Based upon the solar data of Table 5, sol-air data have been computed for locations in clear and in humid industrial areas where the design dry-bulb temperature is 95 F. As given in Table 9, these are for 40 deg north latitude, 18 deg north declination (August 1). Radiation exchange has been included with the convection transfer; a value of 0.25 was used for $\alpha_t/f_{co}$. The data for industrial areas are practically identical with sol-air data for New York City[4] which were derived from an analysis of *U. S. Weather Bureau* records for a 10-year period. A similar analysis for Lincoln, Nebraska[3] leads to somewhat higher sol-air temperatures than the clear atmosphere values given in Table 9 because of the higher dry-bulb temperatures.

Corrections for other conditions indicated by (′), are made as follows:

1. To adjust the data in Table 9 for variations in $t_o$:
   a. Establish the value of $t_o'$, the dry-bulb temperature, for the locality in question.
   b. Determine $t_o' - t_o$.
   c. Add (algebraically) $t_o' - t_o$ to the data tabulated.
2. To adjust the data of Table 9 for other values of $\alpha_t/f_{co}$: interpolate or extrapolate the tabulated data by direct proportion, using the column for $\alpha_t/f_{co} = 0.0$.

Sol-air temperatures are especially helpful in the calculation of periodic heat transfer, as will be illustrated in the material which follows.

## PRINCIPLES OF PERIODIC HEAT FLOW

Calculation principles for periodic heat flow are dealt with briefly in this section; in the section which follows, *practical tables are given to facilitate rapid design estimates.* In addition to the rate of heat entry into the outside building surface, these tables take into account the following factors:

1. The thermal conductivity of material.
2. The density, specific heat and character of material.
3. Thickness of material.
4. Room air temperature.
5. Unit convective conductance between the inside surface and room air; and radiant heat transfer between the inside surfaces and other surfaces in the room.

### Time Lag

The fundamental analysis of periodic heat flow is complicated when compared with steady-state calculations on account of the time-variable storage of heat from point to point through a wall or roof. The cyclic variation of outdoor conditions produces a related cyclic variation of temperature and heat flow throughout each structural section exposed to the weather. The cyclic variations undergo a progressive *shift in phase* and *decrease in amplitude* in going through a wall with constant conditions maintained in the indoor space.

By a *shift in phase* is meant that as the cyclic temperature wave passes through the wall, the time of occurrence of the maximum temperature at any point shifts farther and farther behind the time of the outer-surface maximum for successive positions through the wall. The resultant *time lag* between the outer-surface and inner-surface maximum temperatures is important, for it may be the determining factor in fixing the time of the maximum cooling load.

By a *decrease in amplitude* is meant that as the cyclic temperature wave passes through the wall, the difference between the maximum temperature of a cycle and the mean temperature of the cycle, which is the amplitude of the wave by definition, decreases progressively as the wave passes through the wall. The magnitude of the *temperature amplitude* at the inner wall surface is necessary for the determination of the instantaneous rate of heat transfer to the indoor space.



Practical design data for periodic heat flow comprise a means of determining the time lag and amplitude decrement for different wall constructions, and any given outdoor cycle of sol-air temperature. Both analytical and experimental studies have been made on this problem.[11] While the analytical solution has been written, it is far too detailed for direct use in rapid practical work; and the extensive numerical work required to establish a basis for simplified calculations has been only partially completed. The method reported by Mackey and Wright[11] will be adopted as the basis for the design procedure recommended here.

### Homogeneous Walls or Roofs, Constant Indoor Temperature

For walls or roofs of a single, homogeneous material, the *instantaneous* rate of heat gain within an enclosure where the indoor air temperature is held constant is, approximately,

$$\frac{q}{A} = U\,(t_m - t_i) + \lambda U\,(t_e{}^* - t_m) \text{ Btu per (hour) (square foot)} \quad (5)$$

*where* $t_m$ = 24-hr average sol-air temperature for the particular value of $\frac{\alpha}{f_{co}}$, Fahrenheit degrees.

$\lambda$ = amplitude decrement factor, a variable that depends upon the thickness material, and orientation of the wall or roof; see Table 10 for values. The amplitude decrement factor $\lambda$ as used in this chapter is equivalent to $\left(\frac{1.65 \times \lambda}{U}\right)$ as defined by Mackey and Wright,[11] and also used by Stewart.[12]

$t_e{}^*$ = sol-air temperature at a time earlier than the time for which the heat gain is being found by an amount that is equal to the time lag of the wall or roof, Fahrenheit degrees; see Table 10 for values of time lag.

$U$ = overall coefficient of heat transfer of the wall or roof, Btu per (hour) (square foot) (Fahrenheit degree),

$$U = \frac{1}{\frac{1}{f_{ci}} + \frac{1}{f_{co}} + \frac{L}{k}} = \frac{1}{\frac{1}{1.65} + \frac{1}{4} + \frac{L}{k}} = \frac{1}{0.856 + \frac{L}{k}}$$

$L$ = thickness of building material, inches.

$k$ = thermal conductivity of building material, Btu per (hour) (square foot) (Fahrenheit degree per inch).

$f_{ci}$ = unit indoor surface conductance (radiation and convection combined), Btu per (hour)(square foot)(Fahrenheit degree).

$f_{co}$ = unit outdoor surface conductance (radiation and convection combined), Btu per(hour)(square foot)(Fahrenheit degree).

The time at which the *maximum occurs in the rate of heat entry into the outside surface of walls or roofs* is taken as the time at which the peak point occurs in the sol-air temperature cycle (mean *sun time* is used in the sol-air cycles). The corresponding maximum rate of heat entry follows from Equation 5 with $t_e{}^*$ being the maximum temperature of the sol-air cycle.

The time of *maximum heat gain to the room* is obtained by adding the