pipe coverings was adopted. The value Q of the heat flowing was determined by supplying the heat by means of the heating of a conductor carrying a current of electricity; by measuring the electrical energy supplied the quantity of heat developed may be known with great precision. Further, if this heat is passed through the plate under test and into a calorimeter on the far side, a check upon the value of Q may be had. For the determination of the temperature difference, thermal couples, resistance thermometers, and mercury thermometers were used, but thermal junctions made of thin strips of copper and nickel, or of platinum and platinum-rhodium, were generally found most serviceable.

The apparatus used for the lower temperatures consisted of a thin, electrically-heated plate, to the two sides and edges of which concrete could be applied. Outside of the concrete there were then placed heavy copper or brass plates which could be kept at a constant temperature by an internal circulation of water. Thermal junctions were placed at several points on each surface and in the body of each concrete plate. The electrical input was measured by calibrated Weston instruments, and calibrated thermal junctions gave the value of the temperature difference to the nearest one-one hundredth of a degree. For the thickness, numerous measurements were made with a pair of flat-nosed calipers and averaged. It was necessary to keep this apparatus running for several days before it could be balanced, that is, before the rate of flow of heat outward through the plates became constant and equal to the electrical input.

Later, in order to make tests on plates as thick as some of the walls in common use, another method was adopted. Cubical boxes 36 in. in outside dimension were built with walls of several thicknesses. Inside the boxes were placed electric heaters which served to raise the inside surface to a temperature above that of the surroundings and a small fan served to keep the air in the box stirred to insure uniformity of temperature throughout. The boxes were tightly sealed. The power supplied to both heater and fan was measured as before. Mercury thermometers and thermal junctions, as well as a Callender recording resistance thermometer, were used to measure the difference in the temperatures inside and outside of the box.

Data have been secured on scores of specimens and they are practically identical with the results obtained by the plate tester. It must be borne in mind that the thermal conductivity is based upon the difference in temperature at some two points in the material itself and not the difference in the temperature of the air on the two sides of the specimen. If, for instance, a 6-in. wall of solid stone concrete separates two spaces whose temperatures are 40 deg. Fahr. apart, the surface temperatures of the concrete will be much nearer one another than 40 deg. Fahr. There is a drop in temperature in passing through the wall which is dependent upon the thermal conductivity and upon the quantity of heat passing through. There is a drop in temperature at the surface which is dependent on a rather complex set of relations between the temperature and nature of the surface and the surroundings and the adjacent air. For many materials the amount of heat lost from a surface for small differences in temperature not over 20 deg. Fahr. is between 16 and 18 B.t.u. per sq. ft. per 24 hours for 1 deg. difference between the surface and the average temperature of the surroundings. More than one-half of this is a loss by radiation in accordance with the Stephan-Boltzman law.

$$\text{Energy} = \text{Constant}\ (T^4 - T_0^4)$$

$$W = 5.7\ E \left[ \left(\frac{T}{1000}\right)^4 - \left(\frac{T_0}{1000}\right)^4 \right]$$

where

$W$ = watts
$T$ = absolute temperature of surface
$T_0$ = absolute temperature of surroundings
$E$ = about 0.6 to 0.7 (always less than 1).

For the high temperatures a modification of the entire process was found necessary. The concrete to be tested was cast in the form of a cylinder on the outer surface of and concentric with a steel bar which could be heated to a high temperature by the passage of a heavy current. Outside of the cylinder of concrete was applied a closely fitting "continuous" calorimeter. The temperatures of the bar and of the calorimeter were measured by thermal junctions, and the amount of water and its rise in temperature gave the value of Q. In order to guard against the uncertainty of the temperature at the ends of the bar, the calorimeter was made so as to enclose only about one-half the length of the bar, the rest being covered by guard rings similar to the calorimeter, but without provision for the measurement of the quantity of water.

The heating of the bars required a considerable amount of special apparatus, since it was necessary to provide a current of upwards of 2,000 amperes for the high temperatures, and to be able to vary its amount to any desired value below that point. For this purpose there were installed three 15-kw. transformers connected on the primary side with a three-phase 2,300-volt circuit. By means of divided secondaries and a rather elaborate arrangement of switches, the secondary voltage could be varied from 190 volts down to 55 volts. This secondary voltage was applied to the primary of a second step-down transformer, whose secondary was divided into 20 coils. By means of a switchboard the entire output of the transformer could be had at almost any desired low voltage. This enabled us to heat bars insulated by materials of different composition and of different thicknesses to any desired temperature up to 2,800 deg. Fahr. With this arrangement both the steel and the concrete can be easily melted.

The results obtained are given in Table 4. It is to be regretted that there is no uniformity of practice as to the units to be adopted in reporting the measure of effectiveness of insulators. While the physicist renders his report in calories per square centimeter, per centimeter thickness, per one degree centigrade per second, the steam engineer confines his observations to B.t.u. per hour, per square foot, per inch of thickness, per one degree Fahrenheit, and the refrigerating engineer reports on the basis of a 24-hour time unit. The writer has even seen a report in terms of hogsheads of water raised to the boiling point, time not stated. A brief comparison of these values with those for other materials may be interesting.

**Table 4—Coefficient of Thermal Conductivity of Concrete.**

| Temperature of Hot Side of Plate, Deg. Cent. | Deg. Fahr. | Mixture | Coefficient, Cal. per 1° C. per sq. cm. per cm. per sec. | Coefficient, B.t.u. per 1° F. per sq. ft. per in. thick per 24 hours |
|---|---|---|---|---|
| 35 | 95 | Stone 1—2—5 | 0.00216 | 150. |
| 50 | 122 | Stone 1—2—4 not tamped | 0.00110 to .00160 | 76. to 114. |
| 50 | 122 | Cinder 1—2—4 | 0.00081 | 56. |
| 200 | 392 | Stone 1—2—4 | 0.0021 | 146. |
| 400 | 752 | Stone 1—2—4 | 0.0022 | 153. |
| 500 | 932 | Stone 1—2—4 | 0.0023 | 160. |
| 1000 | 1832 | Stone 1—2—4 | 0.0027 | 188. |
| 1100 | 2012 | Stone 1—2—4 | 0.0029 | 202. |

The specific heat of concrete is slightly less than that of either red brick or fire brick, hence the amount of heat needed to raise the temperature of a pound of brick is about 10 per cent. more than for a pound of concrete. But the density of concrete is enough greater than that of brick to raise