

wall (or floor, roof or ceiling) surfaces, f_i is used to designate the inside film or surface conductance and f_o the outside film or surface conductance.

a = thermal conductance of an air space; the amount of heat expressed in Btu transmitted by radiation, conduction and convection in one hour through an area of 1 sq ft of an air space for a temperature difference of 1 F. The conductance of an air space depends on the mean absolute temperature; the width, the position and the character of the materials enclosing it.

R = resistance or resistivity which is the reciprocal of transmission, conductance, or conductivity, i.e.:

$$\frac{1}{U} = \text{over-all or air-to-air resistance.}$$

$$\frac{1}{k} = \text{internal resistivity.}$$

$$\frac{1}{C} = \text{internal resistance.}$$

$$\frac{1}{f} = \text{film or surface resistance.}$$

$$\frac{1}{a} = \text{air space resistance.}$$

Examples of the application of the over-all coefficient U for determining the heat transfer by transmission, are given in Chapter 6.

FORMULAS FOR CALCULATING OVER-ALL COEFFICIENTS

The simplest method of combining the coefficients for the individual parts of the wall is to use the reciprocals of the coefficients and treat them as resistance units. The total over-all resistance of a wall is equal numerically to the sum of the resistances of the various parts, and the reciprocal of the over-all resistance is likewise the over-all heat transmission coefficient of the wall. For a wall built up of a single homogeneous material of conductivity k and x inches thick the over-all resistance,

$$R = \frac{1}{U} = \frac{1}{f_i} + \frac{x}{k} + \frac{1}{f_o} \quad (1)$$

If the coefficients f_i , f_o and k , together with the thickness of the material x are known, the over-all coefficient U may be readily calculated as the reciprocal of the total heat resistance.

For a compound wall built up of three homogeneous materials having conductivities k_1 , k_2 and k_3 and thicknesses x_1 , x_2 and x_3 respectively, and laid together without air spaces, the total resistance,

$$R = \frac{1}{U} = \frac{1}{f_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{f_o} \quad (2)$$

For a wall with air space construction consisting of two homogeneous materials of thicknesses x_1 and x_2 , and conductivities k_1 and k_2 , respectively, separated to form an air space of conductance a , the over-all resistance,

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

Likewise any combination of homogeneous materials and air spaces can be put into the wall and the over-all resistance of the combination may be calculated by adding the resistances of the individual sections of the wall. In certain special forms of construction such as tile with irregular air spaces it is necessary to consider the conductance C of the unit as built instead of the unit conductivity k , and the resistance of the section is equal to $\frac{1}{C}$. The method of calculating the over-all heat transmission

coefficient for a given wall is comparatively simple, but the selection of the proper coefficients is often complicated. In some cases the construction of the wall is such that the substituting of coefficients in the accepted formula will give erroneous results. This is the case with irregular cored out air spaces in concrete and tile blocks, and walls in which there are parallel paths for heat flow through materials having different heat resistances. In such cases it is necessary to resort to test methods to check the calculations, and in practically all cases it has been necessary to determine fundamental coefficients by test methods.

Conductivity of Homogeneous Materials

The thermal conductivity of homogeneous materials is affected by several factors. Among these are the density of the material, the amount of moisture present, the mean temperature at which the coefficient is determined, the size of fibers or particles, and their arrangements in the material, and possibly position. There are many materials used in building construction and considered as homogeneous for the purpose of calculation, whereas they are not really homogeneous but are merely considered so as a matter of convenience. In general, the thermal conductivity varies with the density of the material, increases with the amount of moisture present, and increases with the mean temperature at which the coefficient is determined. The rate of change for these various factors is not the same for all materials, and in assigning proper coefficients one should make certain that they apply for the conditions under which the material is to be used in a wall. Failure to do this may result in serious errors in the final coefficient.

With respect to position, convection within the material may have an effect on the over-all heat transmission. According to one investigator¹ the actual rate of heat flow through loose insulating material may be somewhat greater than that indicated by the hot plate test, but in another investigation², there was found to be a negligible difference between horizontal and vertical upward heat flow through loose materials.

Surface Conductance Coefficients

Heat is transmitted to or from the surface of a wall by a combination of radiation, convection and conduction. The coefficient will be affected by any factor which has an influence on any one of these three methods of transfer. The amount of heat by radiation is controlled by the character of the surface and the temperature difference between it and the surrounding objects. The amount of heat by conduction and convection is controlled largely by the roughness of the surface, by the air movement over the surface and by the temperature difference between the air and the surface. Because of these variables the surface coefficients may be subject to wide fluctuations for different materials and different conditions. The inside and outside coefficients f_i and f_o are in general affected to the same extent by these various factors and test coefficients determined for inside surfaces will apply equally well to outside surfaces under like conditions. Values for f in still and moving air at different mean temperatures have been determined for various building materials³.

¹The Effect of Convection in Ceiling Insulation, by G. B. Wilkes and L. R. Vianey (A.S.H.V.E. TRANSACTIONS, Vol. 49, 1943, p. 196).

²Heat Transmission Through Insulation as Affected by Orientation of Wall, by F. B. Rowley and C. E. Lund (A.S.H.V.E. TRANSACTIONS, Vol. 49, 1943, p. 331).

³A.S.H.V.E. RESEARCH REPORT No. 869—Surface Conductances as Affected by Air Velocity, Temperature and Character of Surface, by F. B. Rowley, A. B. Algren and J. L. Blackshaw (A.S.H.V.E. TRANSACTIONS, Vol. 36, 1930, p. 429).