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RECOMMENDATIONS FOR CALCULATION OF SOLAR RADIATION ON BUILDINGS

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Functional Requirements in Buildings Sectional Committee, BDC 12

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RECOMMENDATIONS FOR CALCULATION OF SOLAR RADIATION ON BUILDINGS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 26 December 1986, after the draft finalized by the Functional Requirements in Buildings Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 For the functional design of buildings, a proper evaluation of the quantum of solar radiation incident on various building facades is a necessary pre-requisite. The choice of orientation, provision of glass areas and types of glass greatly depend on the quantity of solar radiation incident on building surfaces. Measured data, however, are available only for a very few localities. Moreover, measurements are made only for the horizontal surfaces and further, solar radiation shows wide variability from day to day and hour to hour. For these reasons, the practical assessment of solar radiation on various surfaces of buildings are made only by theoretical computations. In design problems like assessment of cooling capacity of air-conditioning plants where quantitative values of solar radiation are required, it is important that the plant should be able to cope with the cooling load even in the hottest climatic conditions. For these calculations, the solar radiation quantity incident on various surfaces of buildings at different stations in the country should not be exceeded for most, say 95 percent of the time. Such values of solar radiation are termed 'design values'. In this standard comprehensive design solar radiation tables both for summer and winter have been recommended for the whole country which are based on the information provided by Central Building Research Institute (CBRI), Roorkee. It may be noted that the solar radiation design values as given in this standard are not the average values at the various latitudes, but pertain to very clear sky conditions and are close to the maximum available solar radiation quantities in the country. The basic principle for the approach is that the design solar radiation depends not on the variability of any single parameter but on an integration of all relevant parameters varying both in time and magnitude and in respect of astronomical, geographical and meteorological considerations.

0.3 The solar radiation incident upon a surface normal to the sun rays at the mean earth-sun distance, outside the earth's atmosphere is called the 'solar constant' and its presently accepted value is 1396 W/m^2. As the solar radiation passes through the earth's atmosphere, part of it is scattered by the constituents of the atmosphere and part absorbed particularly by ozone, carbon dioxide and water vapour. The remaining portion of the radiation reaches the earth's surface as direct component. Part of the scattered, absorbed and reradiated radiation reach the earth's surface as diffused radiation from the sky. A strong component of the diffused radiation, called circumsolar radiation comes from relatively bright part of sky lying within about 30° around the sun and for the sake of simplification, may be assumed to be concentrated in the sun's disc only. The sum of the direct and circumsolar components is called 'the augmented direct component' or merely the direct component and the remaining diffused radiation, is called uniform background diffused sky radiation, or merely uniform diffused radiation. The values of direct and diffused components at the earth's surface depend on the length of their passage through the earth's atmosphere and hence on the altitude of the sun.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2 - 1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard gives recommendations for solar radiation design values for calculation of solar radiation in buildings for clear sky conditions.

2. GENERAL PRINCIPLE OF DESIGN

2.1 Need for Design Data — Long term measurements of solar radiation on vertical and horizontal surfaces of a building have revealed that the hitherto accepted practice of assuming a standard atmosphere comprised of 300 dust particles/cubic centimetre, 2·5 mm of ozone and 15 mm of precipitable water vapour, yielded estimates of solar radiation which are at least 20 percent higher than their representative values in this country.

2.2 Components of Solar Radiation — The total solar radiation on a surface under clear sky conditions shall comprise of the following components

*Rules for rounding off numerical values (*revised*) and an example for determination of total design solar radiation is given in Appendix A.

a) Direct radiation, I_D;

b) Uniform diffuse sky radiation, I_d; and

c) Ground reflected radiation on surfaces other than the horizontal, I_{GR}.

2.2.1 *Direct Radiation* (I_D) — The direct solar radiation on any plane surface shall be obtained as the multiplication of the direct radiation at normal incidence (I_N) and the cosine of the angle of incidence (i) of the sun's rays on that surface as shown below:

a) For horizontal surfaces $\text{Cos } i = \text{Sin } \theta$

Where θ is the altitude of the sun

Hence direct horizontal solar radiation $I_{DH} = I_N . \text{Sin } \theta$

b) For vertical surfaces, $\text{Cos } i = \text{Cos } \theta . \text{Cos } \beta$ and direct vertical solar radiation $I_{DV} = I_N . \text{Cos } \theta . \text{Cos } \beta$

where β = Angle between the direction of the sun and wall in the horizontal plane.

2.2.1.1 The direct component of solar radiation shall be computed based on the design values of the augmented direct radiation at normal incidence for clear sky conditions as given in Table 1.

2.2.2 *Diffused Radiation from the Sky* — The diffused radiation on any surface shall be computed from the known values of I_{dH}, the uniform background diffused radiation on the horizontal surface, which are also given in Table 1 for various solar altitude angles. For vertical surfaces, the uniform diffused radiation is half of that on a horizontal surface, i.e. $I_{dV} = \frac{1}{2} I_{dH}$.

2.2.3 *Ground Reflected Radiation* — The ground reflected radiation on a vertical surface shall be obtained as given below:

$$I_{GRV} = \frac{1}{2} r_g \times I_{TH}$$

where I_{TH} = total solar radiation on a horizontal surface

$= I_{DH} + I_{dH}$, and

r_g = reflectivity of the ground.

2.2.3.1 Values of the reflectivity of the ground for solar radiation for some common types of ground surfaces shall be as given in Table 2.

TABLE 1 DIRECT SOLAR RADIATION AT NORMAL INCIDENCE AND DIFFUSED RADIATION ON THE HORIZONTAL SURFACE FOR CLEAR SKY CONDITIONS

(*Clause* 2.2.1.1)

Altitude (Degrees) θ	Direct at Normal Incidence (I_N) W/m²	Diffused Sky Radiation on the Horizontal Surface (I_{dH}) W/m²
5	158	112
10	394	128
15	534	138
20	621	147
25	678	152
30	720	158
35	750	163
40	772	166
45	790	170
50	804	172
55	815	174
60	823	177
65	830	178
70	836	179
75	837	180
80	842	181
85	843	181
90	844	181

NOTE — For other solar altitude, the values may be interpolated.

TABLE 2 REFLECTIVITY OF SOME COMMON GROUND SURFACES FOR SOLAR RADIATION

(*Clause* 2.2.3.1)

Sl No.	Type of Surface	Reflectivity (r_g)
1.	Bituminous and gravel	0·14
2.	Brown grass, crushed rock or bare ground	0·20
3.	Old concrete	0·23
4.	Bright green grass	0·25
5.	Red brick tile	0·27
6.	New concrete	0·32

NOTE — For general applications, the ground reflectivity shall be taken as 0·20.

3. CALCULATION OF DESIGN SOLAR RADIATION ON BUILDINGS

3.1 To determine the quantity of solar radiation on any individual surface on the building as a whole, the design values as given in Tables 3 and 4 shall be followed. The values (based on Table 1) are applicable for both summer as well as winter (Direct + Diffuse) and for horizontal and vertical (in eight cardinal orientation) surfaces for all latitudes from 9°N upwards at intervals of 4°. An example for calculation of design solar radiation on buildings is given at Appendix B.

NOTE 1 — For summer, the design values are obtained at each latitude up to 21°N when the noon sun is at the zenith and at latitude 25°N and 29°N, these are for June 22 (Summer solstice) when the noon sun is at the highest altitude. These days have been selected because the solar radiation is very close to its maximum value during summer months at the respective latitudes.

NOTE 2 — The design solar radiation value for winter have been computed for December 22 (Winter solstice) when the noon sun is at the lowest altitute at each latitude. Solar radiation values based on these figures are not expected to exceed on more than a few occasions. The ground reflected component for vertical surfaces has not been included in these computations and this may be easily determined on the basis of the actual reflectivity of the ground at the site.

4. CALCULATION OF DESIGN SOLAR RADIATION ON SLOPING SURFACES OF BUILDINGS

4.1 The quantum of solar radiation on sloping roofs of buildings, shall be calculated as follows:

a) Direct solar radiation on a sloping surface

$$I_{DS} = I_N (\text{Cos}\,\theta\ \text{Cos}\,\beta\ \text{Cos}\,\phi + \text{Sin}\,\theta\ \text{Sin}\,\phi)$$

where ϕ is the angle of inclination of the surface with the vertical (for horizontal surfaces $\phi = 90°$ and for vertical surfaces $\phi = 0$), and

I_N = Solar radiation at normal incidence on the earth's surface (refer Table 1)

b) Diffuse radiation on a sloping surface

$$I_{ds} = I_{dH} \frac{(1 + \sin\phi)}{2}$$

c) Ground reflected radiation on a sloping surface

$$I_{GRS} = r_g \times I_{TH} \times \frac{(1 - \sin\phi)}{2}$$

4.2 A typical example for calculation of solar radiation of sloping surfaces of buildings is given at Appendix C.

TABLE 3 DESIGN (TOTAL) SOLAR RADIATION (DIRECT + DIFFUSE) ON HORIZONTAL AND VERTICAL SURFACES (W/m²)

(*Clause* 3.1)

SUMMER

TABLE 3 (A) LATITUDE 9° N

HRS	H	N	NE	E	SE	S	SW	W	NW
6	93	48	55	56	52	47	47	47	47
7	293	144	495	598	391	70	70	70	70
8	533	144	563	698	471	79	79	79	79
9	741	133	507	634	440	85	85	85	85
10	890	116	399	499	358	88	88	88	88
11	991	109	257	306	230	90	90	90	90
12	1 025	106	101	91	91	91	91	91	101
13	991	109	90	90	90	90	230	306	257
14	890	116	88	88	88	88	358	499	399
15	741	133	85	85	85	85	440	634	507
16	533	144	79	79	79	79	471	698	563
17	293	144	70	70	70	70	391	598	495
18	93	48	47	47	47	47	52	56	55

TABLE 3 (B) LATITUDE 13° N

HRS	H	N	NE	E	SE	S	SW	W	NW
6	93	48	55	56	52	47	47	47	47
7	309	137	502	615	408	71	71	71	71
8	533	123	549	700	487	79	79	79	79
9	741	94	481	636	468	85	85	85	85
10	890	88	364	499	394	109	88	88	88
11	991	90	215	304	269	128	90	90	90
12	1025	91	91	91	122	135	122	91	91
13	991	90	90	90	90	128	269	304	215
14	890	88	88	88	88	109	394	499	364
15	741	94	85	85	85	97	468	636	481
16	533	123	79	79	79	79	487	700	549
17	309	137	71	71	71	71	408	615	502
18	93	48	47	47	47	47	52	56	55

(*Continued*)

TABLE 3 DESIGN (TOTAL) SOLAR RADIATION (DIRECT+DIFFUSE) ON HORIZONTAL AND VERTICAL SURFACES (W/m²) — *Contd*

SUMMER

TABLE 3 (C) LATITUDE 17° N

HRS	H	N	NE	E	SE	S	SW	W	NW
6	126	105	195	205	127	56	56	56	56
7	342	221	569	626	358	72	72	72	72
8	563	209	600	686	418	80	80	80	80
9	752	179	528	620	397	85	85	85	85
10	898	151	412	484	323	88	88	88	88
11	996	126	256	291	207	91	91	91	91
12	1 025	120	112	91	91	91	91	91	112
13	996	126	91	91	91	91	207	291	256
14	898	151	88	88	88	88	323	484	412
15	752	179	85	85	85	85	397	620	528
16	563	209	80	80	80	80	418	686	600
17	342	221	72	72	72	72	358	626	569
18	126	105	56	56	56	56	127	205	195

TABLE 3 (D) LATITUDE 21° N

HRS	H	N	NE	E	SE	S	SW	W	NW
6	151	141	295	312	179	59	59	59	59
7	358	205	568	640	383	73	73	73	73
8	578	177	580	690	443	80	80	80	80
9	764	133	494	618	429	87	86	86	86
10	907	95	368	477	358	88	88	88	88
11	996	91	219	292	249	112	91	91	91
12	1025	91	91	91	112	120	112	91	91
13	996	91	91	91	91	112	248	292	219
14	907	95	88	88	88	88	358	477	368
15	764	133	86	86	86	86	429	618	494
16	578	177	80	80	80	80	443	690	580
17	358	205	73	73	73	73	383	741	568
18	151	141	59	59	59	59	179	312	295

(*Continued*)

TABLE 3 DESIGN (TOTAL) SOLAR RADIATION (DIRECT + DIFFUSE) ON HORIZONTAL AND VERTICAL SURFACES (W/m²) — *Contd*

SUMMER

TABLE 3 (E) LATITUDE 25° N

HRS	H	N	NE	E	SE	S	SW	W	NW
6	195	204	419	426	222	64	64	64	64
7	407	242	605	657	369	76	76	76	76
8	607	209	594	679	414	81	81	81	81
9	776	159	505	607	402	86	86	86	86
10	915	109	368	464	340	88	88	88	88
11	996	91	226	293	241	101	91	91	91
12	1025	91	91	91	112	120	112	91	91
13	996	91	91	91	91	101	241	293	226
14	915	109	88	88	88	88	340	464	368
15	776	159	86	86	86	86	402	607	505
16	607	209	81	81	81	81	414	679	594
17	407	242	76	76	76	76	369	657	605
18	195	204	64	64	64	64	222	426	419

TABLE 3 (F) LATITUDE 29° N

HRS	H	N	NE	E	SE	S	SW	W	NW
6	212	216	449	458	236	65	65	65	65
7	423	234	605	665	381	76	76	76	76
8	606	177	575	685	441	81	81	81	81
9	663	113	236	653	379	83	83	83	83
10	914	88	330	463	376	121	88	88	88
11	999	90	185	295	285	160	90	90	90
12	1 020	91	91	91	154	178	154	91	91
13	999	90	90	90	90	160	285	295	185
14	914	88	88	88	88	121	376	463	330
15	663	113	83	83	83	83	379	654	236
16	606	177	81	81	81	81	441	685	575
17	423	234	76	76	76	76	381	665	605
18	212	216	65	65	65	65	236	458	449

TABLE 4 DESIGN (TOTAL) SOLAR RADIATION (DIRECT + DIFFUSE) ON HORIZONTAL AND VERTICAL SURFACES (W/m²)

(*Clause* 3.1)

WINTER

TABLE 4 (A) LATITUDE 9° N

HRS	H	N	NE	E	SE	S	SW	W	NW
7	197	64	191	413	431	234	64	64	64
8	407	76	231	599	659	378	76	76	76
9	592	81	166	572	690	451	81	81	81
10	741	85	85	455	635	494	114	85	85
11	832	87	87	281	533	523	258	87	87
12	871	87	87	87	395	523	395	87	87
13	832	87	87	87	258	523	533	281	87
14	741	85	85	85	114	494	635	455	85
15	592	81	81	81	81	442	690	572	166
16	407	76	76	76	76	378	659	599	231
17	197	64	64	64	64	234	431	413	191

TABLE 4 (B) LATITUDE 13° N

HRS	H	N	NE	E	SE	S	SW	W	NW
7	166	62	163	341	355	198	62	62	62
8	374	74	207	576	651	387	74	74	74
9	563	80	145	562	697	470	80	80	80
10	702	84	84	444	654	529	144	84	84
11	799	86	86	277	554	557	285	86	86
12	832	87	87	87	424	565	424	87	87
13	799	86	86	86	285	557	554	277	86
14	702	84	84	84	144	529	654	444	84
15	563	80	80	80	80	470	697	562	145
16	374	74	74	74	74	387	651	576	207
17	166	62	62	62	62	198	355	341	163

(*Continued*)

TABLE 4 DESIGN (TOTAL) SOLAR RADIATION (DIRECT + DIFFUSE) ON HORIZONTAL AND VERTICAL SURFACES (W/m²) — *Contd*

WINTER

TABE 4 (C) LATITUDE 17° N

HRS	H	N	NE	E	SE	S	SW	W	NW
7	138	58	123	248	261	155	58	58	58
8	342	72	192	553	633	385	72	72	72
9	518	79	122	549	700	487	79	79	79
10	663	83	83	440	669	556	165	83	83
11	752	85	85	271	577	595	315	85	85
12	789	86	86	86	451	602	451	86	86
13	752	85	85	85	315	595	577	271	85
14	663	83	83	83	165	556	669	440	83
15	518	79	79	79	79	487	700	549	122
16	342	72	72	72	79	385	633	553	192
17	138	58	58	58	58	155	261	248	123

TABLE 4 (D) LATITUDE 21° N

HRS	H	N	NE	E	SE	S	SW	W	NW
7	126	56	105	195	206	127	56	56	56
8	309	71	176	526	609	379	71	71	71
9	487	78	100	532	700	502	78	78	78
10	621	81	81	429	679	578	187	81	81
11	702	84	84	271	599	626	335	84	84
12	741	85	85	85	475	635	475	85	85
13	702	84	84	84	335	626	599	271	84
14	621	81	81	81	187	578	679	429	81
15	487	78	78	78	78	502	700	532	100
16	309	71	71	71	71	379	609	526	176
17	126	56	56	56	56	127	206	195	105

(*Continued*)

TABLE 4 DESIGN (TOTAL) SOLAR RADIATION (DIRECT + DIFFUSE) ON HORIZONTAL AND VERTICAL SURFACES (W/m²) — *Contd*

WINTER

TABLE 4 (E) LATITUDE 25° N

HRS	H	N	NE	E	SE	S	SW	W	NW
7	104	50	64	92	94	71	50	50	50
8	259	69	154	475	557	352	69	69	69
9	440	77	87	519	691	504	77	77	77
10	578	80	80	416	684	598	209	80	80
11	649	83	83	266	614	650	354	83	83
12	688	84	84	84	493	663	493	84	84
13	649	83	83	83	354	650	614	266	83
14	578	80	80	80	209	598	684	416	80
15	440	77	77	77	77	504	691	519	87
16	259	69	69	69	69	352	557	475	154
17	104	50	50	50	50	71	94	92	65

TABLE 4 (F) LATITUDE 29° N

HRS	H	N	NE	E	SE	S	SW	W	NW
7	80	41	41	41	41	41	41	41	41
8	228	66	136	429	509	329	66	66	66
9	391	74	74	491	673	506	85	74	74
10	518	79	79	409	686	607	219	79	79
11	606	81	81	261	621	665	369	81	81
12	635	83	83	83	508	685	508	83	83
13	606	81	81	81	369	665	621	261	81
14	518	79	79	79	219	607	686	409	79
15	391	74	74	74	85	505	673	491	74
16	228	66	66	66	66	329	509	429	136
17	80	41	41	41	41	41	41	41	41

APPENDIX A

(*Clause* 2.2)

EXAMPLE FOR THE DETERMINATION OF TOTAL DESIGN SOLAR RADIATION

A-1. ILLUSTRATIVE EXAMPLE

A-1.1 It is desired to determine the total design solar radiation (i) on the horizontal surface, and (ii) on the west facing wall at 4 p.m. at New Delhi (latitude 29° N). The sun is at an azimuth angle of 81° of north and its altitude is 36°.

A-2. CALCULATION

A-2.1 As a first step the value of I_N for solar altitute of 36° should be interpolated from its given values for altitude angles of 35° and 40° in Table 1.

I_N for solar altitude of 35° = 750 W/m²

and for 40° = 772 W/m²

By interpolation the value of I_N for 36° = 755 W/m²

(i) Direct solar radiation on the horizontal surface

$I_{DH} = I_N . \text{Sin } \theta = 755 \times \text{Sin } 36° = 444 \text{ W/m}^2$

$I_{dH} = 163 \text{ W/m}^2$ (from Table 1)

Hence $I_{TH} = I_{DH} + I_{dH} = 444 + 163 = 607 \text{ W/m}^2$

(ii) Similarly for the vertical surface facing west:

Direct solar radiation on the vertical surface

$I_{DV} = 755. \text{Cos. } 36°. \text{Cos } 9° = 603 \text{ W/m}^2$

Here, $\beta = 9°$. Since the direction of sun is the horizontal plane (i.e. solar azimuth is 81°W of north and that of the west facing wall is 90°W of north).

Since 90° — 81° = 9°

$I_{dV} = \frac{1}{2} I_{dH} = \frac{1}{2} \times 163 = 81{\cdot}5 \text{ W/m}^2$

The total radiation from sun and sky on the vertical surface,

I_{TV} is therefore $= 603 + 81{\cdot}5 = 684{\cdot}5$ W/m^2

Where

I_{TV} = Total solar radiation on a vertical surface.

A-2.2 The ground reflected component on the vertical surface, for a ground reflectivity of 0·2 may be calculated as follows:

Since $I_{TH} = 606$ W/m^2

$I_{GRV} = \frac{1}{2} \times 0{\cdot}2 \times 606 = 60{\cdot}6$ W/m^2

Hence the total of direct, diffused and ground reflected components on the west facing wall at 4 p.m. at New Delhi

$= 603 + 81{\cdot}5 + 60{\cdot}6 = 745{\cdot}1$ W/m^2

APPENDIX B

(*Clause* 3.1)

EXAMPLE FOR THE CALCULATION OF DESIGN SOLAR RADIATION ON BUILDINGS

B-1. ILLUSTRATIVE EXAMPLE

B-1.1 It is desired to determine the design solar radiation in summer from sun and sky on a building 10 metres long, 5 metres wide and 3 metres high, longer sides facing north and south, at 2 p.m. at New Delhi (latitude 29°N).

B-2. CALCULATION

B-2.1 Refer to Table 3 (F) for latitude 29°N (New Delhi). The required computations are as follows:

Sl No.	*Surface*	*Design Solar Radiation* W/m^2	*Area of Surface* m^2	*Total Radiation on the Surface* W
1.	Horizontal roof	914	50	45 700
2.	North wall	88	30	2 640
3.	South wall	121	30	3 630
4.	West wall	463	15	6 945
5.	East wall	88	15	1 320
	Total			60 235

Total solar radiation incident on the building = 60 235 W.

B-2.2 In the above example, if ground reflected radiation is also desired on the vertical surfaces, it may be readily calculated as follows:

Total solar radiation on the horizontal surface = 914 W/m²

Ground reflected component = $\frac{1}{2} \times 0{\cdot}2 \times 914 = 9{\cdot}14$ W/m²

Total area of the vertical walls = 90 m²

Contribution of ground reflected components on the walls

$= 90 \times 91{\cdot}4 = 8\ 226$ W

The sum of all solar radiation components

$= 60\ 235 + 8\ 226 = 68\ 461$ W

APPENDIX C

(*Clause* 4.2)

EXAMPLE FOR THE CALCULATION OF SOLAR RADIATION OF SLOPING SURFACES OF BUILDINGS

C-1. ILLUSTRATIVE EXAMPLE

C-1.1 It is desired to determine the solar radiation on an east facing sloping roof when the sun is at an azimuth angle of 120°E and altitude angle 40° and the slope of the roof with the vertical (ϕ) is 60°.

C-2. CALCULATION

C-2.1 It may be seen from Table 1 that for the altitude angle of 40°,

$I_N = 772$ W/m², and

$I_{dH} = 166$ W/m².

C-2.1.1 Since the azimuth angle for a east facing surface is 90°E and the given azimuth of sun is 120°E, the value of β (wall solar azimuth) = 120° — 90° = 30°

Direct solar radiation, I_{DS}

$= I_N$ (Cos θ. Cos β, Cos ϕ + sin θ sin ϕ)

$= 772\ (\text{Cos } 40° \times \text{Cos } 30° \times \text{Cos } 60° + \text{Sin } 40° \times \text{Sin } 60°)$

$= 686\ \text{W/m}^2$

$$I_{ds} = I_{dH} \frac{(1 + \text{Sin } \phi)}{2}$$

$$= 166 \times \frac{(1 + \text{Sin } 60°)}{2}$$

$$= 166 \times 0{\cdot}933$$

$$= 155\ \text{W/m}^2$$

C-2.3 For the ground reflected radiation, I_{GRS}, the total solar radiation on the horizontal surface, I_{TH} is required.

$$I_{DH} = I_N . \text{Sin } \theta = 772 \times \text{Sin } 40° = 496\ \text{W/m}^2$$

and $I_{TH} = 496 + 166 = 662\ \text{W/m}^2$

Hence $I_{GRS} = 0{\cdot}2 \times I_{TH} \times \dfrac{(1 - \text{Sin } 60°)}{2}$

$8{\cdot}87$, say $9\ \text{W/m}^2$

C-2.4 Hence sum of all the solar radiation components on the slopes surface

$= 686 + 155 + 9$

$= 850\ \text{W/m}^2$