat losses of 134 *R* and 69.6 *R*, correspond, respectively, to 49 deg. and 25.5 deg. of temperature differences. Consequently, the two assumed maximum water temperatures correspond, respectively, to outside temperatures of 21 deg. and 44.5 deg. From such data, a curve like that shown in Fig. 3 may be constructed and used to determine the maximum water temperature for any given outside temperature.

Such a curve will, however, not show the correct water temperatures for all times, as heat loss of buildings depends to a large extent upon the direction and velocity of the wind. The values shown by the curve must, therefore, be modified from time to time by the operating engineer according to the character of the wind prevailing at that particular time.

TEMPERATURE DROP THROUGH THE RADIATOR

For any given radiator, the drop in the temperature of the water as it flows through the radiator is determined by the quantity of water flowing through the radiator in a given time. For example, if a radiator is to dissipate 10,000 B.t.u. per hour with a temperature drop of 10 deg., it is necessary that 1000 lb. of water flow through the radiator per hour. If, on the other hand, the temperature drop is to be 20 deg., only 500 lb. of water must flow through the radiator per hour. If, in both cases, the same size pipe is used, the velocity of the water must be twice as high in the former case as in the latter, and since the friction of water in pipes varies almost as the square of the velocity, it follows that the friction head is almost four times as great in the former case as in the latter. If, in both cases, the friction head must have a fixed value—the same as that of the available pressure head, it is evident that the temperature drop through the radiator decreases as the pipe sizes are increased. It was shown above that the required size of the radiator decreases as the temperature drop through the radiator decreases.

Reducing the temperature drop through the radiator, then, decreases the sizes of the radiators but increases the sizes of the piping; in other words, it decreases the cost of the radiators but increases the cost of the piping. There is, consequently, an optimum temperature drop through the radiators for every installation which carries with it the lowest cost of installation. This optimum temperature drop can be determined by a few trial calculations. As a rule, such calculations are never made; the temperature drop is selected arbitrarily.

A temperature drop of from 20 to 30 deg. is common and generally quite satisfactory.

THE MOTIVE FORCE

Whether gravity circulation or forced circulation is to be adopted for any particular installation is generally evident from the nature of the case. In almost all residence systems and in a good many installations in

larger buildings, gravity circulation is entirely satisfactory and should be adopted because its operation is much more simple and also cheaper than that of forced circulation.

For installations which are too large to function well as gravity systems and for all general heating systems which serve a group of buildings, forced circulation should be adopted.

The optimum velocity of the water in forced circulation systems is subject to calculation. As the velocity is increased, the size, and therefore also the cost, of the piping and radiation is decreased but the cost of the pump and the cost of operating the pump are increased. As a general rule, a velocity of from 6 to 10 ft. per second will be found satisfactory.

In gravity circulation systems, the velocity of the water generally varies from about 1 to about 6 in. per second.

ARRANGEMENT OF PIPING

Having determined the location of the heater and the locations of the several radiators, there are a large number of different ways in which the piping can be arranged to connect the heater and the radiators so as to secure an entirely satisfactory operation of the system, provided the radiators and the several pipes of the system are of correct size so that, in every case, the pressure head for every radiator is exactly equal to the friction head in the circuit of that radiator, when the system is operating at a uniform rate and when each radiator is dissipating its correct quantity of heat.

Fig. 4 shows a very small heating system consisting of a heater, located in the basement, two radiators on the first floor, and two on the second floor. Ten different methods of connecting the heater to the radiator for this small system are shown. It is evident that the ten methods shown are not the only methods which could be used. It is also evident that for a larger heating system, a larger number of different methods of connecting the heater to the radiators exist.

Several attempts have been made to assign distinctive names to the several methods or types of piping for hot-water heating systems. The result is not satisfactory because it is possible to have so many variations of each typical method or system of piping. The following definitions, supplemented by the illustrations of Fig. 4, will serve to describe the more common general types of piping:

1. A *one-pipe* system is one in which the water flows through more than one radiator before it returns to the heater.

2. A *two-pipe* system is one in which all water returns to the heater after it has passed through one radiator. In a two-pipe system all radiators are supplied with water at the temperature at which the water leaves the heater, neglecting the slight cooling which takes place in the pipe leading from the heater to the radiator.

Systems 1, 2, 3, and 4 of Fig. 4 have one-pipe mains and two-pipe risers. Systems 7 and 8 have two-pipe mains and one-pipe riser. Systems 5, 6, 9, and 10 have two-pipe systems throughout.

3. An *over-head* distribution system is one in which a main flow riser extends from the heater to the attic, the distributing main is located in the attic, and the return main in the basement. Systems 7, 8, 9, and 10 illustrate this type.

4. An *under-foot* distribution system is one in which the main flow riser extends only to the basement ceiling, and the main flow line as well as the main return line is located below the basement ceiling. Systems 1, 2, 3, 4, 5, and 6 illustrate this type.