sources, so long as the temperature of these sources is not over approximately 450 F.

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

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

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

$$\left[\begin{array}{l}\text{Heat flow by convective}\\ \text{and radiative exchanges}\\ \text{at the indoor surface}\end{array}\right] = \left[\begin{array}{l}\text{Absorbed}\\ \text{solar}\\ \text{radiation}\end{array}\right] \pm \left[\begin{array}{l}\text{Radiative exchanges be-}\\ \text{tween outer surface of glass}\\ \text{and outdoor surroundings}\end{array}\right]$$

$$\pm \left[\begin{array}{l}\text{Convective exchanges}\\ \text{between outer surface of}\\ \text{glass and outdoor air}\end{array}\right] \pm \left[\begin{array}{l}\text{Heat storage}\\ \text{within the}\\ \text{glass section}\end{array}\right] \quad (2b)$$

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.

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

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 degrees.
t_o = temperature of outdoor air, Fahrenheit degrees.
S = rate at which glass stores energy, Btu per (hour)(square foot).

Transmissivity and absorptivity vary with both wave length of the incident radiation and incident angle. Values of τ and α for a single sheet of the average ordinary drawn window glass are given in Table 12 for a standard distribution of solar energy.[4] Values for two air-spaced sheets are also given. Normal incidence transmittance values for some commonly-used types and combinations are given in Table 15. 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 an approximately equal and opposite change in absorptivity. Hence, the *total heat flow* is not greatly altered. Transmittance data for other types of glass and various patterns of 8-in. glass block are given in A.S.H.A.E. research papers.[19, 20, 21, 22, 23]

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 a 75 F indoor temperature, an indoor surface conductance for convection f_{ci} as given by Equation 3, and an equivalent surface conductance for radiation f_{ri} as given by Equation 4. Indoor surfaces seen by the glass are assumed to radiate as a black body at room air temperature.

$$f_{ci} = 0.27\,(t_{gi} - t_i)^{0.25} \quad (3)$$

$$f_{ri} = 0.162\left[\left(\frac{t_{gi} + 460}{100}\right)^4 - \left(\frac{t_i + 460}{100}\right)^4\right] \Big/ (t_{gi} - t_i) \quad (4)$$

where

t_{gi} = temperature of indoor surface of glass, Fahrenheit.
t_i = temperature of indoor air, Fahrenheit.

A more complete treatment of the problem is given in an A.S.H.A.E. research paper.[22]

Example 8: Find the total heat gain at 10 a.m. sun time for a single unshaded sheet of common window glass in a wall facing 18 deg east of south on August 1 at 50 deg north latitude. The indoor temperature is 75 F; the outdoor temperature is 83 F. Use clear atmosphere radiation values and $f_{cro} = 4.0$.

Solution: From *Example* 2, K is 0.557; hence, the angle of incidence, θ, is 56 deg 9 min. From *Example* 4, I_D = 152.0, I_d = 26.6. By interpolation in Table 12, τ_D is found to be 0.81, α_D is 0.06; τ_d and α_d are 0.79 and 0.06, respectively.

The heat gain due to transmitted solar radiation is

$$(q/A)_\tau = 152.0 \times 0.81 + 26.6 \times 0.79 = 144.1 \text{ Btu per (hr)(sq ft).}$$

The heat gain by convection and radiation from the indoor surface is found from Fig. 3:

$$t_o + \frac{\alpha_t I_t}{f_{co}} = 83 + \frac{0.06\,(152.0 + 26.6)}{4} = 85.7 \text{ F}$$

from which

$$(q/A)_{cr} = 11.5 \text{ Btu per (hr)(sq ft).}$$

From Equation 2a the total heat flow is

$$(q/A) = 144.1 + 11.5 = 155.6 \text{ Btu per (hr)(sq ft).}$$

Design Tables for Flat Glass

Tables 13 and 14 give design values of instantaneous rates of heat gain for *single unshaded common window glass* for a solar declination of 18 deg. This corresponds to a nominal August 1 day. The tables are based upon the solar intensity values for a clear atmosphere as given in Table 4. Table 13 represents the first bracketed term of Equation 2a; therefore, the values are dependent only upon values of I and τ. Table 14 is the second term of Equation 2a, and is based upon a 80 F indoor temperature and a