especially true in wall constructions in which there are parallel paths of heat flow, and one path has a high heat transfer while others have a low heat transfer. The method of making this calculation can best be shown by *Example 1* and Fig. 5. As this wall was tested by the hot box method at the *University of Minnesota*, a direct comparison can be made between calculated and tested values.

Example 1: Calculate the coefficient of heat transmission U for a wall shown in Fig. 5. Wall construction consists of two 4-in. concrete walls separated by a 2½-in. space filled with insulation; ¼-in. diameter metal tie rods are imbedded a distance of 1 in. in each 4-in. concrete wall, and spaced 9 in. vertically and 12 in. horizontally. Values of k are: insulation 0.30, concrete 12.00, tie rods 400.00.

Solution: In Fig. 5 the following paths of heat flow from plane A to plane F will be noted:

1. From A to B: One path through 3 in. of concrete.
2. From B to C: Two paths, (a) through 1 in. of tie rod, and (b) through 1 in. of concrete.
3. From C to D: Two paths, (a) through 2½ in. of tie rod, and (b) through 2½ in. of insulation.
4. From D to E: Two paths, (a) through 1 in. of tie rod, and (b) through 1 in. of concrete.
5. From E to F: One path through 3 in. of concrete.

It will be noted that items 2 and 4 are paths of similar flow, and could be treated as one. If equilibrium or steady state heat transfer is assumed, there will exist a temperature difference between the metal tie rod and the concrete, and also between the metal tie rod and the insulating material. The rate of heat transfer between these materials is dependent upon their conductivity values and the temperature difference. As the conductivity of the metal tie rods is considerably higher than that of the concrete or insulating material, it cannot be assumed that the same rate of heat transfer takes place for all parallel paths. Likewise, an appreciable error would be made by assuming that no heat transfer takes place between the metal tie rod and the surrounding materials. Although the pattern of the isotherms is unknown, the following method of calculation does partially take into account the heat flow between the metal tie rods and its bounding materials.

Parallel Flow. The conductances through the areas of parallel heat flow may be determined as follows:

1. The area of each ¼-in. diameter tie rod is 0.00034 sq ft, and as the tie rods are spaced 9 in. vertically, and 12 in. horizontally, there will be 0.00034 × 4/3 = 0.00045 sq ft of tie rod to each square foot of wall area. Then from plane B to plane C, the conductance C_1 is

$$C_1 = \frac{0.00045}{1.0} \times \frac{400}{1.0} + \frac{0.99955}{1.0} \times \frac{12}{1.0} = 0.180 + 11.994 = 12.174$$

2. For tie rod and insulation from plane C to plane D the conductance C_2 is

$$C_2 = \frac{0.00045}{1.0} \times \frac{400}{2.5} + \frac{0.99955}{1.0} \times \frac{0.30}{2.5} = 0.072 + 0.120 = 0.192$$

3. For tie rod and concrete from plane D to plane E the conductance C_3 is

$$C_3 = \frac{0.00045}{1.0} \times \frac{400}{1.0} + \frac{0.99955}{1.0} \times \frac{12}{1.0} = 0.180 + 11.994 = 12.174$$

Series Flow. After the conductance values have been determined, the total resistance and U value can be determined as follows:

$$R_T = \frac{1}{f_i} + \frac{x_1}{k_1} + \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{x_2}{k_2} + \frac{1}{f_o}$$

$$R_T = \frac{1}{1.65} + \frac{3.0}{12.0} + \frac{1}{12.174} + \frac{1}{0.192} + \frac{1}{12.174} + \frac{3.0}{12.0} + \frac{1}{6.0}$$

$$R_T = 0.606 + 0.250 + 0.0822 + 5.208 + 0.0822 + 0.250 + 0.167 = 6.727$$

$$U = \frac{1}{R_T} = \frac{1}{6.727} = 0.149 \text{ Btu per (hr) (sq ft) (F deg).}$$

The Hot Box test value, from *University of Minnesota*, for this wall, corrected for a 15 mph wind velocity, was U = 0.150 Btu per (hr) (sq ft) (F deg). The error between the calculated and test values would be

$$\frac{0.150 - 0.149}{0.150} \times 100 = 0.67 \text{ percent.}$$

If the effect of the tie rods were omitted from the calculations, the over all U value would be 0.103. Although the percentage of area occupied by the tie rods per square foot of wall area is $\frac{0.00045}{1.0} \times 100 = 0.045$ percent, the error between the calculated and test values would be

$$\frac{0.150 - 0.103}{0.150} \times 100 = 31 \text{ percent.}$$

Values Used in Calculation of *U* Value Tables

Tables 5 through 15 are based on values given in Table 4. The following conditions have been used:

Equilibrium or steady-state heat transfer, eliminating effects of heat capacity

Surrounding surfaces at ambient air temperatures.

Exterior wind velocity of 15 mph for winter and 7.5 mph for summer.

Surface emissivity of ordinary building materials ϵ = 0.90.

Stud space in frame construction not insulated. (See Table 16 for method of correcting for added insulation.)

In construction involving air spaces the U values shown are calculated for areas between framing. See Fig. 6 in section Correction for Framing page 209 if an allowance is to be made for their effect.

Air space resistance values used are those shown in Table 4 under Air Spaces.

Air spaces are ¾ in. or more in width.

Variations of conductivity with mean temperature neglected.

Corrections for framing to be made on basis of parallel heat flow through 2 × 4 in. (nominal) studs, 16 in. on centers, the framing covering 15 percent of wall area, as indicated in Fig. 6.

Thermal resistance for gypsum board and insulating board apply equally to plain material and to those which may be decorated at the factory or on the job.

In order to condense the tables an average resistance value (Av.R) has been used in some cases for types of materials having approximately the same thermal resistance values. The difference between the average value and the exact value for any given material usually causes no significant change in the resulting U value.

Actual thicknesses of lumber assumed to be as follows:

Nominal	*Actual*	*Nominal*	*Actual*
1 in. (S-2-S)	25/32 in.	3 in. (S-2-S)	2⅝ in.
1½ in. (S-2-S)	1 5/16 in.	4 in. (S-2-S)	3⅝ in.
2 in. (S-2-S)	1⅝ in.	Finish flooring, (maple or oak)	¾ in.
2½ in. (S-2-S)	2⅛ in.		

Coefficients for frame construction are corrected for the effect of framing where such correction would increase the coefficients, but not where the correction would decrease the coefficients.[11]

It should be noted that the effects of poor workmanship in construction