$$\begin{bmatrix}\text{Heat flow by convective and radiative exchanges at the indoor surface}\end{bmatrix} = \begin{bmatrix}\text{Absorbed solar radiation}\end{bmatrix} \pm \begin{bmatrix}\text{Radiative exchanges between outer surface of glass and outdoor surroundings}\end{bmatrix}$$

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

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.

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

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. 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 A.S.H.A.E. 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 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]

Design Tables for Flat Glass

Tables 12 and 13 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

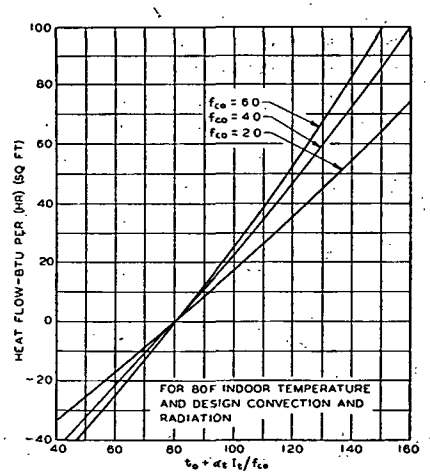


FIG. 3. CONVECTION AND RADIATION HEAT FLOW FOR VERTICAL SINGLE GLASS

the solar intensity values for a clear atmosphere as given in Table 4. Table 12 represents the first bracketed term of Equation 2a; therefore, the values are dependent only upon values of I and τ. Table 13 is the second term of Equation 2a, and is based upon a 80 F indoor temperature and a dry-bulb temperature cycle, with a 95 F maximum as tabulated. *The total heat gain is the sum* of the Table 12 and Table 13 values. In preparing Table 13, convection and radiation heat exchange were combined, and a combined surface conductance of 4.0 used. Corrections to be applied for other design temperatures are given in Table 24 in a later section, Effect of Deviation from Design Conditions.

Tables 12 and 13 may be used for other types of glass with good accuracy, by using the factors given in Table 14. Table 12 values are multiplied by the appropriate factor given in Table 14 to obtain heat gain due to transmitted solar radiation. For glasses having a transmittance for normally incident radiation differing from the table values, factors may be found by linear interpolation. To obtain instantaneous rates of heat gain by convection and radiation, two steps are required. First, Table 13 values are