

series or in parallel. In using the resistance concept, the calculations involved are analogous to the application of Ohm's Law in electricity, viz., the heat flow or thermal current is directly proportional to the thermal potential or temperature difference, and inversely proportional to the thermal resistance:

$$q_{re} = \frac{t_1 - t_2}{R} \quad (6)$$

Following the electrical analogy, when there is a thermal current flowing through several resistances in series, the resistances are additive:

$$R_T = R_1 + R_2 + R_3 + \dots + R_n \quad (7)$$

Similarly, conductance is the reciprocal of resistance, and for heat flow

TABLE 4. HEAT TRANSMISSION BY RADIATION FOR BLACK-BODY CONDITIONS*
Expressed in Btu per (square foot) (hour)

TEMP F DEG	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	106	107	108	109
40	109	110	111	112	113	114	115	116	117	118
50	118	119	120	121	122	123	124	125	126	127
60	127	128	129	130	131	132	133	134	135	136
70	137	138	139	140	141	142	143	144	145	146
80	148	149	150	151	152	153	154	155	156	157
90	159	160	161	162	163	164	165	166	167	168
100	170	171	172	173	174	175	176	177	178	179
110	183	184	185	186	187	188	189	190	191	192
120	196	197	198	199	200	201	202	203	204	205
130	211	212	213	214	215	216	217	218	219	220

*Example: 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) (hour).

through several resistances in parallel, the conductances are additive:

$$C_T = \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad (8)$$

Practical Heat Transfer Problems

The use of these relations for resistance and conductance makes possible the solution of many practical heat transfer problems. As discussed in Chapters 9, 27 and 35, the practical analyses of heat transfer in building walls, in fin-tube coils and in pipe coverings, are usually computed by this method. The same resistance analysis may be applied to complicated steady-state conduction problems. Table 6 gives the resistances in six common cases of steady-state conduction.

A complete analysis by the resistance method is well illustrated by

Heat Transfer

considering the heat transfer from the air outside to the cold water inside of an insulated pipe. The temperature gradients and the nature of the resistance analysis are indicated by the two sketches of Fig. 4.

Since air is sensibly transparent to radiation, there will be some heat transfer by both radiation and convection to the outer insulation surface. The mechanisms act in parallel on the air side. The total transfer by radiation and convection then passes through the insulating layer and the

TABLE 5. TOTAL HEAT EMISSION BY RADIATION*

BODY OR MEAN RADIANT TEMPERATURE F DEG	Radiation in Btu per (square foot) (hour) emitted to surroundings with a temperature of absolute zero by bodies at various temperatures and with emissivity factor ϵ				BODY OR MEAN RADIANT TEMPERATURE F DEG	Radiation in Btu per (square foot) (hour) emitted to surroundings with a temperature of absolute zero by bodies at various temperatures and with emissivity factor ϵ			
	ϵ 1.00	ϵ 0.95	ϵ 0.90	ϵ 0.80		ϵ 1.00	ϵ 0.95	ϵ 0.90	ϵ 0.80
30	99.7	94.7	89.8	79.7	71	137.0	130.1	123.3	109.7
35	103.9	98.7	93.6	83.1	72	137.9	131.0	124.0	110.3
40	108.0	102.8	97.2	86.4	73	138.9	132.0	124.9	111.0
45	112.5	106.9	101.3	89.0	74	140.2	133.1	126.1	112.1
46	113.3	107.7	102.0	90.8	75	141.6	134.4	127.4	113.2
47	114.3	108.6	102.9	91.5	80	147.2	140.0	132.5	117.9
48	115.2	109.5	103.8	92.3	85	152.9	145.2	137.6	122.4
49	116.0	110.3	104.5	92.8	90	158.5	150.5	142.7	126.9
50	116.9	111.0	105.3	93.6	100	170.3	161.7	153.2	136.2
51	117.9	112.0	106.4	94.4	110	182.3	173.2	164.2	146.0
52	118.8	112.9	106.9	95.1	120	195.6	185.7	176.1	156.5
53	119.8	113.8	107.8	95.9	130	210.9	200.4	189.8	168.8
54	120.6	114.6	108.6	96.6	140	224.1	212.9	201.8	179.2
55	121.7	115.5	109.4	97.3	150	238.0	226.1	214.4	190.5
56	122.6	116.4	110.3	98.1	160	252.1	239.8	226.9	201.8
57	123.5	117.4	111.3	98.9	170	271.6	258.0	244.5	217.2
58	124.4	118.2	112.0	99.6	180	289.1	274.9	260.1	231.3
59	125.3	119.0	112.8	100.3	190	307.7	292.1	276.9	246.1
60	126.3	119.9	113.8	101.1	200	326.5	310.2	293.9	261.3
61	127.1	120.7	114.4	101.8	210	349.3	331.9	314.3	279.5
62	128.2	121.8	115.3	102.6	220	373.0	354.4	335.7	298.2
63	129.1	122.6	116.2	103.3	250	439.5	417.6	395.6	351.6
64	130.1	123.5	117.1	104.1	300	577.3	548.2	519.6	461.8
65	131.0	124.4	117.9	104.8	350	743.0	705.8	668.6	594.3
66	132.1	125.5	118.8	105.8	400	945.8	898.5	850.8	756.5
67	133.0	126.4	119.7	106.4	450	1181.0	1121.0	1063.0	944.0
68	134.0	127.3	120.5	107.2	500	1470.0	1396.0	1323.0	1176.0
69	135.0	128.3	121.5	108.0	550	1798.0	1708.0	1619.0	1439.0
70	136.0	129.3	122.3	108.8	600	2181.0	2072.0	1962.0	1745.0

* These factors are calculated from the formula where

$$q_r = \epsilon \left(\frac{0.173 \times T^4}{100,000,000} \right)$$

q_r = total radiation, Btu per (sq ft) (hr)

ϵ = emissivity.

T = absolute temperature, Fahrenheit degrees.

pipe wall by thermal conduction, and thence by convection and radiation into main cold water streams. (Radiation is not significant on the water side as liquids are sensibly opaque to radiation, although water transmits energy in the visible region). The contact resistance between the insulation and the pipe wall is presumed to be equal to zero.

Referring to Fig. 4, the heat transferred for a given length N of pipe, q_{re} , Btu per hour, may be thought of as flowing through the parallel resistances R_r and R_c , associated with the insulation surface radiation and convection transfer. Then the flow is through the resistance offered to thermal conduction by the insulation, R_s , through the pipe wall resistance, R_p , and into the water stream through the convection resistance, R_i .