D = diameter of pipe or circular duct or height of vertical wall, inches. (Effect of diameter or height becomes constant at 24 in.)

T_{av} = average of wall surface and surrounding air temperature, degrees Fahrenheit absolute.

$t_s - t_f$ = temperature excess between wall surface and surrounding air, degrees Fahrenheit.

For horizontal cylinders, the value of $C = 1.016$ has been well established by various investigations. For vertical plates, the value of $C = 1.394$ has been fairly well established. Suggested values [3] of C for horizontal plates warmer than the surrounding air, are 1.79 when facing upward and 0.89 when facing downward.

TABLE 2. HEAT TRANSMISSION BY FREE CONVECTION FOR LARGE VERTICAL SURFACES

Expressed in Btu per square foot per hour

TEMP DEG F	TEMPERATURE DIFFERENCE BETWEEN BODY AND SURROUNDING STILL AIR AT 80 F													
	0	10	20	30	40	50	60	70	80	90	100	110	120	130
0	0	4.4	10.4	17.4	25.0	33.2	41.8	50.6	59.9	69.4	79.4	89.2	99.4	109.8
1	0.3	4.9	11.1	18.1	25.8	34.1	42.6	51.5	60.8	70.3	80.4	90.2	100.4	110.9
2	0.6	5.5	11.8	18.9	26.7	34.9	43.5	52.4	61.8	71.3	81.4	91.2	101.5	112.0
3	1.0	6.0	12.5	19.7	27.5	35.7	44.3	53.4	62.7	72.3	82.4	92.2	102.6	113.0
4	1.4	6.6	13.2	20.5	28.3	36.6	45.2	54.3	63.7	73.3	83.3	93.3	103.6	114.1
5	1.8	7.3	13.9	21.2	29.2	37.4	46.1	55.2	64.6	74.3	84.2	94.3	104.7	115.2
6	2.3	7.9	14.6	22.0	30.0	38.3	47.0	56.1	65.6	75.3	85.2	95.3	105.7	116.3
7	2.8	8.5	15.3	22.7	30.8	39.1	47.8	57.1	66.5	76.3	86.2	96.3	106.7	117.3
8	3.3	9.1	16.0	23.5	31.6	40.0	48.7	58.0	67.5	77.4	87.2	97.4	107.8	118.4
9	3.8	9.7	16.7	24.3	32.4	40.9	49.7	59.0	68.4	78.4	88.2	98.4	108.8	119.5

The heat transmission by free convection from vertical walls *24 in. or more in height* is given in Table 2 as calculated from Equation 2a for an ambient air temperature of 80 F. The values in Table 2 are not changed appreciably by a considerable change in air temperature for a given temperature excess. For instance, a change in air temperature from 80 to 40 F will increase the heat transmission given in Table 2 by only 1.3 per cent.

Table 2 can also be used for calculating the free convection rate of transmission for various commercial shapes such as pipes and ducts. These calculations are simplified by the use of the factors in Tables 3 and 4. Table 3 gives factors by which the values in Table 2 must be multiplied to obtain the free-convective transfer from various shapes *whose characteristic dimensions are 24 in. or over*, and Table 4 gives the factors to be used in conjunction with the factors in Table 3 for obtaining the free convection from Table 2 for pipes and ducts *whose characteristic dimensions are less than 24 in.*

For example, the free convection transfer from a 3 in. O.D. horizontal cylinder for a temperature difference of 40 F = 25.0 × 0.73 × 1.52 = 27.7 Btu per (square foot) (hour).

Problems in either forced convection or natural convection may be solved by the simple first-power equation if the convection coefficient is expressed as a unit conductance:

$$q_c = h_c A (t_1 - t_2) \tag{2b}$$

where

q_c = heat transmission by convection, Btu per hour.

A = surface area, square feet.

$t_1 - t_2$ = temperature difference between the surface and the fluid degrees Fahrenheit.

h_c = unit conductance, from Table 5, Btu per (square foot) (hour) (degree Fahrenheit temperature difference.)

TABLE 3. FREE CONVECTION FACTORS FOR VARIOUS SHAPES

SHAPES	FACTOR
Horizontal cylinders 24 in. in diam. or over	0.73
Long vertical cylinders 24 in. in diam. or over	0.88
Vertical plates 24 in. in height or over	1.00
Horizontal plates warmer than air facing upward	1.28
Horizontal plates warmer than air facing downward	0.64
Horizontal plates cooler than air facing upward	0.64
Horizontal plates cooler than air facing downward	1.28

TABLE 4. FREE CONVECTION FACTORS FOR VARIOUS DIAMETER PIPES OR VARIOUS HEIGHT PLATES

Actual O.D., or height, in.	1	2	3	4	5	6	7	8
Factor	1.88	1.64	1.52	1.43	1.37	1.32	1.28	1.25
Actual O.D., or height, in.	9	10	12	14	16	18	20	22
Factor	1.22	1.19	1.15	1.11	1.09	1.06	1.04	1.02

Thermal Radiation Equation

The relation shown in Equation 3 is usually applicable to systems in which radiant exchange takes place between the surfaces of solids, as sche-

$$q_r = \sigma A_1 F_A F_E (T_1^4 - T_2^4) \tag{3}$$

matically shown in Fig. 3. Gaseous and luminous radiation are not considered in this discussion. Equation 3 states that the net radiation current per unit transfer area of surface 1, q_r/A Btu per (hour) (square foot), which *sees* surface 2 through a non-absorbing medium, is proportional to the difference of the fourth powers of the absolute surface temperatures $(T_1^4 - T_2^4)$. The proportionality factor $(\sigma F_A F_E)$ may be conveniently separated into three parts:

σ = the Stefan-Boltzmann radiation constant.

= 1730 × 10^{-12} Btu per (hour) (square foot) (degree Fahrenheit absolute temperature to the fourth power).

F_A = the configuration factor is dimensionless and ≤ 1. This factor accounts for the shape and relative position of the two surfaces. The value of $F_A = 1$ may be used in the cases of large parallel planes, long concentric cylinders or smaller bodies in large enclosures.

F_E = the emissivity factor is also dimensionless and ≤ 1. This factor accounts for the absorption and emission characteristics of the surfaces for the radiation which exists. Individual emissivities (e) should be taken from Table 6 and applied, for either radiation or absorption, as follows:

a. For a small body in a large enclosure, use the emissivity of the small body only: $F_E = e_1$.