

Table 11 . . . Summer Coefficients of Heat Transmission  $U$  of Flat Roofs Covered with Built-Up Roofing\*  
Btu per (hour) (square foot) (1 deg difference between the air on the two sides)

| Type of Roof Deck<br>(Ceiling not shown)                                                                                                      | Thickness of Roof Deck (inches) | Insulation on Top of Deck (Covered With Built Up Roofing) |                                              |      |      |      |                  |                                                          |      |      |       |
|-----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------------------------------------------|----------------------------------------------|------|------|------|------------------|----------------------------------------------------------|------|------|-------|
|                                                                                                                                               |                                 | No Ceiling—<br>Underside of Roof Exposed                  |                                              |      |      |      |                  | Furred Ceiling with Air Space, Metal Lath<br>and Plaster |      |      |       |
|                                                                                                                                               |                                 | No<br>insulation                                          | Insulating board <sup>a</sup> thickness, in. |      |      |      | No<br>insulation | Insulating board <sup>a</sup> thickness, in.             |      |      |       |
|                                                                                                                                               |                                 |                                                           | ½                                            | 1    | 1½   | 2    |                  | ½                                                        | 1    | 1½   | 2     |
| Flat metal roof deck<br>                                     | 4 Ply<br>Felt<br>Roof           | 0.73                                                      | 0.35                                         | 0.23 | 0.17 | 0.13 | 0.40             | 0.25                                                     | 0.18 | 0.14 | 0.12  |
|                                                                                                                                               | Ditto<br>+ ½ in. Slag           | 0.54                                                      | 0.30                                         | 0.20 | 0.16 | 0.13 | 0.34             | 0.22                                                     | 0.16 | 0.13 | 0.11  |
| Precast cement tile<br>                                      | 4 Ply<br>Felt<br>Roof 1½        | 0.67                                                      | 0.33                                         | 0.22 | 0.17 | 0.13 | 0.38             | 0.24                                                     | 0.18 | 0.14 | 0.12  |
|                                                                                                                                               | Ditto<br>+ ½ in. Slag 1½        | 0.50                                                      | 0.28                                         | 0.20 | 0.15 | 0.12 | 0.32             | 0.21                                                     | 0.17 | 0.13 | 0.11  |
| Concrete<br>                                                 | 4 Ply<br>Felt<br>Roof 2         | 0.65                                                      | 0.33                                         | 0.22 | 0.16 | 0.13 | 0.37             | 0.24                                                     | 0.18 | 0.14 | 0.12  |
|                                                                                                                                               | 4 Ply<br>Felt<br>Roof 4         | 0.59                                                      | 0.31                                         | 0.21 | 0.16 | 0.13 | 0.36             | 0.23                                                     | 0.17 | 0.13 | 0.12  |
|                                                                                                                                               | 4 Ply<br>Felt<br>Roof 6         | 0.54                                                      | 0.30                                         | 0.20 | 0.16 | 0.13 | 0.33             | 0.22                                                     | 0.17 | 0.13 | 0.11  |
|                                                                                                                                               | Ditto 2<br>+ ½ in. Slag 4       | 0.49                                                      | 0.28                                         | 0.20 | 0.15 | 0.12 | 0.31             | 0.21                                                     | 0.16 | 0.13 | 0.11  |
| Gypsum and wood fiber <sup>b</sup><br>on ½" gypsum board<br> | 4 Ply<br>Felt<br>Roof 2½        | 0.34                                                      | 0.23                                         | 0.17 | 0.13 | 0.12 | 0.25             | 0.18                                                     | 0.14 | 0.12 | 0.097 |
|                                                                                                                                               | 4 Ply<br>Felt<br>Roof 3½        | 0.28                                                      | 0.20                                         | 0.15 | 0.12 | 0.11 | 0.21             | 0.16                                                     | 0.13 | 0.11 | 0.094 |
|                                                                                                                                               | Ditto 2½<br>+ ½ in. Slag 3½     | 0.29                                                      | 0.20                                         | 0.16 | 0.13 | 0.11 | 0.22             | 0.16                                                     | 0.13 | 0.11 | 0.093 |
|                                                                                                                                               | Ditto 3½<br>+ ½ in. Slag 3½     | 0.25                                                      | 0.18                                         | 0.14 | 0.12 | 0.10 | 0.19             | 0.15                                                     | 0.13 | 0.10 | 0.090 |
| Wood <sup>c</sup><br>                                        | 4 Ply<br>Felt<br>Roof 1         | 0.43                                                      | 0.26                                         | 0.19 | 0.15 | 0.12 | 0.29             | 0.20                                                     | 0.15 | 0.13 | 0.11  |
|                                                                                                                                               | 4 Ply<br>Felt<br>Roof 1½        | 0.33                                                      | 0.22                                         | 0.17 | 0.13 | 0.11 | 0.24             | 0.18                                                     | 0.14 | 0.12 | 0.097 |
|                                                                                                                                               | 4 Ply<br>Felt<br>Roof 2         | 0.29                                                      | 0.20                                         | 0.16 | 0.13 | 0.11 | 0.22             | 0.16                                                     | 0.13 | 0.11 | 0.094 |
|                                                                                                                                               | 4 Ply<br>Felt<br>Roof 3         | 0.22                                                      | 0.16                                         | 0.13 | 0.11 | 0.09 | 0.17             | 0.13                                                     | 0.12 | 0.10 | 0.085 |
|                                                                                                                                               | Ditto 1<br>+ ½ in. Slag 2       | 0.35                                                      | 0.23                                         | 0.17 | 0.14 | 0.11 | 0.25             | 0.18                                                     | 0.14 | 0.12 | 0.10  |
|                                                                                                                                               | Ditto 1½<br>+ ½ in. Slag 2      | 0.29                                                      | 0.20                                         | 0.15 | 0.12 | 0.10 | 0.21             | 0.17                                                     | 0.13 | 0.11 | 0.093 |
|                                                                                                                                               | Ditto 2<br>+ ½ in. Slag 2       | 0.26                                                      | 0.19                                         | 0.14 | 0.12 | 0.10 | 0.20             | 0.15                                                     | 0.13 | 0.10 | 0.090 |
|                                                                                                                                               | Ditto 3<br>+ ½ in. Slag 3       | 0.20                                                      | 0.15                                         | 0.12 | 0.10 | 0.09 | 0.16             | 0.13                                                     | 0.11 | 0.09 | 0.081 |

\* The summer coefficients are considered temporary, and have been calculated with an outdoor wind velocity of 8 mph. For summer an inside surface conductance of 1.3 has been used instead of the regular 1.63 value. In all of these roofs a 4 ply felt roof has been assumed 1/4 in. thick, thermal conductivity = 1.33. Pitch and slag have been assumed as an additional thickness of 1/4 in. which has been assigned thermal conductivity = 1.0. In both cases thermal conductivity refers to one inch thickness.

<sup>b</sup> 87 1/2 percent gypsum, 12 1/2 percent wood fiber. Thickness indicated includes 1/4 in. gypsum board. This is a poured roof.

<sup>c</sup> Nominal thickness of wood is specified, but actual thickness was used in calculations.

<sup>d</sup> If corkboard insulation is used, the coefficient  $U$  may be decreased 10 percent.

surface, is exposed to the sun. The location is the central part of the United States. Design temperatures are: outdoor 95 F; daily range 20 deg; indoor temperature 80 F. Find the heat-flow rate at 2:00 p.m. for a day in July.

**Solution:** For the purpose of selecting the equivalent temperature differentially, this construction is assumed to be equal approximately to an uninsulated 6-in. concrete roof, for which the equivalent temperature is found to be 38 deg in the 2:00 p.m. column of Table 9. Calculate the overall heat transmission coefficient  $U$  (see Equation 3 of Chapter 9) of the roof as follows:

$$U = \frac{1}{\frac{1}{1.2} + \frac{4}{12} + \frac{4}{4.9} + \frac{0.375}{1.33} + \frac{0.50}{1.00} + \frac{1}{4.0}} = 0.33$$

The heat-flow rate is then  $38 \times 0.33$  equals 12.5 Btu per (hr) (sq ft).

#### TABLES FOR CALCULATING SOLAR HEAT GAIN THROUGH GLASS AREAS

##### Basic Principles

In order to set forth the principles involved in calculating heat flow through glass areas, the general instantaneous heat balance relation will be presented. It will be shown schematically in Fig. 2. The net heat gain for the indoor space is the result of several contributing factors.

The following observations concerning the behavior of

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glass with respect to radiant energy will lead to a better understanding of the heat balance relation.

1. Glass transmits, in varying degrees, radiation having wavelengths between 0.29 and 4.75 microns. The percentage of each wavelength transmitted is dependent upon the chemical and physical characteristics of the glass, and upon the angle of incidence of the radiant energy. Of the energy not transmitted, part is absorbed and part reflected.

2. Glass is opaque to radiant energy emitted from sources below 450 F.

3. Because of the above principles, it is convenient to group radiant energy into two classifications, solar radiant energy and low temperature radiant energy.

The complete heat balance for a glass section can be expressed for a unit time interval as follows:

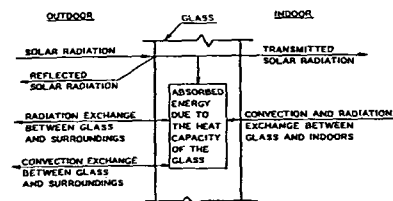


Fig. 2 . . . Instantaneous Heat Balance for a Glass or Glass Block Section

$$\begin{aligned} \text{[Total heat flow, through glass section]} &= \text{[Transmitted, Solar radiation]} \\ &\pm \text{[Heat flow by convective and radiative exchanges at the indoor surface]} \end{aligned} \quad (2a)$$

The second term of the right side of Equation 2a can also be expressed by a heat balance equation as follows:

$$\begin{aligned} \text{[Heat flow by convective and radiative exchanges at the indoor surface]} &= \text{[Absorbed solar radiation]} \\ &\pm \text{[Radiative exchanges between outer surface of glass and outdoor surroundings]} \end{aligned} \quad (2b)$$

Equations 2a and 2b can be combined and expressed in symbolic terms by Equation 2c. Tabular values of the two bracketed terms of Equation 2a are presented later in this section for various types of glass for specific design conditions.

$$(q/A) = [r_p I_D + r_d I_s] + [a_p I_D + a_d I_s + e_p R_o - f_{co} R_{po}] - f_{co} (t_{po} - t_o) - S \quad (2c)$$

where

$(q/A)$  = instantaneous rate of heat flow, Btu per (hour) (square foot).

$r_D, r_d$  = transmittance of glass for direct and diffuse solar radiation, respectively.

$I_D, I_s$  = incident direct and diffuse solar radiation, respectively, Btu per (hour) (square foot).

$a_D, a_d$  = absorptance of glass for direct and diffuse solar radiation, respectively.

$e_p$  = emissivity of glass at temperature  $t_{po}$ .

$R_o$  = low temperature radiant energy falling on glass from outdoor surroundings, Btu per (hour) (square foot).

$R_{po}$  = low temperature radiant energy emitted by a surface with emissivity equal to 1.0 at temperature  $t_{po}$ .

$f_{co}$  = outdoor convective conductance, Btu per (hour) (square foot) (Fahrenheit degree).

$t_{po}$  = temperature of outdoor surface of glass, Fahrenheit.

$t_o$  = temperature of outdoor air, Fahrenheit.

$S$  = rate at which glass stores energy, Btu per (hour) (square foot).

Transmissivity and absorptivity vary with both wavelength of the incident radiation and incident angle. Normal incidence transmittance values for some commonly used types and combination are given in Table 14. Some variation in these values can be expected in practice due to variations in manufacture and in solar energy distribution. However, a change in transmissivity causes a compensating change in absorptivity. Generally, the total heat flow is not greatly altered. Transmittance data for a number of types of glass and various patterns of 8-in. glass block are given in ASHRAE research papers<sup>13, 20, 21, 22, 23, 24</sup>.

As stated earlier in this chapter, present data as to the value of  $R_o$  are inadequate, so for the present it is suggested that  $f_{co}$  be increased to include radiation, and the term  $e_p R_o - e_p R_{po}$  be disregarded. It is not practicable to give values of  $S$  in this chapter. However, for ordinary glass, the value of  $S$  is small.

Fig. 3 is a graphical solution, for single glass, of Equation 2b. Only absorbed solar radiation is considered, although low temperature radiation exchange and heat storage can be added algebraically to  $a_d I_s$  if such data are available. The small thermal resistance of the glass has been neglected. The heat-flow rates are for 80 F indoor temperature, an in-

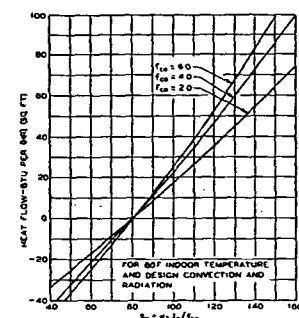


Fig. 3 . . . Convection and Radiation Heat Flow for Vertical Single Glass