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.[7] 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[7] 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,

$$\frac{q}{A} = U\,(t_m - t_i) + \lambda U\,(t_e^* - t_m) \text{ Btu per (hour) (square foot)} \qquad (6)$$

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

λ = amplitude decrement factor, a variable that depends upon the thickness, material, and orientation of the wall or roof; see Table 12 for values. The amplitude decrement factor λ as used in this chapter is equivalent to $\left(\frac{1.65 \times \lambda}{U}\right)$ as defined by Mackey and Wright[7] and also used by Stewart.[11]

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 12 for values of time lag.

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

$$U = \frac{1}{\frac{1}{f_i} + \frac{1}{f_o} + \frac{L}{k}} = \frac{1}{\frac{1}{1.65} + \frac{1}{4} + \frac{L}{k}} = \frac{1}{0.856 + \frac{L}{k}}$$

L = thickness of building material, feet.

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

f_i = unit convective conductance (film coefficient of heat transfer) of indoor air, Btu per (hour) (square foot) (Fahrenheit degree).

f_o = unit convective conductance (film coefficient of heat transfer) of outdoor air for summer conditions of approximately 7.5 mph wind velocity, 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 6 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 time lag to the time of maximum sol-air temperature (from Tables 10 or 11) for the particular wall or roof.

The magnitude of the second term in Equation 6 relative to the first term indicates the relative portion of the structural heat in-flow assignable to periodic heat flow. The periodic term is continually passing through a *cyclic variation* from zero to a positive maximum, to zero, to a negative maximum, to zero again and so on over each 24 hour cycle. Surfaces with different exposures pass through these cycles with maximum points at different times of day.

TABLE 12. PERIODIC HEAT FLOW DATA FOR HOMOGENEOUS WALLS OR ROOFS

Material	Thickness, In.	Over-all Coefficient, Btu per (hr) (sq ft) (°F) U[a]	Thermal Resistance of Solid Material, (hr) (sq ft) (°F)/Btu $\frac{L}{k}$	Time Lag, Hr	Factor, λ, in Equation 6			
					Horizontal and North	East	South	West
Stone	8	0.67	0.64	5.5	0.51	0.36	0.48	0.42
	12	0.55	0.96	8.0	0.28	0.19	0.26	0.22
	16	0.47	1.28	10.5	0.17	0.10	0.15	0.13
	24	0.36	1.92	15.5	0.06	0.03	0.05	0.04
Solid Concrete	2	0.98	0.17	1.1	0.93	0.87	0.92	0.89
	4	0.84	0.33	2.5	0.79	0.68	0.76	0.72
	6	0.74	0.50	3.8	0.61	0.46	0.58	0.51
	8	0.66	0.67	5.1	0.49	0.33	0.46	0.39
	12	0.54	1.00	7.8	0.29	0.17	0.26	0.22
	16	0.46	1.33	10.2	0.17	0.09	0.15	0.12
Common Brick	4	0.60	0.80	2.3	0.83	0.75	0.81	0.78
	8	0.41	1.60	5.5	0.51	0.39	0.49	0.44
	12	0.31	2.40	8.5	0.26	0.17	0.25	0.21
	16	0.25	3.20	12.0	0.13	0.08	0.12	0.10
Face Brick	4	0.77	0.44	2.4	0.81	0.70	0.78	0.74
Wood	½	0.68	0.62	0.17	1.0	1.0	1.0	1.0
	1	0.48	1.25	0.45	1.0	0.99	0.99	0.99
	2	0.30	2.50	1.3	0.98	0.91	0.96	0.94
Insulating Board	½	0.42	1.51	0.08	1.0	1.0	1.0	1.0
	1	0.26	3.03	0.23	1.0	1.0	1.0	1.0
	2	0.14	6.05	0.77	1.0	1.0	1.0	1.0
	4	0.08	12.1	2.7	0.83	0.74	0.81	0.76
	6	0.05	18.2	5.0	0.64	0.49	0.61	0.55

[a] Based upon an outdoor combined film coefficient of 4.0 and an indoor combined film coefficient of heat transfer of 1.65 Btu per (hour) (square foot) (Fahrenheit degree).

An example in the use of Tables 10, 11, and 12 follows:

Example 3. Find the instantaneous design rate of heat gain through an 8-in. west wall of common brick ($b = 0.7$, $f_o = 4$) located in New York, N. Y., at 9:30 p.m. sun time, when the temperature of the indoor air is constant at 80 F.

From Table 12, $U = 0.41$, the time lag is 5.5 hr, and $\lambda = 0.44$.

By linear interpolation on the basis of the value of b/f_o in Table 10,

$$t_m = 84.8 + \frac{0.175}{0.25}(96.5 - 84.8) = 93 \text{ F}.$$