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 wall as shown in Fig. 4. Wall construction consists of two 4-inch concrete walls separated by a 2½ in. space filled with insulation; ½-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.

In Fig. 4 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.

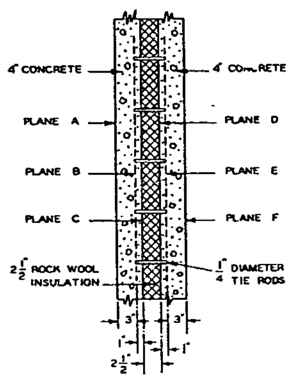

FIG. 4. SECTION OF CONCRETE WALL HAVING STEEL TIE RODS AND INSULATION

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 0.0036 square feet and as the tie rods are spaced 9 inches vertically, and 12 inches horizontally, there will be $0.00036 \times \frac{4}{3} = 0.00048$ square feet of tie rod to each square foot of wall area. Then from plane B to plane C, the conductance C_1 is

$$C_1 = \frac{0.00048}{1.0} \times \frac{400}{1.0} + \frac{0.99952}{1.0} \times \frac{12}{1.0} = 0.192 + 11.994 = 12.186$$

2. For Tie Rod and Insulation from plane C to plane D the conductance C_2 is

$$C_2 = \frac{0.00048}{1.0} \times \frac{400}{2.5} + \frac{0.99952}{1.0} \times \frac{0.30}{2.5} = 0.077 + 0.120 = 0.197$$

3. For Tie Rod and Concrete from plane D to plane E the conductance C_3 is

$$C_3 = \frac{0.00048}{1.0} \times \frac{400}{1.0} + \frac{0.99952}{1.0} \times \frac{12}{1.0} = 0.192 + 11.994 = 12.186$$

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

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

$$R_T = \frac{1}{1.65} + \frac{3.0}{12.0} + \frac{1}{12.186} + \frac{1}{0.197} + \frac{1}{12.186} + \frac{3.0}{12.0} + \frac{1}{6.0}$$

$$R_T = 0.606 + 0.250 + 0.0821 + 5.076 + 0.0821 + 0.250 + 0.167 = 6.513$$

$$U = \frac{1}{R_T} = \frac{1}{6.513} = 0.153 \text{ Btu per (hr) (sq ft) (F deg).}$$

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

$$\frac{0.153 - 0.150}{0.150} \times 100 = 2 \text{ per cent.}$$

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 $\frac{0.0048}{1.0} \times 100 = 0.048$ per cent, the error between the calculated and test values would be

$$\frac{0.150 - 0.103}{0.103} \times 100 = 45 \text{ per cent.}$$

In making the calculations for values of U shown in Tables 5 to 18, the following conditions have been assumed:

Equilibrium or steady-state heat transfer, eliminating effects of heat capacity.
Surrounding surfaces at ambient air temperatures.
Exterior wind velocity of 15 mph.
Surface emissivity of ordinary building materials = 0.83.
No correction for position or direction of heat flow. (Average coefficients used).
Air spaces are ¾ in. or more in width.
Variation of conductivity with mean temperature neglected.
Corrections for framing made on basis of parallel heat flow through 2 × 4 in. (nominal) studs, 16 in. on centers, the framing covering 15 per cent of wall area.
Actual thicknesses of lumber assumed to be as follows:

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