

Table 4 Values of K , the Cosine of the Incident Angle, for Various Oriented Walls and a Horizontal Surface
Computed for 18 Deg Declination, North (August 1)

Latitude ↓	Sun Time AM →	K = Cosine of the Incident Angle θ						
		N	NE	E	SE	S	SW	Horiz.
30 Deg north	6 a.m. 6 p.m.	0.267	0.862	0.952	0.484			0.156
	7 5	0.144	0.752	0.919	0.548			0.367
	8 4	0.030	0.604	0.824	0.561			0.566
	9 3		0.427	0.672	0.524	0.068		0.737
	10 2		0.224	0.476	0.438	0.144		0.866
	11 1		0.039	0.246	0.310	0.192		0.951
40 Deg north	5 a.m. 7 p.m.	0.406	0.934	0.914	0.358			0.009
	6 6	0.237	0.840	0.951	0.505			0.199
	7 5	0.079	0.705	0.919	0.594			0.391
	8 4		0.533	0.824	0.631	0.069		0.566
	9 3		0.337	0.673	0.614	0.196		0.713
	10 2		0.129	0.475	0.542	0.292		0.829
50 Deg north	5 a.m. 7 p.m.	0.385	0.922	0.920	0.373			0.078
	6 6	0.199	0.813	0.951	0.532			0.233
	7 5	0.010	0.656	0.918	0.643			0.399
	8 4		0.465	0.824	0.700	0.166		0.545
	9 3		0.252	0.673	0.699	0.316		0.689
	10 2		0.030	0.475	0.642	0.433		0.766
60 Deg north	5 a.m. 7 p.m.	0.385	0.922	0.920	0.373			0.078
	6 6	0.199	0.813	0.951	0.532			0.233
	7 5	0.010	0.656	0.918	0.643			0.399
	8 4		0.465	0.824	0.700	0.166		0.545
	9 3		0.252	0.673	0.699	0.316		0.689
	10 2		0.030	0.475	0.642	0.433		0.766
70 Deg north	5 a.m. 7 p.m.	0.385	0.922	0.920	0.373			0.078
	6 6	0.199	0.813	0.951	0.532			0.233
	7 5	0.010	0.656	0.918	0.643			0.399
	8 4		0.465	0.824	0.700	0.166		0.545
	9 3		0.252	0.673	0.699	0.316		0.689
	10 2		0.030	0.475	0.642	0.433		0.766
80 Deg north	5 a.m. 7 p.m.	0.385	0.922	0.920	0.373			0.078
	6 6	0.199	0.813	0.951	0.532			0.233
	7 5	0.010	0.656	0.918	0.643			0.399
	8 4		0.465	0.824	0.700	0.166		0.545
	9 3		0.252	0.673	0.699	0.316		0.689
	10 2		0.030	0.475	0.642	0.433		0.766
90 Deg north	5 a.m. 7 p.m.	0.385	0.922	0.920	0.373			0.078
	6 6	0.199	0.813	0.951	0.532			0.233
	7 5	0.010	0.656	0.918	0.643			0.399
	8 4		0.465	0.824	0.700	0.166		0.545
	9 3		0.252	0.673	0.699	0.316		0.689
	10 2		0.030	0.475	0.642	0.433		0.766
Horizontal	5 a.m. 7 p.m.	0.385	0.922	0.920	0.373			0.078
	6 6	0.199	0.813	0.951	0.532			0.233
	7 5	0.010	0.656	0.918	0.643			0.399
	8 4		0.465	0.824	0.700	0.166		0.545
	9 3		0.252	0.673	0.699	0.316		0.689
	10 2		0.030	0.475	0.642	0.433		0.766

$$I_D = K \times I_{Dn} = 0.557 \times 273 = 152.0 \text{ Btu per (hr) (sq ft).}$$

By linear interpolation, the diffuse irradiation is:

$$I_d = 25 + 18/90 (33 - 25) = 26.6 \text{ Btu per (hr) (sq ft).}$$

The total solar irradiation is:

$$I_t = 152.0 + 26.6 = 178.6 \text{ Btu per (hr) (sq ft).}$$

PERIODIC HEAT FLOW THROUGH WALLS AND ROOFS

The calculation of heat flow through a structural section of a building exposed to the weather requires consideration of the diurnal cycles of solar irradiation and air temperature.

Various analytical techniques have been employed for combining the effects of the heat capacity of the structural section of the building and the variation in outdoor weather. One of the most promising analytical techniques is that employed by Buchberg.¹²⁻¹⁴ This method employs the transfer function concept for the building wall or roof. If the frequency response for various wall and roof configurations is determined, the data can be used with the Fourier series of outdoor weather to predict the periodic variation of heat flow to the interior of the space. Usually, the fundamental and three or less harmonics are sufficient to represent the combination of outdoor temperature and solar irradiation or sol-air temperature.

The Sol-Air Temperature

The complex interrelationship of the above factors can be considerably simplified through the use of the sol-air temperature concept. The sol-air temperature t_a is the temperature of the outdoor air, which, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of incident

solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air, or $t_a = t_o + (aI)/h_a$.

The sol-air temperature data^{15,16} as developed by Mackey and Wright for an industrial atmosphere were used as a basis for preparing Table 7 which shows summer design sol-air temperatures. Sol-air temperatures may also be estimated from experimental observation of surface temperatures of walls and roofs which appear in the literature.^{17,18} Both analytical and experimental studies have been made on the problem.¹⁹ of heat flow through walls and roofs. Those concerned with a further study of the details of cooling load estimates in particular relation to periodic heat flow will find much of value and interest in the reports of experimental studies of these problems.^{1-15,20-24}

PRACTICAL TABLES FOR CALCULATING SOLAR HEAT GAIN THROUGH WALLS AND ROOFS

The analytical¹² method reported by Mackey and Wright was used by Stewart¹⁶ to obtain temperature differentials based on Table 7 and shown in Tables 8 and 9. These analytical procedures, as well as those using Tables 8 and 9, presented here, yield generally higher rates of heat gain than those reported for Pittsburgh in early ASHRAE experimental studies. Current authoritative opinion indicates a preference for analytical calculations. Thermal and physical properties of materials used in these tables are given in a paper.²⁵ The rate of heat flow is obtained by multiplying the overall heat transmission coefficient of the structure by the equivalent temperature differential obtained from the tables.

Tables 8 and 9 were developed by using an outside surface conductance of 4.0 and an inside film conductance of 1.65

Air-Conditioning Cooling Load

Table 5 Values of the Wall Solar Azimuth, γ , for Various Oriented Walls and Solar Altitude
Computed for 18 Deg Declination, North (August 1)

Latitude ↓	Sun Time AM →	Solar Altitude β Degrees	Azimuth Angle γ, Degrees					
			N	NE	E	SE	S	SW
30 Deg north	6 a.m. 6 p.m.	9.0	74	29	16	61		
	7 5	21.5	81	26	9	54		
	8 4	34.5	88	43	2	47	Shade	
	9 3	47.5	Shade	51	6	39	84	
	10 2	60.0		62	17	28	73	
	11 1	72.0		83	38	7	52	Shade
40 Deg north	5 a.m. 7 p.m.	11.5	66	21	24	69		
	6 6	23.0	78	31	14	59		
	7 5	34.5	85	40	5	50	Shade	
	8 4	45.5	Shade	50	5	40	85	
	9 3	56.0		61	16	29	74	
	10 2	64.5		78	31	14	59	Shade
50 Deg north	5 a.m. 7 p.m.	13.5	67	22	23	68		
	6 6	25.0	78	32	12	57		
	7 5	33.0	85	45	0	45	90	
	8 4	42.0	Shade	57	12	33	78	
	9 3	50.0		70	25	20	65	
	10 2	56.0		87	42	3	48	Shade
60 Deg north	5 a.m. 7 p.m.	15.0	68	23	22	67		
	6 6	26.5	79	33	11	56		
	7 5	35.0	86	46	0	44	90	
	8 4	43.0	Shade	58	13	32	79	
	9 3	51.0		71	26	19	68	
	10 2	58.0		89	45	0	57	Shade
70 Deg north	5 a.m. 7 p.m.	16.5	69	24	21	66		
	6 6	28.0	80	34	10	55		
	7 5	36.5	87	47	0	43	90	
	8 4	44.5	Shade	59	14	30	79	
	9 3	52.5		72	27	18	68	
	10 2	59.5		90	46	0	57	Shade
80 Deg north	5 a.m. 7 p.m.	18.0	70	25	20	65		
	6 6	29.5	81	35	9	54		
	7 5	38.0	88	48	0	42	90	
	8 4	46.0	Shade	60	15	29	79	
	9 3	54.0		73	28	17	68	
	10 2	61.0		91	47	0	57	Shade
90 Deg north	5 a.m. 7 p.m.	19.5	71	26	19	64		
	6 6	31.0	82	36	8	53		
	7 5	39.5	89	49	0	41	90	
	8 4	47.5	Shade	61	16	28	79	
	9 3	55.5		74	29	16	68	
	10 2	62.5		92	48	0	57	Shade

Btu (hr) (sq ft) (°F deg). A reduction was made in the temperature differentials for roofs amounting to some 20 percent of solar radiation as explained by Stewart.¹⁶ This was to compensate for several factors, one of which is the radiant heat lost to the sky which is not included in the Mackey and Wright method. Experimental work by Parmelee²⁶ and previous work by Brunt²⁷ give data showing the magnitude of this radiant heat loss from a roof or wall to the sky. Temperature differentials for roofs probably would be reduced below those shown in Table 8 whenever the radiant heat lost to the sky is included in calculation of sol-air temperature. The temperature differentials for roofs were based on an inside surface conductance of 1.65 because the charts prepared by Mackey and Wright¹⁶ used this value, and it was not practicable to repeat their work using a different film coefficient. An examination of the values given in their paper indicates that the temperature differential would be changed very little even if a value 1.20 were used instead of 1.65. To obtain the heat-flow rates through roofs, more accurate

values will be obtained if the overall heat transmission coefficient is calculated by using 1.2 as the inside film conductance for summer.

The roof coefficients of transmission for summer shown in Table 10 are based on surface conductances f_{ro} of 4.0 for an outside roof surface and 1.08 for an inside ceiling surface.

Since there is little difference in wall transmission coefficients for summer (based on the conductances of 4.0 and 1.63) and the winter coefficients (based on 6.0 and 1.63) it is recommended that the overall coefficient U , for walls, be taken directly from the tables in Chapter 24 in which they are based on an outside film conductance of 6.0, corresponding to a 15 mph wind velocity.

Advantages of Equivalent Temperature Differential Method

The advantages of the equivalent temperature differential method of determining the total heat transmission are given in following paragraphs, and are apparent from Examples 6 to 7.

1. The total sensible heat flow is obtained by multiplying the overall heat transmission coefficient U , and the equivalent temperature differential indicated in Tables 8 and 9.

2. The temperature differentials listed for a few representative types of construction may be used on all classes of walls and roofs, even though the overall heat transmission coefficient is different, provided the structure has thermal and physical properties similar to one of those listed in Tables 8 and 9.

3. Adjustments can be made, according to instructions given in the footnotes, for room and outdoor conditions different from those on which the tables are based.

Table 6 Approximate Solar Declinations in Degrees

Date	Declination	Date	Declination
April 1	4.5	July 1	23.0
April 15	10.0	July 15	21.5
May 1	15.0	Aug. 1	18.0
May 15	19.0	Aug. 15	14.0
June 1	22.0	Sept. 1	8.5
June 15	23.5	Sept. 15	3.0