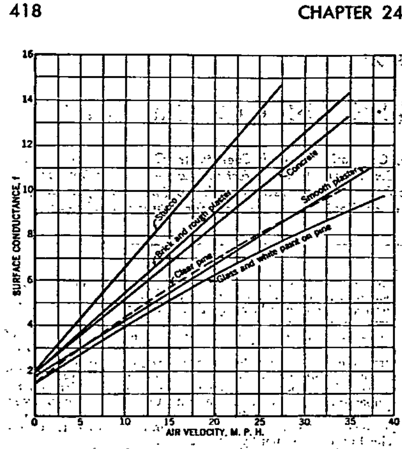


Fig. 1 . . . . Surface Conductance for Different Surfaces as Affected by Air Movement

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

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

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:

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

and

$$U = 1/R_T$$

The temperature at any interface can be calculated since the temperature drop through any component of the wall is proportional to its resistance. Thus the temperature drop Δt_1 through R_1 in Equation 1 is:

$$\Delta t_1 = R_1/R_T(t_i - t_o) \qquad (4)$$

where t_i and t_o are the indoor and outdoor temperatures respectively.

Hence, the temperature at the interface between R_1 and R_2 is:

$$t_{1-2} = t_i - \Delta t_1 \qquad (5)$$

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 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 homogeneous materials, the conductance of non-homogeneous materials (such as concrete blocks), the surface conductances of both sides of the construction, and the conductances of any air spaces.

If the conductivities of the materials in a wall are highly dependent on temperature, the mean temperature in use must be known in order to assign the correct value. In such cases it is perhaps most convenient to use a trial and error procedure for the calculation of the total resistance, R_T. First, the mean operating temperature for each layer is estimated and conductivities k or conductances C selected. The total resistance R_T is then calculated as in Equation 3 and then the temperature at each interface is calculated from Equations 4 and 5.

The mean temperature of each component (arithmetic mean of its surface temperatures) can then be used to obtain conductivities k or conductances C. This procedure can then be repeated until the conductivities or conductances have been correctly selected for the resulting mean temperatures. Generally, this can be done in two or three trial calculations.

Table 1 . . . . Thermal Conductivity (k) Values of Soils in Approximate Order of Decreasing Values*

Mean Temperature—40 F

Soil Designation	Mechanical Analysis % by Weight: Gravel	Sand	Silt	Clay	Moisture Content—%: 4			10		20	
					Dry Density-lb per cu ft						
	Over 2.0 mm	0.5 to 2.00 mm	0.005 to 0.05 mm	Under 0.005 mm	100	110	120	90	110	90	100
Fine Crushed Quartz	0.0	100.0	0.0	0.0	12.0	16.0					
Crushed Quartz	15.5	79.0	5.5		11.5	16.0	22.0				
Graded Ottawa Sand	0.0	99.9	0.1		10.0	14.0					
Fairbanks Sand	27.5	70.0	2.5		8.5±	10.5	13.5		15.0		
Lowell Sand	0.0	100.0	0.0	0.0	8.5	11.0			13.5		
Chena River Gravel	80.0	19.4	0.6			9.0±	13.0				
Crushed Feldspar	25.5	70.3	4.2		6.0	7.5	9.5				
Crushed Granite	16.2	77.0	6.8		5.5	7.5	10.0				
Dakota Sandy Loam	10.9	57.9	21.2	10.0		6.5	9.5		13±		
Crushed Trap Rock	27.0	63.0	10.0		5.0	6.0	7.0				
Ramsey Sandy Loam	0.4	53.6	27.5	18.5	4.5	6.5			10.0		
Northway Fine Sand	0.0	97.0	3.0	0.0	4.5	5.5			8.5		
Northway Sand	3.0	97.0	0.0	0.0	4.5	6.0			7.5±		
Healy Clay	0.0	1.9	20.1	78.0	4.0±			5.5	9.0±	8.0	10.0
Fairbanks Silt Loam	0.0	7.6	80.9	11.5				5.0	9.0±	7.5	10.0
Fairbanks Silty Clay Loam	0.0	9.2	63.8	27.0				5.0	9.0±	7.5	9.5
Northway Silt Loam	1.0	21.0	64.4	13.6				4.0±	7.0±	6.0±	7.0±

* k = Btu per (square foot) (hour) (Fahrenheit degree per inch).

Series and Parallel Heat Flow Paths

In many practical installations the components are arranged so that parallel heat flow paths of different conductances result. If there is no lateral heat flow between paths, each path may be considered to extend from inside to outside, and the transmittance of each path may be calculated using Equation 1 or 3. The average transmittance is then:

$$U_{(av)} = a(U_a) + b(U_b) + \cdots, + n(U_n) \qquad (6)$$

where $a, b, \cdots, n$ are respective fractions of a typical basic area composed of several different paths whose transmittances are $U_a, U_b, \cdots, U_n$.

If heat can flow laterally in any continuous layer so that transverse isothermal planes result, the total average resistance $R_{T(av)}$ will be the sum of the resistances of the layers between such planes, each layer being calculated by the appropriate Equation 1 or Equation 6. This is a series combination of layers, of which one (or more) provides parallel paths.

The calculated transmittance, assuming parallel heat flow only, is usually considerably lower than that calculated with the assumption of combined series-parallel heat flow. The actual transmittance will be some value between the two calculated values. In the absence of test values for the combination, an intermediate value should be used. An examination of the construction will usually reveal whether a value closer to the higher or lower calculated value should be used. Generally, if the construction contains any highly conducting layer in which lateral conduction is very high compared to the transmittance through the wall, a value closer to the series-parallel calculation should be used. If, however, there is no layer of high lateral conductance, a value closer to the parallel heat flow calculation should be used. This is illustrated in *Example 1*.

Example 1: Consider a construction consisting of:

1. Inside surface having film coefficient $f_i = 2$.
2. A continuous layer of material of resistance $R_1 = 1$.
3. A parallel combination containing two heat flow paths of proportionate areas, $a = 0.1$, and $b = 0.9$, with resistances $R_{a2} = 1$ and $R_{b2} = 8$.
4. A continuous layer of material of resistance $R_3 = 0.5$.
5. Outside surface having film coefficient $f_o = 4$.

Solution: If parallel heat flow paths are assumed from air to air the total resistance through area a will be:

$$R_{aT} = 1/f_i + R_1 + R_{a2} + R_3 + 1/f_o$$
$$= 0.5 + 1 + 1 + 0.5 + 0.25 = 3.25$$

and

$$U_a = 1/R_{aT} = 1/3.25$$

The resistance and transmittance through area b will be:

$$R_{bT} = 1/f_i + R_1 + R_{b2} + R_3 + 1/f_o$$
$$= 0.5 + 1 + 8 + 0.5 + 0.25 = 10.25$$

and

$$U_b = 1/R_{bT} = 1/10.25$$

Then the average calculated transmittances will be:

$$U_{(av)} = a(U_a) + b(U_b) = \frac{0.1}{3.25} + \frac{0.9}{10.25} = 0.118.$$

If, however, isothermal planes are assumed to occur at both surfaces of R_1 and at both surfaces of R_3, the total calculated resistance will be:

$$R_T = 1/f_i + R_1 + \frac{(R_{a2})(R_{b2})}{aR_{b2} + bR_{a2}} + R_3 + 1/f_o$$

$$\frac{(R_{a2})(R_{b2})}{aR_{b2} + bR_{a2}} = \text{the combined resistance of } R_{a2} \text{ and } R_{b2} = 4.71$$

Then

$$R_T = 0.5 + 1 + 4.71 + 0.5 + 0.25 = 6.96$$

and

$$U_{(av)} = 1/6.96 = 0.144$$

If R_1 and R_3 are homogeneous materials, a value of about 0.125 might be selected, whereas, if they contain a highly conducting layer, then a value of 0.135 might be selected.

When the construction contains one or more paths of small area having a very high conductance compared to the conductance of the remaining area, the following method is suggested:

Heat Flow Through Panels Containing Metal

The transmittance of a panel which includes metal or other highly conductive material extending wholly or partly through insulation should, if possible, be determined by test in the guarded hot box. When a calculation is required, a good approximation can be made by a *Zone Method*. This involves two separate computations—one for a chosen limited portion, *Zone A*, containing the highly conductive element, and the other for the remaining portion of simpler construction, called *Zone B*. The two computations are then combined, and the average transmittance per unit of overall area is calculated. The basic laws of heat transfer are applied, by adding area conductances $C \cdot A$ of *elements in parallel*, and adding area resistances $1/C \cdot A$ of *elements in series*.

The surface shape of *Zone A* is determined by the metal element. For a metal beam (Fig. 2) the *Zone A* surface is a strip of width W, centered on the beam. For a rod perpendicular to panel surfaces it is a circle of diameter W. The value of W is calculated from Equation 7, which is empirical.

$$W = m + 2d \qquad (7)$$

where

m = width or diameter of the metal heat path terminal, inches.

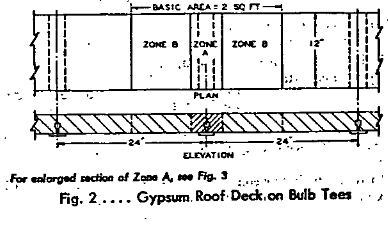
d = distance from panel surface to metal, inches. The value of d should not be taken less than 0.5 in. (for still air).

In general, the value of W should be calculated by Equation 7 for each end of the metal heat path, and the larger value, within the limits of the *basic area*, should be used as illustrated in *Example 2*.

Example 2: Calculate the transmittance of the roof deck shown in Figs. 2 and 3. Tee-bars on 24-in. centers support glass fiber form boards, gypsum concrete, and built-up roofing. The conductivities of components are: steel 312; gypsum concrete 1.66; glass fiber 0.25. The conductance of built-up roofing is 3.0.

Solution: The basic area is 2 sq ft (24 in. × 12 in.), with a tee-bar (12 in. long) across the middle. This area is divided into two zones, *A* and *B*.

Zone A is determined from Equation 7 as follows:



For enlarged section of Zone A, see Fig. 3

Fig. 2 . . . . Gypsum Roof Deck on Bulb Tees