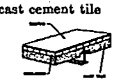
Table 11 . . . . Summer Coefficients of Heat Transmission U of Flat Roofs Covered with Built-Up Roofing[a]

Btu per (hour) (square foot) (F deg difference between the air on the two sides)

Type of Roof Deck (Ceiling not shown)	Thickness of Roof Deck (Inches)	Insulation on Top of Deck (Covered With Built Up Roofing)									
		No Ceiling—Underside of Roof Exposed					Furred Ceiling with Air Space, Metal Lath and Plaster				
		No insulation	Insulating board[d] thickness, in. ½	1	1½	2	No insulation	Insulating board[d] thickness, in. ½	1	1½	2
Flat metal roof deck 	4 Ply Felt Roof	0.73	0.35	0.23	0.17	0.13	0.40	0.25	0.18	0.14	0.12
	Ditto + 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 	4 Ply Felt Roof 1⅝	0.67	0.33	0.22	0.17	0.13	0.38	0.24	0.18	0.14	0.12
	Ditto + ½ in. Slag 1⅝	0.50	0.28	0.20	0.15	0.12	0.32	0.21	0.17	0.13	0.11
Concrete 	4 Ply 2	0.65	0.33	0.22	0.16	0.13	0.37	0.24	0.18	0.14	0.12
	Felt 4	0.59	0.31	0.21	0.16	0.13	0.36	0.23	0.17	0.13	0.12
	Roof 6	0.54	0.30	0.20	0.16	0.13	0.33	0.22	0.17	0.13	0.11
	Ditto 2	0.49	0.28	0.20	0.15	0.12	0.31	0.21	0.16	0.13	0.11
	4	0.46	0.27	0.19	0.15	0.12	0.30	0.21	0.16	0.13	0.11
	+ ½ in. Slag 6	0.42	0.26	0.19	0.14	0.12	0.29	0.20	0.16	0.13	0.10
Gypsum and wood fiber[b] on ½" gypsum board 	4 Ply Felt 2½	0.34	0.23	0.17	0.13	0.12	0.25	0.18	0.14	0.12	0.097
	Roof 3½	0.28	0.20	0.15	0.12	0.11	0.21	0.16	0.13	0.11	0.094
	Ditto 2½	0.29	0.20	0.16	0.13	0.11	0.22	0.16	0.13	0.11	0.093
	+ 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[c] 	4 Ply 1	0.43	0.26	0.19	0.15	0.12	0.29	0.20	0.15	0.13	0.11
	Felt 1½	0.33	0.22	0.17	0.13	0.11	0.24	0.18	0.14	0.12	0.097
	Roof 2	0.29	0.20	0.16	0.13	0.11	0.22	0.16	0.13	0.11	0.094
	3	0.22	0.16	0.13	0.11	0.09	0.17	0.13	0.12	0.10	0.085
	1	0.35	0.23	0.17	0.14	0.11	0.25	0.18	0.14	0.12	0.10
	Ditto 1½	0.29	0.20	0.15	0.12	0.10	0.21	0.17	0.13	0.11	0.093
	+ ½ in. Slag 2	0.26	0.19	0.14	0.12	0.10	0.20	0.15	0.13	0.10	0.090
	3	0.20	0.15	0.12	0.10	0.09	0.16	0.13	0.11	0.09	0.081

[a] 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 1.2 has been used instead of the regular 1.65 value. In all of these roofs a 4 ply felt roof has been assumed ⅜ in. thick, thermal conductivity = 1.33. Pitch and slag have been assumed as an additional thickness of ½ in. which has been assigned thermal conductivity = 1.0. In both cases thermal conductivity refers to one inch thickness.

[b] 87½ percent gypsum, 12½ percent wood fiber. Thickness indicated includes ½ in. gypsum board. This is a poured roof.

[c] Nominal thickness of wood is specified, but actual thickness was used in calculations.

[d] 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 differential*, 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 × 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

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:

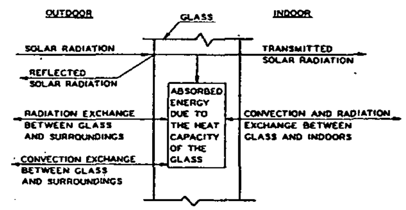


Fig. 2 . . . . Instantaneous Heat Balance for a Glass or Glass Block Section

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

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

$$\begin{bmatrix}\text{Heat flow by convective}\\ \text{and radiative exchanges}\\ \text{at the indoor surface}\end{bmatrix} = \begin{bmatrix}\text{Absorbed}\\ \text{solar}\\ \text{radiation}\end{bmatrix} \pm \begin{bmatrix}\text{Radiative exchanges be}\\ \text{-tween outer surface of glass}\\ \text{and outdoor surroundings}\end{bmatrix} \quad (2b)$$
$$\pm \begin{bmatrix}\text{Convective exchanges}\\ \text{between outer surface of}\\ \text{glass and outdoor air}\end{bmatrix} \pm \begin{bmatrix}\text{Heat storage}\\ \text{within the}\\ \text{glass section}\end{bmatrix}$$

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.

$$(q/A) = [\tau_D I_D + \tau_d I_d] + [\alpha_D I_D + \alpha_d I_d + \epsilon_{go} R_s - \epsilon_{go} R_{go} - f_{co}(t_{go} - t_o) - S] \quad (2c)$$

where

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

τ_D, τ_d = transmittance of glass for direct and diffuse solar radiation, respectively.

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

α_D, α_d = absorptance of glass for direct and diffuse solar radiation, respectively.

ϵ_{go} = emissivity of glass at temperature t_{go}.

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

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

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

t_{go} = 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 ASHAE research papers.[19, 20, 21, 22, 23, 24]

As stated earlier in this chapter, present data as to the value of R_s are inadequate, so for the present it is suggested that f_{co} be increased to include radiation, and the term $\epsilon_{go}R_s - \epsilon_{go}R_{go}$ 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 $\alpha_t I_t$ 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-

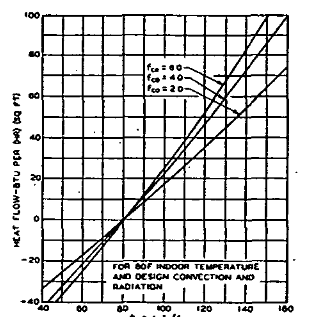


Fig. 3 . . . . Convection and Radiation Heat Flow for Vertical Single Glass