Table 2 . . . . Variation in Surface Conductance Coefficient for Vertical Surfaces with Different Temperatures of Surrounding Surface

Surrounding Surface Temperature	75 F	70 F	69 F	60 F	50 F
Convection—Btu per (hr) (sq ft)	6.6	6.6	6.6	6.6	6.6
Radiation—Btu per (hr) (sq ft)	4.4	8.6	9.6	17.0	24.9
Total—Btu per (hr) (sq ft)	11.0	15.2	16.2	23.6	31.5

tion, is illustrated in Table 2, which applies to a vertical surface at 80 F, with ambient air at 70 F and with radiation exchange corresponding to an effective emissivity of 0.83.[4]

In many cases, because the heat resistance of the internal parts of the wall is high compared with the surface resistance, the surface factors are of minor importance. In other cases, e.g., single glass windows, the surface resistances constitute almost the entire resistance and are therefore very important. An analysis of various factors affecting surface conductance and the difference between surface and air temperatures will be found in Reference 5. (See also Chapter 30.)

The convection part of the surface conductance is affected markedly by air movement. This is illustrated by Fig. 4, which shows the results of tests[6] made on 12-in. square samples of different materials at a mean temperature of 20 F, and for wind velocities up to 40 mph. These conductances include the radiation portion of the coefficient which, for the conditions of the tests, was about 0.7 Btu per (hr) (sq ft) (F deg). More recent tests[7] on smooth surfaces show that surface length also affects significantly the convection part of conductance; the average value decreases as the surface length increases. Moreover, observations[8] of the magnitude of low temperature radiant energy received from outdoor surroundings show that only under certain conditions may the out-of-doors be treated as a black body radiating at air temperature.

Because of these factors, the selection of surface conductance coefficients for a practical building becomes a matter of judgment. Surface conductances are shown in Tables 3 and 4. *In calculating the overall heat transmission coefficients for the walls, etc., of Tables 5 through 16, the appropriate indoor and outdoor surface coefficients given in Table 4 for Air Surfaces have been used.* Both values combine the effects of convection and radiation, and are applicable to ordinary building materials. They should not be used for low emissivity surfaces such as bright metal. For exposed reflective surfaces refer to Table 3, Section A, and to footnotes under Table 16.

In special cases, where surface conductances become important factors in the overall rates of heat transfer, more selective coefficients may be required. Principles and data given in Chapter 5, Heat Transfer, may be applied in such cases.

Air Space Conductance

The transfer of heat across an air space involves the boundary surfaces as well as the intervening air, and depends markedly on the orientation of the air space and the direction of heat flow. The coefficients given for air space conductance represent the total conductance from one surface bounding the air space to the other. The total conductance is the sum of a component due to radiation and a component due to convection and conduction combined. These components may vary independently of each other.

The radiation portion of the coefficient is affected by the temperature of the two boundary surfaces, and by their respective surface emissivities ϵ, the combined effect of which is expressed by means of the *effective emissivity* E of the air space. The radiation component is not affected by the thickness of the space or by its orientation or direction of heat flow. The heat transfer by convection and conduction combined, however, is markedly affected by the orientation of the air space and the direction of heat flow, is significantly affected by the temperature difference across the space and in some cases by the thickness of the space, and is affected to only a small extent by the mean temperature of its surfaces. For air spaces usually employed in building construction, the radiation and convection-conduction components may vary independently of each other.

Table 3, Section C, gives the thermal conductances and resistances of air spaces of uniform thickness and moderately

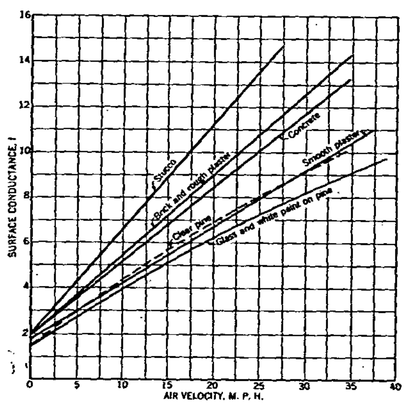


Fig. 4 . . . . Curves Showing Relation Between Surface Conductance for Different Surfaces at 20 F Mean Temperature

smooth surfaces, based on experimental measurements conducted at the National Bureau of Standards.[9] Although the conductances of air spaces vary to some extent with thickness in the range over ¾ in., average values are tabulated for the range from ¾ in. to 4 in., for all except horizontal spaces with heat flow downward. The error involved by averaging is less than 10 percent in the extreme case and less than 5 percent in most. For more exact values Reference 9 may be consulted.

For narrow air spaces, which may be defined as those for which the product of the cube of the thickness of the space in inches times the temperature difference (Fahrenheit degrees) across the space is less than 3 for heat flow horizontally or downward, or less than 1 for heat flow upward, the conductance is the sum of the radiative heat transfer coefficient and that for conduction alone through air, since convection is practically suppressed. The radiation component can be computed by means of Equation 4 and Table 4 of Chapter 5; the conduction component can be computed using the conductivity of air at the appropriate mean temperature (see Table 1, Chapter 5).

The effects of different mean temperatures, temperature differences, and effective emissivities are indicated in Table 3 of this chapter, Section C. As indicated, use may be made of interpolation and moderate extrapolation of conductance values in the table to obtain conductances for conditions moderately different from those given. Interpolation of resistance values is not recommended, especially in relation to emissivity values.

Table 3, Section B, gives values for the surface reflectivities and emissivities of materials used as boundaries of air spaces in building construction, for total radiation at ordinary building temperatures. Effective emissivities for various combinations of these materials, for use in conjunction with Section C of Table 3, are given in the last two columns of Section B.

When considering heat transfer across air spaces in building construction, the emissivities of the boundary surfaces must be known. The possibility of change in emissivity of highly reflective surfaces due to exposure to conditions promoting chemical action, deposition of dust, soiling of the surface, or the application of coatings, even though transparent to the eye, must be considered in selecting a material for use.[10] Surface emissivity values should be obtained by tests.

OVERALL COEFFICIENTS AND THEIR PRACTICAL USE

The values in Tables 3 and 4 for component elements and materials were selected by the ASHAE Technical Advisory Committee on Insulation as representative for dry materials at 75 F mean temperature. They are based on available published data obtained by the guarded hot plate method (*ASTM* C177-45) or by the guarded hot box method (*ASTM* C236-54T). Because there are variations in commercially available materials of the same type, not all of these selected representative values will be in exact agreement with data for individual products. The exact value for a certain manufacturer's material can be secured from unbiased tests or from guaranteed data of the manufacturer.

The most exact method of determining the heat transmission coefficient for a given combination of building materials assembled as a building section is to test a representative section in a guarded hot box. However, it is not practicable to test all the combinations which may be of interest in building construction. Experience has indicated that U values for many constructions, when calculated by the methods given in this chapter, using accurate values for the component materials, are in good agreement with values determined by guarded hot box measurements.

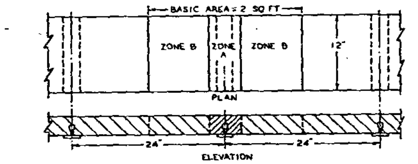
Caution

Although the validity of calculating U values for all of the types of constructions in Tables 5 through 16 has not been fully demonstrated, calculated values are given because measured values are not available. It is emphasized that the calculated values in Tables 5 through 16 are given for the convenience of the user.

In calculating U values, exemplary conditions of components and installations are assumed, i.e., that insulating materials are uniformly of the nominal thickness and conductivity, that air spaces are of uniform thickness and surface temperatures, that effects due to moisture are not involved, and that installation details are in accordance with design. Some evidence of departures of measured values from calculated values for certain insulated constructions is given in *Building Materials and Structures Report* BMS 151, National Bureau of Standards. In order to provide a reasonable factor of safety to account for departures of constructions from exemplary conditions, in part due to field construction requirements and practices, some may wish, before making corrections for framing (as indicated in Fig. 6), to increase moderately the calculated U values of the insulated walls, floors and ceiling sections obtained from Table 16. Where reflective air spaces are involved, increases of U values up to 10 percent for applications where heat flow is horizontal or upward, and up to 20 percent where heat flow is downward, appear reasonable on the basis of present information.

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 ap-



For enlarged section of Zone A, see Fig. 6

Fig. 5 . . . . Gypsum Roof Deck on Bulb Tees

proximation 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, i.e., 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. 5) 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 4, which is empirical.

$$W = m + 2d \qquad (4)$$

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 4 for each end of the metal heat path, and the larger value, within the limits of the *basic area*, used as illustrated in *Example 1*.

Example 1: Calculate the transmittance of the roof deck shown in Figs. 5 and 6. 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.

(*Continued on p. 113*)