ϵ = emissivity; the ratio of the total radiant flux emitted by a surface to that emitted by an ideal black body at the same temperature.

E = effective emissivity; the combined effect of the surface emissivities ϵ of the boundary surfaces of an air space; the boundaries assumed to be parallel and of large dimensions as compared to the distance between them.

r = surface reflectivity; the ratio of the radiant flux reflected by an opaque surface to that falling upon it.

R = thermal resistance. Its value is obtained from the reciprocal of heat transfer as expressed by U, k, C, f or a. It is expressed in (hours) (square feet) (Fahrenheit degrees) per (Btu). For example, a wall with a U value of 0.25 would have a resistance value of $R = 1/0.25 = 4.0$. Therefore, 4 hours would be required for the transfer of one Btu for each square foot of area and each degree of temperature differential.

CALCULATING OVERALL COEFFICIENTS

From Chapter 5, Equation 7, the total resistance to heat flow through a wall is equal numerically to the sum of the resistances in series.

$$R_T = R_1 + R_2 + R_3 + R_4 + \ldots + R_n \quad (1)$$

where R_1, R_2, etc., are the individual resistances of the wall components.

R_T = total resistance.

For a wall of a single homogeneous material of conductivity k and thickness x, with surface coefficients f_i and f_o,

$$R_T = \frac{1}{f_i} + \frac{x}{k} + \frac{1}{f_o} \quad (2)$$

Then by definition, $U = 1/R_T$

For a wall with air space construction and consisting of two homogeneous materials of conductivities k_1 and k_2, thicknesses x_1 and x_2, respectively, and separated by an air space of conductance a,

$$R_T = \frac{1}{f_i} + \frac{x_1}{k_1} + \frac{1}{a} + \frac{x_2}{k_2} + \frac{1}{f_o} \quad (3)$$

and $U = 1/R_T$

For types of building materials having non-uniform or irregular sections such as hollow clay tile or concrete blocks, it is necessary to use the conductance C of the section unit as manufactured instead of a conductivity k. The resistance of the section $1/C$ is therefore substituted for x/k in Equations 2 and 3.

It will be noted that in order to compute the U value of a construction it is first necessary to know the conductivity and thickness of the homogeneous material, the conductance of non-homogeneous materials (such as concrete blocks), the surface conductances of both sides of the construction, and the conductances of any contained air spaces. These items are discussed in the pages that follow.

Conductivities and Conductances

The method of calculating the overall coefficient of heat transmission for a given construction is comparatively simple, but accurate values of conductivities and conductances must be used to obtain satisfactory results. In addition, there are sometimes parallel heat flow paths of different resistances in the same wall, and these may necessitate modification of the formula. In such cases calculated results should be checked by test.

The determination of the fundamental conductivities and conductances requires considerable skill and experience to obtain accurate results. It is recommended that thermal conductivities of homogeneous materials be determined by means of the Guarded Hot Plate.[1] For determination of conductances, a Guarded Hot Box method[2] is generally used.

Conductivity of Homogeneous Materials

Thermal conductivity is a property of a homogeneous material and of types of building materials such as lumber, brick, and stone, which may be considered homogeneous. Most insulating materials, except reflective types, are of a porous nature and consist of combinations of solid matter with small voids. Such materials including fibrous, cellular, or granular matter are generally known as mass or bulk insulations. The thermal conductivity of these materials will vary with density; mean temperature; size of voids, fibers, or particles; degree and extent of bond between particles; moisture present; and the arrangement of fibers or particles within the material.

The effect of density upon conductivity (at constant mean temperature) is illustrated for two fibrous materials in Fig. 1. Typical variation of conductivity with mean temperature is shown in Fig. 2.

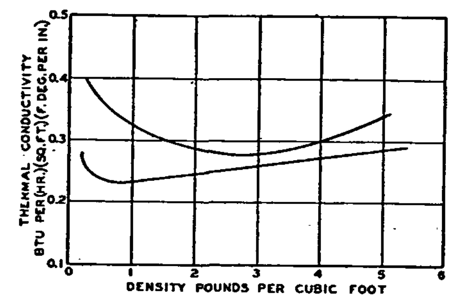

Fig. 1. Typical Variation of Thermal Conductivity with Density—for Fibrous Material

Thermal Conductivity of Soil

The following statements are based largely on results of a study[3] made in the *Engineering Experiment Station, University of Minnesota*, and published in *Bulletin* No. 28. Tests were made on nineteen different soils which represented a wide textural variety, including gravel, sand, sandy loam, silt loam and clay, as well as some crushed rocks and a fibrous peat. Moisture contents in tests varied from air-dried values to those greater than the optimum moisture content; densities varied from a loosely-poured condition to the maximum density obtainable by heavy ramming. The general findings of the investigation are as follows:

Effect of Temperature. Soils were tested at several mean temperatures. The degree of influence of temperature depends upon whether it is above or below freezing. For increases of moisture content exceeding about 6 to 12 percent, the conductivity of frozen soil becomes progressively greater than that of the unfrozen soil.

Effect of Density. Density affects the thermal conductivity of a soil in about the same manner for all soils, at any moisture content, and for either the frozen or unfrozen condition. On the average, each one pound per cubic foot increase in dry density increases the thermal conductivity by about 3 percent.

Effect of Moisture. An increase in moisture content, up to the point of saturation,