

Fig. 3 .... Enlarged Section of Zone A of Fig. 2

Top Side $W = m + 2d = 0.625 + 2 \times 1.5 = 3.625$ in.

Bottom Side $W = m + 2d = 2.0 + 2 \times 0.5 = 3.0$ in.

Using the larger value of W, the area of *Zone A* is $(12 \times 3.625)/144 = 0.302$ sq ft. The area of *Zone B* is $2.0 - 0.302 = 1.698$ sq ft.

To determine the area transmittance for *Zone A* the structure within the zone is divided into five sections parallel to the top and bottom surfaces as shown in Fig. 3. The area conductance $C \cdot A$ of each section is calculated by adding the area conductances of its metal and non-metal paths. The area conductances of the sections are converted to area resistances $1/(C \cdot A)$ and added, to obtain in the total resistance of *Zone A*. These calculations are shown in the following table.

Section	Area × Conductance		C·A	1/(C·A) = R/A
Air (outside, 15 mph)	0.302	× 6.0	1.812	0.552
No. 1, Roofing	0.302	× 3.0	0.906	1.105
No. 2, Gypsum concrete	0.302	× 1.66/1.125	0.445	2.250
No. 3, Steel	0.052	× 312.0/0.625	26.0	} 0.038
No. 3, Gypsum concrete	0.250	× 1.66/0.625	0.664	
No. 4, Steel	0.0104	× 312/1.00	3.24	} 0.302
No. 4, Glass fiber	0.292	× 0.25/1.00	0.073	
No. 5, Steel	0.167	× 312/0.125	416.0	0.002
Air, (inside)	0.302	× 1.63	0.493	2.030
			Total R/A =	6.279

Area transmittance of *Zone A* = $A/R = 1/6.279 = 0.159$.

For Zone B, the unit resistances are added and then converted to area transmittance as shown in the following table.

Section	Resistance, R	
Air (outside, 15 mph)	1/6.0	= 0.17
Roofing	1/3.0	= 0.33
Gypsum concrete	1.75/1.66	= 1.05
Glass fiber	1.00/0.25	= 4.00
Air (inside)	1/1.63	= 0.61
Total resistance of a sq ft		= 6.16

Unit transmittance = $1/R = 0.162$

Area transmittance $U \cdot A$

for *Zone B* = $1.698 \times 0.162 = 0.276$

for *Zone A* = 0.159

Total area transmittance of *basic area* = 0.435

Transmittance per sq ft = $0.435/2.0 = 0.218$

In tests on similar construction, made by the guarded hot box method, one laboratory reported a U value of 0.219 Btu per (sq ft) (hr) (F deg), and another laboratory reported a U value of 0.206 Btu per (sq ft) (hr) (F deg).

When the steel is a large proportion of the heat path, as in *Example 2*, the detailed calculations of resistance in sections 3, 4, and 5 of *Zone A* are not justified. If only the steel were considered, the final result of *Example 2* would be unchanged.

If the steel path is small, such as for a tie rod, the detailed calculations for sections 3, 4, and 5 are necessary.

Caution

A panel with internal metallic structure, bonded on one or both sides to a metal skin or covering, presents special problems of lateral heat flow not covered in the foregoing *Zone Method*.

Series Heat Flow Through Unequal Areas

A construction may be made up of two or more layers (flat or of small curvature), of unequal area, separated by an air space and arranged so that heat flows through the layers in series. The most common such construction is a ceiling and roof combination where the attic space is unheated and unventilated. A combined coefficient based on the most convenient area from air inside to air outside can be calculated from Equation 8.

$$R_T = \frac{1}{U_1} + \frac{1}{n_2 U_2} + \frac{1}{n_3 U_3} + \cdots + \frac{1}{n_p U_p} \qquad (8)$$

The combined coefficient U is the reciprocal of R_T or, $U = 1/R_T$.

where

U = combined coefficient to be used with A_1.

R_T = total resistance to all elements in series.

$U_1, U_2, \cdots, U_p$ = coefficient of transmission of $A_1, A_2, \cdots, A_p$ respectively.

$n_2, n_3, \cdots, n_p$ = area ratios $A_2/A_1, A_3/A_1, \cdots, A_p/A_1$, respectively.

It should be noted that the overall coefficient should be multiplied by the area A_1 to determine the heat loss. Values of $U_1, U_2, U_3 \cdots, U_p$ should be calculated using Equations 1, 2, or 3, and, if any layer contains parallel heat flow paths (i.e., windows or dormers on roofs), Equation 6 may be used.

In the calculation, the resistance of the air spaces between layers should be accounted for by assigning one half of an appropriate air space resistance to each of the layers, rather than the conductance of the surface.

OVERALL COEFFICIENTS AND THEIR PRACTICAL USE

The values in Tables 2, 3, and 4 for component elements and materials were selected by the ASHRAE Technical Committee 2.4, Thermal Insulation and Moisture Barriers, as representative. 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, and when corrections are made for framing member heat loss, are in good agreement with values determined by guarded hot box measurements.

Table 2 .... Surface Conductances and Resistances for Still Air

All conductance values expressed in Btu per (hr) (sq ft) (F deg temp diff)

SECTION A. Surface Conductances for Still Air[a,b]

Position of Surface	Direction of Heat Flow	Surface Emissivity: Non-reflective ε=0.90 C	R	Reflective ε=0.20 C	R	Reflective ε=0.05 C	R
STILL AIR							
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping—45 deg	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping—45 deg	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
MOVING AIR (Any Position)							
15 mph Wind (for winter)	Any	6.00	0.17				
7½ mph Wind (for summer)	Any	4.00	0.25				

SECTION B. Reflectivity and Emissivity Values of Various Surfaces[c] and Effective Emissivities of Air Spaces

Surface	Reflectivity in Percent	Average Emissivity ε	Effective Emissivity E of Air Space: With one surface having emissivity ε and other 0.90	With both surfaces of emissivity ε
Aluminum foil, bright	92 to 97	0.05	0.05	0.03
Aluminum sheet	80 to 95	0.12	0.12	0.06
Aluminum coated paper, polished	75 to 84	0.20	0.20	0.11
Steel, galvanized, bright	70 to 80	0.25	0.24	0.15
Aluminum paint	30 to 70	0.50	0.47	0.35
Building materials: wood, paper, glass, masonry, nonmetallic paints	5 to 15	0.90	0.82	0.82

[a] For ventilated attics or spaces above ceilings under summer conditions (heat flow down) see Table 17.

[b] Conductances are for surfaces of the stated emissivity facing virtual black-body surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10 deg and for surface temperature of 70 F.

[c] See also Chapter 4, Table 4.

Simplified Procedure for Determining *U* Values

Tables 5 through 17 represent a short cut enabling the engineer to determine and compare values for many modes of construction. The procedure is to determine the U value for the uninsulated construction in Tables 5 through 15; the benefit derived from the addition of insulating materials is shown in Table 16 (Part A to Part E). The final U value can be corrected for framing by use of Fig. 4. Additional summer values for ventilated and nonventilated attics are given in Table 17.

This simplified procedure provides a quick means for the engineer to evaluate carefully the economic considerations involved in the selection of an insulating material, as adapted to various building constructions.

Special attention must be given to vapor barriers as outlined in Chapters 22 and 23. Moisture from condensation or other sources materially reduces the heat-flow resistance of insulation.

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 $\epsilon = 0.90$.

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. 4 if an allowance is to be made for this effect.

Air space resistance values used are those shown in Table 3.

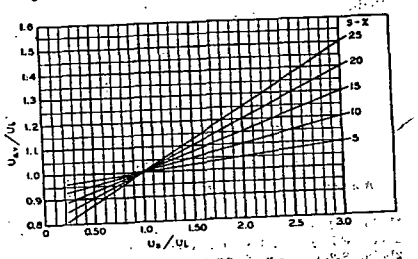
Air spaces are ¾ in. or more in width.

Variations of conductivity with mean temperature are 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 shown in Fig. 4.

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 tables 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.



U_{av} = average U value for building section.

U_f = U value for area between framing members.

U_o = U value for area backed by framing members.

S = percentage of area backed by framing members.

Fig. 4 .... Correction for Effect of Framing in Insulated Building Sections