

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 for $40\text{ F} = 25.0 \times 0.73 \times 1.52 = 27.7$ Btu per square foot per hour.

The increased rate of heat transfer due to forced convection can be calculated from Equation 2b:

$$q_{fc} = 1 + 0.225 V \quad (2b)$$

where

q_{fc} = heat transfer by forced convection, Btu per square foot per hour per degree Fahrenheit temperature difference.

V = velocity of air, feet per second.

This equation is approximately correct for large surfaces exposed to air currents at temperatures of approximately 70 to 80 F.

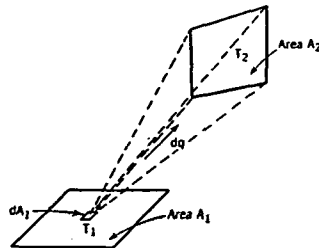


FIG. 3. RADIATION BETWEEN SURFACES

Thermal Radiation Equation

$$\frac{dq}{dA_1} = \sigma F_A F_E (T_1^4 - T_2^4) \quad (3)$$

This relation, which is sometimes applicable to systems in which radiant exchange takes between the surfaces of solids, states that the net radiation current per unit transfer area of surface 1, $(dq)/(dA_1)$, Btu per hour per 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 per square foot per degree Fahrenheit absolute temperature to the fourth power.

F_A = the angle factor is dimensionless and ≤ 1 . This factor accounts for the relative geometry of the two surfaces, and is called the shape factor.

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.

The radiation conditions described are schematically shown in Fig. 3. Gaseous and luminous radiation will not be discussed here.

TABLE 5. HEAT TRANSMISSION BY RADIATION FOR BLACK-BODY CONDITIONS^a

Expressed in Btu per square foot per hour

TEMP. DEG F	0	-1	-2	-3	-4	-5	-6	-7	-8	-9
-30	59.3	58.7	58.2	57.7	57.2	56.7	56.2	55.7	55.2	54.7
-20	65.2	64.7	64.1	63.5	62.9	62.3	61.7	61.1	60.5	59.9
-10	71.4	70.8	70.1	69.5	68.9	68.3	67.7	67.1	66.4	65.8
0	78.0	77.4	76.7	76.0	75.4	74.7	74.0	73.4	72.7	72.1
	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
0	78.0	78.7	79.4	80.1	80.8	81.5	82.2	82.9	83.6	84.3
10	85.0	85.7	86.5	87.2	88.0	88.7	89.4	90.2	90.9	91.7
20	92.4	93.3	94.0	94.8	95.6	96.4	97.2	98.0	98.8	99.6
30	100	101	102	103	104	105	105	106	107	108
40	109	110	111	112	112	113	114	115	116	117
50	118	119	120	121	122	123	123	124	125	126
60	127	128	129	130	131	132	133	134	135	136
70	137	138	139	140	142	143	144	145	146	147
80	148	149	150	151	152	153	154	155	156	157
90	159	160	161	162	163	164	166	167	168	169
100	170	171	173	174	175	176	178	179	180	182
110	183	184	185	187	188	189	191	192	193	195
120	196	197	199	200	201	203	204	206	207	209
130	211	212	214	215	217	218	220	221	222	224

^aExample: Radiation from walls of room at 32 F to surface at -25 F for effective emissivity of 0.95 = $(102 - 62.3) 0.95 = 37.7$ Btu per square foot per hour.

The radiation under black-body conditions, or for an emissivity of 1.0, is given in Table 5 for cold surfaces as low as -39 F to warmer surfaces as high as 139 F. The emissivities of a number of surfaces ordinarily encountered in engineering practice are shown in Table 9⁵.

In many problems involving heat transfer by the mechanisms of radiation and convection in parallel (simultaneous heat transfer by the two mechanisms to the same surface), it is algebraically convenient to employ a first power radiation rate equation of a form similar to Equation 2 for convection, namely:

$$\frac{dq}{dA_1} = h_r (t_1 - t_2) \quad (3a)$$

where h_r is the unit radiation conductance. Comparison of this equation with Equation 3 yields the relation:

$$h_r = \sigma F_A F_E \frac{(T_1^4 - T_2^4)}{(T_1 - T_2)} \approx \sigma F_A F_E (4 T_{ave}^3) \quad (3b)$$

where

$$T_{ave} = \frac{(T_1 + T_2)}{2}$$

This unit conductance (h_r) is to be used with caution for its behavior is

⁵Heat Insulation in Air Conditioning, by R. H. Heilman (Industrial and Engineering Chemistry, Vol. 28, July 1936, p. 782).