Smart Grid and Renewable Energy, 2011, 2, 45-55
doi:10.4236/sgre.2011.21006 Published Online February 2011 (http://www.SciRP.org/journal/sgre)

Estimation of Hourly Solar Radiation on Horizontal and Inclined Surfaces in Western Himalayas

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Received November 25th, 2010; revised January 12th, 2011, accepted January 16th, 2011.

ABSTRACT

The hourly solar radiation data required for solar energy system design evaluation and performance studies is generally not available for a number of sites especially in remote locations. As such accurate determination of hourly solar radiation data, is important both at horizontal; *surfaces and inclined surfaces. A model to estimate global solar radiation using temperature and sunshine hour data has been developed* (*Chandel et al.* [1]) *which is used to calculate the hourly solar radiation Data. The hourly solar radiation has also been calculated using Gueymard* [2] *daily integration approach from the measured daily solar radiation data. These two predicted hourly solar radiation data values are compared with measured hourly values to test the accuracy of the models. The total solar radiation on the inclined surfaces and vertical surfaces for different orientations, have also been estimated. The estimated values are found to be in close agreement with measured values. The method presented can be used to estimate hourly, global, diffuse solar radiation for horizontal surfaces and total solar radiation on inclined and vertical surfaces at different orientations with greater accuracy for any location.*

***Keywords*:** *Solar Energy, Hourly Solar Radiation, Diffuse Solar Radiation*

1. Introduction

The measured hourly values of solar radiation data are not available for large number of stations. Thus, accurate estimation of hourly values of global and diffused solar radiation data is essential for the design and performance evaluation of solar energy systems. The hourly solar radiation can be estimated using Gueymard [2] daily integration approach. It requires measured value of daily solar radiation, which is not available for most of the locations. This can be estimated by using sunshine hour data or temperature data. A model has been developed based on latitude and altitude of a location to estimate monthly average global solar radiation using sunshine hour and temperature data (Chandel *et al*. [1]). The values of solar radiation obtained using this model are used to estimate hourly solar radiation following Gueymard [2] daily integration approach. In order to verify the accuracy of the results obtained, the hourly solar radiation is also estimated from the measured daily solar radiation data for Delhi.

This method is first used to predict hourly global solar radiation for Delhi [Latitude 28.58˚N, Longitude 77.2˚E, altitude 216 m (amsl)] for which 10-15 years measured data are available. Establishing the accuracy, the model is then used to calculate the values for location like Shimla [Latitude (31.1˚N), Longitude (77.1˚E) and altitude of 2002 m (amsl)] for which the measured data are not available.

The hourly diffuse solar radiation for Delhi has also been calculated using correlation given by Orgill and Hollands [3] with modified value of regression coefficient 'c' in Section III. The total hourly value of solar radiation on inclined south surfaces and vertical surfaces at different orientations has been estimated for Delhi in Section IV. The relation given by Klein [4] does not predict accurate results on north orientation, which is modified particularly for the months with negative declination.

2. Hourly Global Solar Radiation

The daily average extra terrestrial irradiation on a hori-

zontal surface Go is given as

$$G_o = k\omega_s R G_{sc} \sinh_o \quad (1)$$

where $k = 24/\pi$,

$$\cos\omega_s = -\tan\phi\tan\delta \quad (2)$$

ϕ is negative for Southern hemisphere, h_o is given as

$$\sin h_o = qA(\omega_s)/\omega_s \quad (3)$$

with

$$q = \cos\phi\cos\delta \quad (4)$$

and

$$A(\omega_s) = \sin\omega_s - \omega_s\cos\omega_s \quad (5)$$

where

$$So = k\omega_s \quad (6)$$

$$\sin h = q(\cos\omega - \cos\omega_s) \quad (7)$$

where ω is +ve for morning and –ve for evening .The extra terrestrial radiation hourly/daily ratio is given as [Whillier [5], Liu and Jordan [6]]

$$r_o = (\cos\omega - \cos\omega_s)/kA(\omega_s) \quad (8)$$

Following Gueymard [2] the daily irradiation G is given by

$$G = kqRG_{sc}\left[a_1 A(\omega_s) + qa_2 B(\omega_s)\right] \quad (9)$$

where

$$B(\omega_s) = \omega_s\left(0.5 + \cos^2\omega_s\right) - 0.75\sin 2\omega_s \quad (10)$$

The hourly/daily ratio $r_t = G_h/G$ is obtained by

$$r_t = r_o\left[1 + q(a_2/a_1)kA(\omega_s)r_o\right]/\left[1 + q(a_2/a_1)B(\omega_s)/A(\omega_s)\right] \quad (11)$$

where

$$a_1 = 0.41341K_t + 0.61197K_t^2 - 0.01886K_tS_o + 0.00759S_o \quad (12)$$

$$a_2 = \mathrm{Max}\left(0.054, 0.28116 + 2.2475K_t - 1.76118K_t^2 - 1.84535\sin h_o + 1.6811\sin^3 h_o\right) \quad (13)$$

are dependent on both K_t and ω_s. Here K_t is the ratio of irradiation measured at the earth surface to that calculated at the top of the atmosphere. In present calculation a_2 is calculated using 0.28116 in Equation (13), which gives maximum value of a_2 in comparison to 0.054. In present study the values of K_t has been used suggested by Gueymard [2] *i.e.* 0.610.

The mean hourly global solar radiation for Delhi [**Table 1**] has been calculated using Equations (9) and (11) with measured values of daily solar radiation, which reveals that the estimated values are close to the measured values for the period 1967-1978 [Mani [7]]. The mean hourly global solar radiation for Delhi [**Table 2**] has also been calculated using Equations (9) and (11) with estimated values of daily solar radiation using Chandel *et al.* [1] model, which reveals that the estimated values are close to the measured values except for the month of July and August. The percentage variation in the estimation of hourly values of solar radiation using measured daily values and predicted values by Chandel *et al.* [1] with measured values of hourly values of solar radiation has been presented in **Table 3**. This table reveals that predicted values by can be used for the estimation of hourly values of solar radiation except for the months of July and August where the percentage error is high. The model is used to calculate the hourly values for Shimla, which are presented in **Table 4**.

3. Hourly Diffuse Solar Radiation

The estimation of hourly diffuse solar radiation is essential to calculate the direct radiation from the total solar radiation. A number of methods have been used to determine the hourly diffuse solar radiation. Liu and Jordan [6] developed a method to calculate mean hourly diffuse radiation from mean daily totals, which gives results with reasonably accuracy. Orgill and Hollands [3] have used the data from Canadian stations to correlate the diffuse hourly Solar radiation D_h and total solar radiation G_h with the hourly clearness index, k_T [ratio of the hourly global radiation to the hourly extra terrestrial radiation]. Following this approach, the equation for the correlation is written as

$$D_h/G_h = (c + dk_T) \quad (14)$$

The hourly G_{oh} on a horizontal surface has been calculated using the relation Duffie & Beckman [8]

$$G_{oh} = G_{sc}\,24/\pi k\left((\omega_2 - \omega_1)\sin\phi\sin\delta + (\sin\omega_2 - \sin\omega_1)\cos\phi\cos\delta\right) \quad (15)$$

ω_2 and ω_1 are the hour angle where $\omega_2 > \omega_1$.

$$k_T = G_h/G_{oh}$$

The value of regression coefficient d is chosen as –0.249, whereas the value of c is taken for different months using Delhi data as:

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
0.37	0.36	0.36	0.41	0.42	0.55	0.61	0.60	0.42	0.33	0.32	0.35

Table 1. Measured* and estimated Hourly global solar radiation (kwh/m^2) using measured daily values for Delhi.

LAT	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5.30	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)	0.000 (0.010)	0.039 (0.030)	0.046 (0.036)	0.029 (0.026)	0.000 (0.012)	0.000 (0.003)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
6.30	0.000 (0.004)	0.002 (0.020)	0.071 (0.066)	0.143 (0.130)	0.202 (0.177)	0.183 (0.164)	0.140 (0.130)	0.108 (0.101)	0.083 (0.079)	0.022 (0.036)	0.000 (0.009)	0.000 (0.003)
7.30	0.113 (0.096)	0.177 (0.163)	0.264 (0.260)	0.335 (0.339)	0.389 (0.383)	0.344 (0.339)	0.271 (0.275)	0.238 (0.243)	0.249 (0.248)	0.201 (0.202)	0.139 (0.128)	0.093 (0.085)
8.30	0.292 (0.271)	0.367 (0.364)	0.466 (0.475)	0.535 (0.554)	0.583 (0.581)	0.511 (0.510)	0.409 (0.425)	0.377 (0.392)	0.428 (0.431)	0.392 (0.406)	0.332 (0.319)	0.262 (0.259)
9.30	0.466 (0.433)	0.545 (0.540)	0.652 (0.655)	0.718 (0.727)	0.759 (0.746)	0.665 (0.657)	0.536 (0.549)	0.505 (0.512)	0.594 (0.587)	0.570 (0.581)	0.513 (0.495)	0.426 (0.425)
10.30	0.604 (0.556)	0.684 (0.670)	0.795 (0.781)	0.858 (0.848)	0.893 (0.865)	0.782 (0.757)	0.633 (0.640)	0.604 (0.607)	0.722 (0.698)	0.708 (0.701)	0.655 (0.620)	0.556 (0.543)
11.30	0.680 (0.618)	0.759 (0.727)	0.872 (0.845)	0.934 (0.910)	0.966 (0.925)	0.845 (0.809)	0.686 (0.672)	0.658 (0.640)	0.792 (0.757)	0.783 (0.764)	0.733 (0.685)	0.627 (0.605)
12.30	0.680 (0.615)	0.759 (0.728)	0.872 (0.844)	0.934 (0.903)	0.966 (0.920)	0.845 (0.813)	0.686 (0.671)	0.658 (0.659)	0.792 (0.747)	0.783 (0.758)	0.733 (0.680)	0.627 (0.605)
13.30	0.604 (0.552)	0.684 (0.659)	0.795 (0.769)	0.858 (0.833)	0.893 (0.844)	0.782 (0.750)	0.633 (0.606)	0.604 (0.595)	0.722 (0.689)	0.708 (0.692)	0.655 (0.613)	0.556 (0.538)
14.30	0.466 (0.430)	0.545 (0.534)	0.652 (0.635)	0.718 (0.699)	0.759 (0.719)	0.665 (0.639)	0.536 (0.518)	0.505 (0.510)	0.594 (0.571)	0.570 (0.569)	0.513 (0.490)	0.426 (0.418)
15.30	0.292 (0.268)	0.367 (0.358)	0.466 (0.458)	0.535 (0.523)	0.583 (0.547)	0.511 (0.483)	0.409 (0.412)	0.377 (0.392)	0.428 (0.417)	0.392 (0.391)	0.332 (0.315)	0.262 (0.255)
16.30	0.113 (0.099)	0.177 (0.165)	0.264 (0.249)	0.335 (0.318)	0.389 (0.352)	0.344 (0.318)	0.271 (0.273)	0.238 (0.255)	0.249 (0.244)	0.201 (0.191)	0.139 (0.125)	0.093 (0.086)
17.30	0.000 (0.005)	0.002 (0.021)	0.071 (0.064)	0.143 (0.122)	0.202 (0.158)	0.183 (0.159)	0.140 (0.141)	0.108 (0.107)	0.083 (0.074)	0.022 (0.033)	0.000 (0.010)	0.000 (0.003)
Total	**4.309 (3.987)**	**5.069 (5.001)**	**6.240 (6.138)**	**7.048 (6.935)**	**7.624 (7.287)**	**6.706 (6.544)**	**5.381 (5.334)**	**4.979 (5.053)**	**5.734 (5.602)**	**5.351 (5.355)**	**4.743 4.523)**	**3.929 (3.843)**

(*measured values are in brackets).

Table 2. Estimated Hourly global solar radiation (kwh/m^2) using daily values predicted by Chandel *et al.* (2004) for Delhi.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.5	0.000	0.000	0.000	0.000	0.027	0.047	0.036	0.000	0.000	0.000	0.000	0.000
82.5	0.000	0.002	0.060	0.123	0.170	0.190	0.179	0.138	0.079	0.017	0.000	0.000
67.50	0.097	0.149	0.222	0.292	0.338	0.355	0.345	0.306	0.241	0.167	0.107	0.081
52.50	0.251	0.315	0.397	0.471	0.514	0.527	0.518	0.483	0.416	0.334	0.263	0.231
37.50	0.402	0.472	0.561	0.637	0.675	0.684	0.677	0.646	0.579	0.492	0.415	0.378
22.50	0.522	0.597	0.688	0.764	0.799	0.803	0.798	0.771	0.705	0.616	0.535	0.497
7.5	0.589	0.665	0.757	0.833	0.866	0.868	0.864	0.839	0.774	0.684	0.602	0.563
–7.5	0.589	0.665	0.757	0.833	0.866	0.868	0.864	0.839	0.774	0.684	0.602	0.563
–22.5	0.522	0.597	0.688	0.764	0.799	0.803	0.798	0.771	0.705	0.616	0.535	0.497
–37.5	0.402	0.472	0.561	0.637	0.675	0.684	0.677	0.646	0.579	0.492	0.415	0.378
–52.5	0.251	0.315	0.397	0.471	0.514	0.527	0.518	0.483	0.416	0.334	0.263	0.231
–67.5	0.097	0.149	0.222	0.292	0.338	0.355	0.345	0.306	0.241	0.167	0.107	0.081
–82.5	0.000	0.002	0.060	0.123	0.170	0.190	0.179	0.138	0.079	0.017	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.027	0.047	0.036	0.000	0.000	0.000	0.000	0.000
Total (Measured)	**3.721 (3.987)**	**4.399 (5.001)**	**5.370 (6.138)**	**6.241 (6.935)**	**6.779 (7.287)**	**6.948 (6.544)**	**6.832 (5.334)**	**6.367 (5.053)**	**5.590 (5.602)**	**4.620 (5.355)**	**3.842 (4.523)**	**3.498 (3.843)**

Table 3. Percentage variation in estimation of hourly values using measured daily values* and using predicted daily solar radiation by Chandel *et al.*.**

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Measured (kWh/m^2)	3.987	(5.001)	(6.138)	(6.935)	(7.287)	(6.544)	(5.334)	(5.053)	(5.602)	(5.355)	(4.523)	(3.843)
**** (%)**	4.64	10.10	10.59	8.07	5.01	8.40	30.80	28.70	1.98	11.82	13.20	6.97
*** (%)**	8.08	1.36	1.66	1.63	4.62	2.48	0.88	1.46	2.36	0.07	4.86	2.24

Table 4. Estimated Hourly global radiation (kwh/m^2) for Shimla.

5.30	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
6.30	0.000	0.000	0.000	0.000	0.028	0.043	0.023	0.003	0.000	0.000	0.000	0.000
7.30	0.000	0.000	0.038	0.099	0.141	0.147	0.085	0.066	0.052	0.011	0.000	0.000
8.30	0.061	0.096	0.144	0.233	0.275	0.270	0.152	0.134	0.157	0.134	0.071	0.039
9.30	0.176	0.210	0.260	0.375	0.416	0.397	0.216	0.201	0.270	0.272	0.184	0.124
10.30	0.292	0.322	0.370	0.508	0.545	0.513	0.272	0.259	0.375	0.406	0.293	0.209
11.30	0.386	0.410	0.455	0.610	0.644	0.602	0.313	0.303	0.456	0.511	0.380	0.276
12.30	0.439	0.459	0.501	0.666	0.698	0.651	0.335	0.326	0.501	0.569	0.428	0.314
13.30	0.439	0.459	0.501	0.666	0.698	0.651	0.335	0.326	0.501	0.569	0.428	0.314
14.30	0.386	0.410	0.455	0.610	0.644	0.602	0.313	0.303	0.456	0.511	0.380	0.276
15.30	0.292	0.322	0.370	0.508	0.545	0.513	0.272	0.259	0.375	0.406	0.293	0.209
16.30	0.176	0.210	0.260	0.375	0.416	0.397	0.216	0.201	0.270	0.272	0.184	0.124
17.30	0.061	0.096	0.144	0.233	0.275	0.270	0.152	0.134	0.157	0.134	0.071	0.039
18.30	0.000	0.000	0.038	0.099	0.141	0.147	0.085	0.066	0.052	0.011	0.000	0.000
Total	**2.710**	**2.995**	**3.536**	**4.984**	**5.468**	**5.204**	**2.770**	**2.582**	**3.623**	**3.803**	**2.713**	**1.925**

The hourly diffuse solar radiation values for Delhi are given in **Table 5** which reveals that the estimated values are close to the measured values Mani [7]. This method has been used to estimate the hourly diffuse values for Shimla (**Table 6**).

4. Total Hourly Radiation on Inclined Surfaces

The values of hourly total solar radiation at tilted surfaces are required for assessing the thermal performance of solar collectors; in solar passive heating and cooling of buildings as these systems/collectors are to be installed at inclined angles for maximum efficiency. Generally, radiation stations measure the solar radiation data on a horizontal surface so it is important to estimate the solar radiation at inclined surfaces for which global radiation tilt factor has to be calculated.

Klein [4] developed a method to calculate tilt factors using an isotropic model for computing diffuse sky radiation, following Liu & Jordan [6], which was applicable only for true south. Robinson [9] and Revfeim [10] proposed models, which assume a part of sky radiation to be direct radiation and the remaining part as isotropic. In the present case we have used the model of Klein [4] to calculate tilt factor for surfaces of various surface azimuth angles. The hourly total radiation on tilted surface G_{Th} is given as

$$G_{Th} = G_h r \tag{16}$$

where r is global radiation tilt factor and is given by

$$r = \left(1 - D_h/G_h\right) r_b + r_d \left(D_h/G_h\right) + r_r \rho \tag{17}$$

and

$$r_b = \cos\theta / \cos\theta z \tag{18}$$

The angle of incidence of beam radiation θ, is related to other angles by relation:

$$\begin{aligned}\cos\theta = {} & \sin\phi\left(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta\right) \\ & + \cos\phi\left(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta\right) \\ & + \cos\delta\sin\gamma\sin\beta\sin\omega\end{aligned} \tag{19}$$

Table 5. Measured* and estimated Hourly diffuse solar radiation (kwh/m^2) for Delhi.

LAT	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5.30	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)	0.000 (0.009)	0.016 (0.027)	0.025 (0.033)	0.018 (0.023)	0.000 (0.009)	0.000 (0.002)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
6.30	0.000 (0.003)	0.001 (0.013)	0.025 (0.043)	0.056 (0.083)	0.081 (0.114)	0.097 (0.124)	0.083 (0.096)	0.063 (0.074)	0.034 (0.053)	0.007 (0.026)	0.000 (0.007)	0.000 (0.002)
7.30	0.040 (0.051)	0.060 (0.076)	0.087 (0.113)	0.126 (0.153)	0.148 (0.190)	0.178 (0.215)	0.158 (0.178)	0.137 (0.153)	0.098 (0.123)	0.061 (0.087)	0.042 (0.057)	0.031 (0.045)
8.30	0.095 (0.103)	0.114 (0.126)	0.143 (0.159)	0.190 (0.202)	0.211 (0.244)	0.256 (0.286)	0.233 (0.257)	0.211 (0.224)	0.159 (0.178)	0.110 (0.128)	0.090 (0.099)	0.081 (0.092)
9.30	0.138 (0.140)	0.156 (0.159(	0.185 (0.189)	0.241 (0.236)	0.261 (0.279)	0.322 (0.342)	0.299 (0.316)	0.277 (0.277)	0.210 (0.22)	0.147 (0.154)	0.125 (0.122)	0.119 (0.123)
10.30	0.166 (0.160)	0.183 (0.183)	0.213 (0.210)	0.275 (0.262)	0.296 (0.303)	0.370 (0.382)	0.347 (0.358)	0.325 (0.317)	0.245 (0.256)	0.169 (0.169)	0.145 (0.137)	0.144 (0.144)
11.30	0.179 (0.174)	0.196 (0.191)	0.226 (0.222)	0.292 (0.274)	0.313 (0.315)	0.395 (0.399)	0.372 (0.372)	0.351 (0.334)	0.263 (0.269)	0.180 (0.179)	0.154 (0.145)	0.155 (0.155)
12.30	0.179 (0.172)	0.196 (0.190)	0.226 (0.226)	0.292 (0.279)	0.313 (0.318)	0.395 (0.399)	0.372 (0.365)	0.351 (0.331)	0.263 (0.263)	0.180 (0.177)	0.154 (0.146)	0.155 (0.156)
13.30	0.166 (0.162)	0.183 (0.180)	0.213 (0.215)	0.275 (0.274)	0.296 (0.308)	0.370 (0.377)	0.347 (0.333)	0.325 (0.302)	0.245 (0.248)	0.169 (0.169)	0.145 (0.142)	0.144 (0.147)
14.30	0.138 (0.137)	0.156 (0.160)	0.185 (0.197)	0.241 (0.250)	0.261 (0.286)	0.322 (0.340)	0.299 (0.291)	0.277 (0.265)	0.210 (0.217)	0.147 (0.154)	0.125 (0.124)	0.119 (0.125)
15.30	0.095 (0.100)	0.114 (0.125)	0.143 (0.163)	0.190 (0.212)	0.211 (0.247)	0.256 (0.279)	0.233 (0.241)	0.211 (0.210)	0.159 (0.167)	0.110 (0.126)	0.090 (0.099)	0.081 (0.092)
16.30	0.040 (0.051)	0.060 (0.075)	0.087 (0.113)	0.126 (0.156)	0.148 (0.189)	0.178 (0.203)	0.158 (0.174)	0.137 (0.149)	0.098 (0.118)	0.061 (0.083)	0.042 (0.055)	0.031 (0.043)
17.30	0.000 (0.005)	0.001 (0.000)	0.025 (0.041)	0.056 (0.079)	0.081 (0.107)	0.097 (0.114)	0.083 (0.101)	0.063 (0.075)	0.034 (0.048)	0.007 (0.021)	0.000 (0.006)	0.000 (0.002)
Total	**1.237 (1.240)**	**1.418 (1.474)**	**1.757 (1.861)**	**2.358 (2.473)**	**2.637 (2.922)**	**3.259 (3.540)**	**3.002 (3.135)**	**2.730 (2.727)**	**2.020 (2.152)**	**1.348 (1.465)**	**1.109 (1.141)**	**1.059 (1.117)**

(*measured values are in bracket).

Table 6. Estimated hourly diffuse solar radiation (kwh/m^2) for Shimla.

LAT	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5.30	0.000	0.000	0.000	0.000	0.012	0.023	0.014	0.002	0.000	0.000	0.000	0.000
6.30	0.000	0.000	0.013	0.040	0.057	0.079	0.051	0.039	0.022	0.003	0.000	0.000
7.30	0.022	0.033	0.049	0.090	0.108	0.141	0.090	0.079	0.063	0.042	0.022	0.013
8.30	0.060	0.069	0.086	0.139	0.157	0.203	0.127	0.116	0.105	0.080	0.053	0.041
9.30	0.094	0.101	0.117	0.181	0.199	0.256	0.159	0.149	0.142	0.112	0.080	0.065
10.30	0.118	0.124	0.139	0.211	0.229	0.296	0.181	0.172	0.168	0.134	0.099	0.083
11.30	0.131	0.136	0.150	0.226	0.244	0.316	0.193	0.184	0.182	0.145	0.108	0.093
12.30	0.131	0.136	0.150	0.226	0.244	0.316	0.193	0.184	0.182	0.145	0.108	0.093
13.30	0.118	0.124	0.139	0.211	0.229	0.296	0.181	0.172	0.168	0.134	0.099	0.083
14.30	0.094	0.101	0.117	0.181	0.199	0.256	0.159	0.149	0.142	0.112	0.080	0.065
15.30	0.060	0.069	0.086	0.139	0.157	0.203	0.127	0.116	0.105	0.080	0.053	0.041
16.30	0.022	0.033	0.049	0.090	0.108	0.141	0.090	0.079	0.063	0.042	0.022	0.013
17.30	0.000	0.000	0.013	0.040	0.057	0.079	0.051	0.039	0.022	0.003	0.000	0.000
Total	**0.850**	**0.927**	**1.109**	**1.772**	**2.002**	**2.605**	**1.618**	**1.481**	**1.363**	**1.031**	**0.724**	**0.591**

For North facing surfaces in the month having –ve declination in place of Equation (19) following relation is used:

$$\cos\theta = \sin\delta\sin(\beta-\phi) + \cos\delta\cos\omega\cos(\beta-\phi) \quad (20)$$

For North facing surfaces in the month having +ve declination

$$\cos\theta = \sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\cos(\phi-\beta) \quad (21)$$

The angle of incidence θz is the zenith angle of the Sun,

$$\cos\theta z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega \quad (22)$$

r_d is the ratio of the diffuse radiation flux falling on the tilted surface to that falling on horizontal surface, assuming that the sky is an isotropic source of diffuse radiation,

$$r_d = (1+\cos\beta)/2 \quad (23)$$

Assuming that the reflection of the beam on the ground is isotropic and the reflectivity is ρ the tilt factor for reflected radiation is

$$r_r = \rho(1-\cos\beta)/2 \quad (24)$$

The hourly tilt factor for Delhi on south facing surface has been estimated and presented in **Table 7** which is in close agreement with the values given by Mani [7]. The solar radiation values for different orientations for the typical summer month May and winter month December have been calculated and are given in **Tables 8** and **9**. The estimated values are close to the measured values. However, **Tables 8** and **9** reveal that for west orientation the estimated values in the morning are negative whereas for east orientation the evening values are negative, these values are taken to be zero.

Using this method total hourly solar radiation on south, east, west and north tilted surface for Shimla are presented in **Tables 10-13** and for inclined surfaces at different tilt angles are presented in **Tables 14-15**. Here we made a study of ground-reflected component of radiation on inclined surfaces with varying inclination angles for Lucknow (Latitude 26.750, Longitude 80.850), Mumbai (Latitude 19.120 N, Longitude 72.850 E), Calcutta (Latitude 22.650 N, Longitude 88.350 E), and Pune (Latitude 18.530 N, Longitude 73.910 E) cities of India using isotropic and anisotropic models [11]. The total solar radiation incident on a tilted surface facing south Ht with different tilt angles is then calculated using both Liu and Jordan isotropic model and Klucher's anisotropic model [12].

Table 7. Computed* and estimated hourly global radiation tilt (tilt = lat) factors for south facing surfaces (Azimuth zero) for Delhi.

LAT	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
5.30	0.000 (4.221)	0.000 (1.656)	1.236 (1.086)	0.789 (0.856)	0.670 (0.788)	0.704 (0.826)	0.748 (0.822)	0.801 (0.855)	0.984 (0.922)	3.102 (1.288)	0.000 (1.832)	0.000 (7.424)
6.30	1.954 (1.684	1.461 (1.342)	1.133 (1.101)	0.939 (0.943)	0.845 (0.868)	0.840 (0.871)	0.866 (0.881)	0.914 (0.945)	1.040 (1.012)	1.350 (1.236)	1.863 (1.612)	2.255 (1.857)
7.30	1.484 (1.443)	1.297 (1.270)	1.121 (1.111)	0.985 (0.987)	0.909 (0.916)	0.894 (0.904)	0.911 (0.917)	0.952 (0.951)	1.055 (1.039)	1.246 (1.208)	1.469 (1.416)	1.577 (1.526)
8.30	1.375 (1.363)	1.249 (1.239)	1.118 (1.116)	1.006 (1.010)	0.941 (0.944)	0.921 (0.923)	0.934 (0.937)	0.970 (0.970)	1.063 (1.052)	1.214 (1.194)	1.370 (1.353)	1.435 (1.426)
9.30	1.335 (1.332)	1.231 (1.224)	1.119 (1.118)	1.018 (1.021)	0.957 (0.961)	0.936 (0.940)	0.946 (0.949)	0.979 (0.980)	1.068 (1.058)	1.202 (1.187)	1.333 (1.321)	1.383 (1.377)
10.30	1.320 (1.315)	1.224 (1.218)	1.119 (1.118)	1.023 (1.027)	0.965 (0.968)	0.943 (0.946)	0.951 (0.954)	0.983 (0.984)	1.070 (1.061)	1.198 (1.183)	1.320 (1.314)	1.364 (1.358)
11.30	1.320 (1.316)	1.224 (1.218)	1.119 (1.117)	1.023 (1.026)	0.965 (0.968)	0.943 (0.946)	0.951 (0.954)	0.983 (0.986)	1.070 (1.061)	1.198 (1.183)	1.320 (1.312)	1.364 (1.357)
12.30	1.335 (1.329)	1.231 (1.224)	1.119 (1.115)	1.018 (1.019)	0.957 (0.961)	0.936 (0.940)	0.946 (0.948)	0.979 (0.981)	1.068 (1.059)	1.202 (1.186)	1.333 (1.316)	1.383 (1.373)
13.30	1.375 (1.365)	1.249 (1.237)	1.118 (1.111)	1.006 (1.007)	0.941 (0.945)	0.921 (0.924)	0.934 (0.936)	0.970 (0.971)	1.063 (1.051)	1.214 (1.193)	1.370 (1.350)	1.435 (1.420)
14.30	1.484 (1.450)	1.297 (1.268)	1.121 (1.106)	0.985 (0.985)	0.909 (0.918)	0.894 (0.906)	0.911 (0.915)	0.952 (0.951)	1.055 (1.041)	1.246 (1.206)	1.469 (1.414)	1.577 (1.523)
15.30	1.954 (1.704)	1.461 (1.349)	1.133 (1.096)	0.939 (0.944)	0.845 (0.875)	0.840 (0.871)	0.866 (0.879)	0.914 (0.944)	1.040 (1.013)	1.350 (1.236)	1.863 (1.624)	2.255 (1.904)

*values in brackets from Table-278, A. Mani (1980).

Table 8. Total Estimated and measured* hourly total solar radiation (kwh/m^2) on different orientation for the month for May in Delhi.

Is	Iw	Ie	In	LAT
0.000 (0.017)	0.000 (0.017)	0.484 (0.017)	0.000 (0.017)	**5.30**
0.000 (0.075)	0.000 (0.075)	0.493 (0.300)	0.000 (0.128)	**6.30**
0.057 (0.133)	0.000 (0.133)	0.559 (0.491)	0.057 (0.178)	**7.30**
0.160 (0.180)	0.000 (0.180)	0.587 (0.563)	0.160 (0.184)	**8.30**
0.253 (0.258)	0.000 (0.214)	0.559 (0.545)	0.253 (0.214)	**9.30**
0.325 (0.321)	0.003 (0.238)	0.472 (0.459)	0.325 (0.238)	**10.30**
0.364 (0.354)	0.171 (0.250)	0.335 (0.327)	0.364 (0.250)	**11.30**
0.364 (0.353)	0.335 (0.327)	0.171 (0.251)	0.364 (0.251)	**12.30**
0.325 (0.317)	0.472 (0.449)	0.003 (0.238)	0.325 (0.238)	**13.30**
0.253 (0.256)	0.559 (0.522)	0.000 (0.215)	0.253 (0.215)	**14.30**
0.160 (0.178)	0.587 (0.519)	0.000 (0.178)	0.160 (0.181)	**15.30**
0.057 (0.130)	0.559 (0.432)	0.000 (0.130)	0.057 (0.168)	**16.30**
0.000 (0.069)	0.493 (0.252)	0.000 (0.069)	0.000 (0.113)	**17.30**
0.000 (0.014)	0.386 (0.117)	0.000 (0.014)	0.000 (0.051)	**18.30**

*Vlues are in brackets.

Table 9. Total Estimated and measured* hourly total solar radiation (kwh/m^2) on different orientation for the Month of December for Delhi.

Is	Ie	Iw	LAT	In
0.000 (0.001)	0.000 (0.002)	0.000 (0.001)	**5.30**	0.000 (0.001)
0.296 (0.199)	0.470 (0.310)	0.000 (0.031)	**6.30**	0.000 (0.031)
0.440 (0.407)	0.507 (0.472)	0.000 (0.072)	**7.30**	0.000 (0.072)
0.578 (0.565)	0.484 (0.477)	0.000 (0.104)	**8.30**	0.025 (0.104)
0.688 (0.662)	0.388 (0.378)	0.000 (0.126)	**9.30**	0.132 (0.126)
0.749 (0.710)	0.233 (0.226)	0.047 (0.138)	**10.30**	0.193 (0.138)
0.749 (0.709)	0.047 (0.139)	0.233 (0.226)	**11.30**	0.211 (0.139)
0.688 (0.652)	0.000 (0.127)	0.388 (0.374)	**12.30**	0.189 (0.127)
0.578 (0.552)	0.000 (0.104)	0.484 (0.466)	**13.30**	0.136 (0.104)
0.440 (0.399)	0.000 (0.072)	0.507 (0.462)	**14.30**	0.069 (0.072)
0.296 (0.211)	0.000 (0.030)	0.470 (0.330)	**15.30**	0.009 (0.030)
0.000 (0.002)	0.000 (0.001)	0.000 (0.001)	**16.30**	0.000 (0.001)

*Values are in brackets

Table 10. Estimated total hourly solar radiation (kwh/m^2) on south orientation for Shimla.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
82.50	0.000	0.000	0.033	0.006	0.000	0.000	0.005	0.009	0.022	0.069	0.000	0.000
67.50	0.153	0.128	0.097	0.078	0.041	0.051	0.036	0.042	0.080	0.162	0.193	0.164
52.50	0.244	0.207	0.166	0.156	0.104	0.112	0.065	0.072	0.143	0.264	0.304	0.260
37.50	0.334	0.282	0.230	0.229	0.163	0.168	0.088	0.096	0.200	0.362	0.412	0.355
22.50	0.406	0.341	0.280	0.286	0.208	0.210	0.105	0.114	0.245	0.439	0.498	0.431
7.50	0.445	0.373	0.307	0.317	0.233	0.234	0.113	0.123	0.269	0.482	0.546	0.473
–7.50	0.445	0.373	0.307	0.317	0.233	0.234	0.113	0.123	0.269	0.482	0.546	0.473
–22.50	0.406	0.341	0.280	0.286	0.208	0.210	0.105	0.114	0.245	0.439	0.498	0.431
–37.50	0.334	0.282	0.230	0.229	0.163	0.168	0.088	0.096	0.200	0.362	0.412	0.355
–52.50	0.244	0.207	0.166	0.156	0.104	0.112	0.065	0.072	0.143	0.264	0.304	0.260
–67.50	0.153	0.128	0.097	0.078	0.041	0.051	0.036	0.042	0.080	0.162	0.193	0.164
–82.5	0.000	0.000	0.033	0.006	-.018	0.000	0.005	0.009	0.022	0.069	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**3.167**	**2.662**	**2.226**	**2.148**	**1.481**	**1.551**	**0.823**	**0.912**	**1.918**	**3.554**	**3.907**	**3.364**

Table 11. Estimated total hourly solar radiation (kwh/m^2) on east orientation for Shimla.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.50	0.000	0.000	0.000	0.000	0.213	0.171	0.098	0.099	0.000	0.000	0.000	0.000
82.50	0.000	0.000	0.242	0.295	0.269	0.227	0.120	0.119	0.220	0.308	0.000	0.000
67.50	0.259	0.268	0.283	0.348	0.311	0.273	0.134	0.134	0.258	0.376	0.115	0.261
52.50	0.293	0.292	0.299	0.373	0.330	0.302	0.141	0.140	0.275	0.406	0.212	0.297
37.50	0.288	0.281	0.284	0.359	0.319	0.305	0.138	0.137	0.265	0.386	0.246	0.292
22.50	0.240	0.232	0.234	0.306	0.274	0.280	0.127	0.125	0.225	0.313	0.222	0.240
7.50	0.152	0.151	0.157	0.218	0.202	0.229	0.108	0.104	0.161	0.196	0.153	0.149
–7.50	0.044	0.051	0.063	0.109	0.112	0.160	0.083	0.078	0.081	0.055	0.061	0.035
–22.50	0.000	0.000	0.000	0.000	0.018	0.083	0.054	0.047	0.000	0.000	0.000	0.000
–37.50	0.000	0.000	0.000	0.000	0.000	0.008	0.023	0.014	0.000	0.000	0.000	0.000
–52.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
–67.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
–82.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**1.276**	**1.275**	**1.561**	**2.007**	**2.047**	**2.038**	**1.026**	**0.995**	**1.484**	**2.040**	**1.008**	**1.275**

Table 12. Estimated total hourly solar radiation (kwh/m^2) on west orientation for Shimla.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
82.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
67.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
52.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37.50	0.000	0.000	0.000	0.000	0.000	0.008	0.023	0.014	0.000	0.000	0.000	0.000
22.50	0.000	0.000	0.000	0.000	0.018	0.083	0.054	0.047	0.000	0.000	0.000	0.000
7.50	0.044	0.051	0.063	0.109	0.112	0.160	0.083	0.078	0.081	0.055	0.036	0.035
–7.50	0.152	0.151	0.157	0.218	0.202	0.229	0.108	0.104	0.161	0.196	0.178	0.149
–22.50	0.240	0.232	0.234	0.306	0.274	0.280	0.127	0.125	0.225	0.313	0.295	0.240
–37.50	0.288	0.281	0.284	0.359	0.319	0.305	0.138	0.137	0.265	0.386	0.366	0.292
–52.50	0.293	0.292	0.299	0.373	0.330	0.302	0.141	0.140	0.275	0.406	0.381	0.297
–67.50	0.259	0.268	0.283	0.348	0.311	0.273	0.134	0.134	0.258	0.376	0.345	0.261
–82.5	0.000	0.000	0.242	0.295	0.269	0.227	0.120	0.119	0.220	0.308	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**1.276**	**1.275**	**1.561**	**2.007**	**1.834**	**1.867**	**0.929**	**0.896**	**1.484**	**2.040**	**1.601**	**1.275**

Table 13. Estimated total hourly solar radiation (kwh/m^2) on north orientation for Shimla.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
82.50	0.000	0.000	0.017	0.006	0.000	0.000	0.005	0.009	0.022	0.000	0.000	0.000
67.50	0.000	0.022	0.078	0.078	0.041	0.051	0.036	0.042	0.080	0.051	0.000	0.000
52.50	0.039	0.084	0.144	0.156	0.104	0.112	0.065	0.072	0.143	0.136	0.057	0.022
37.50	0.098	0.145	0.206	0.229	0.163	0.168	0.088	0.096	0.200	0.219	0.131	0.080
22.50	0.148	0.193	0.255	0.286	0.208	0.210	0.105	0.114	0.245	0.285	0.191	0.128
7.50	0.175	0.220	0.281	0.317	0.233	0.234	0.113	0.123	0.269	0.321	0.225	0.156
–7.50	0.175	0.220	0.281	0.317	0.233	0.234	0.113	0.123	0.269	0.321	0.225	0.156
–22.50	0.148	0.193	0.255	0.286	0.208	0.210	0.105	0.114	0.245	0.285	0.191	0.128
–37.50	0.098	0.145	0.206	0.229	0.163	0.168	0.088	0.096	0.200	0.219	0.131	0.080
–52.50	0.039	0.084	0.144	0.156	0.104	0.112	0.065	0.072	0.143	0.136	0.057	0.022
–67.50	0.000	0.022	0.078	0.078	0.041	0.051	0.036	0.042	0.080	0.051	0.000	0.000
–82.5	0.000	0.000	0.017	0.006	0.000	0.000	0.005	0.009	0.022	0.000	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**0.921**	**1.329**	**1.962**	**2.148**	**1.499**	**1.551**	**0.823**	**0.912**	**1.918**	**2.025**	**1.206**	**0.771**

Table 14. Estimated total hourly solar radiation (kwh/m^2) on south orientation (tilt = lat) for Shimla.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
82.50	0.000	0.000	0.042	0.070	0.076	0.000	0.053	0.044	0.045	0.043	0.000	0.000
67.50	0.120	0.130	0.145	0.197	0.187	0.051	0.105	0.098	0.143	0.181	0.158	0.118
52.50	0.244	0.246	0.256	0.334	0.303	0.112	0.152	0.147	0.246	0.337	0.311	0.244
37.50	0.369	0.359	0.361	0.461	0.410	0.168	0.190	0.187	0.342	0.488	0.463	0.373
22.50	0.471	0.449	0.442	0.560	0.492	0.210	0.217	0.215	0.416	0.607	0.586	0.477
7.50	0.527	0.498	0.487	0.614	0.537	0.234	0.232	0.230	0.456	0.673	0.655	0.536
–7.50	0.527	0.498	0.487	0.614	0.537	0.234	0.232	0.230	0.456	0.673	0.655	0.536
–22.50	0.471	0.449	0.442	0.560	0.492	0.210	0.217	0.215	0.416	0.607	0.586	0.477
–37.50	0.369	0.359	0.361	0.461	0.410	0.168	0.190	0.187	0.342	0.488	0.463	0.373
–52.50	0.244	0.246	0.256	0.334	0.303	0.112	0.152	0.147	0.246	0.337	0.311	0.244
–67.50	0.120	0.130	0.145	0.197	0.187	0.051	0.105	0.098	0.143	0.181	0.158	0.118
–82.5	0.000	0.000	0.042	0.070	0.076	0.000	0.053	0.044	0.045	0.043	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**3.460**	**3.362**	**3.468**	**4.472**	**4.010**	**1.551**	**1.897**	**1.845**	**3.296**	**4.658**	**4.347**	**3.498**

Table 15. Estimated total hourly solar radiation (kwh/m^2) on south orientation (tilt = lat + 15) for Shimla.

Hour angle	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
97.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
82.50	0.000	0.000	0.043	0.055	0.052	0.066	0.041	0.036	0.042	0.056	0.000	0.000
67.50	0.142	0.141	0.143	0.176	0.156	0.165	0.090	0.088	0.135	0.192	0.184	0.144
52.50	0.267	0.256	0.251	0.307	0.266	0.268	0.135	0.134	0.235	0.345	0.338	0.272
37.50	0.392	0.368	0.353	0.428	0.367	0.364	0.172	0.172	0.327	0.494	0.491	0.402
22.50	0.494	0.456	0.432	0.523	0.445	0.437	0.198	0.199	0.398	0.611	0.615	0.508
7.50	0.550	0.505	0.475	0.575	0.488	0.477	0.211	0.213	0.437	0.676	0.683	0.567
–7.50	0.550	0.505	0.475	0.575	0.488	0.477	0.211	0.213	0.437	0.676	0.683	0.567
–22.50	0.494	0.456	0.432	0.523	0.445	0.437	0.198	0.199	0.398	0.611	0.615	0.508
–37.50	0.392	0.368	0.353	0.428	0.367	0.364	0.172	0.172	0.327	0.494	0.491	0.402
–52.50	0.267	0.256	0.251	0.307	0.266	0.268	0.135	0.134	0.235	0.345	0.338	0.272
–67.50	0.142	0.141	0.143	0.176	0.156	0.165	0.090	0.088	0.135	0.192	0.184	0.144
–82.5	0.000	0.000	0.043	0.055	0.052	0.066	0.041	0.036	0.042	0.056	0.000	0.000
–97.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**3.689**	**3.452**	**3.392**	**4.130**	**3.549**	**3.552**	**1.693**	**1.685**	**3.148**	**4.749**	**4.623**	**3.785**

5. Conclusions

The mean hourly global solar radiation has been estimated using daily integration approach by Gueymard [2] for Delhi, which accurately predicts the monthly average hourly global solar radiation using model [1]. The hourly diffuse solar radiation has been calculated by improving the method of Orgill and Hollands [3], which gives good fit. The tilt factor for south surfaces has been calculated using method of Klein [4] and hourly total solar radiation on the inclined south surfaces for Delhi and Shimla has been calculated. The values of tilt factor are found to be close to the values given by Mani [7] except for early morning and late evening. The method presented can be used to calculate hourly global, diffuse solar radiation for horizontal surfaces and total solar radiation on inclined & vertical surfaces at different orientations with greater accuracy for any location.

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Nomenclature

G_h = hourly solar radiation (KWh/m^2)
G_0 = extra terrestrial solar radiation (KWh/m^2)
Gsc = solar constant 1.357 KW/m^2
c = regression coefficient
d = regression coefficient
ω_s = sunrise hour angle (degrees)
ω = hour angle measured from solar noon (degrees)
φ = latitude of the place (degrees)
δ = declination angle (degrees)
h_o = solar elevation outside of the atmosphere (degrees)
S_o = day length (Hrs.)
P = atmospheric pressure at the site (K Pa)
P_0 = standard atmospheric pressure (K Pa)
H = hourly solar elevation (KWh/m^2)
D_h = mean hourly diffuse solar radiation (KWh/m^2)
r = ground surface reflectivity
b = slope (degrees)
r_b = tilt factor for beam radiation
q = angle of incidence of beam radiation (degrees)
g = surface azimuth angle (degrees)
q_z = zenith angle of the Sun (degrees)
r_d = tilt factor for diffuse radiation
k_T = clearness index
R = global radiation tilt factor
a^1 = regression constant
a^2 = regression constant
G_{OH} = hourly extra terrestrial solar radiation (KWh/m^2)
G_{TH} = total hourly solar radiation on tilt surface (KWh/m^2)

