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Average Monthly Solar Radiations At Various Places Of North East India

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Abstract:
The amount of solar energy reaching the Earth's atmosphere and surface is dependent on geographic location (latitude and longitude of the place), orientation, seasonal variations, time of a day and atmospheric conditions. Information on the availability of solar radiation is needed in many applications dealing with the harnessing of solar energy. In India, the Meteorological Department measures sunshine duration, global radiation, and diffuse radiation at some selected place. Locations where no measurements exist, monthly average or hourly average solar radiation can be estimated by using empirical correlation developed from the measured data of nearby locations having similar climatological conditions. In this paper, direct incident solar radiation, global horizontal solar radiation and diffuse radiation incidence have been calculated for different places of north-east India, viz. Guwahati, Shillong, Sibsagar and Silchar. The monthly average direct normal irradiance and global horizontal irradiance provided by National Renewable Energy Laboratory based on the hourly estimates of radiation over seven years (2002-2008) revealed that daily average of solar radiation in and around Assam is in the range of 3 - 6 kWh/m^2/ day. By employing the method proposed by Sukhatme, the daily average of global and horizontal diffuse solar radiation have been calculated for Jodhpur, New Delhi and Vishakhapatnam apart from the above mentioned locations of North-East India. The measured values available for Jodhpur, New Delhi, Vishakhapatnam, and Shillong with the Meteorological Department are comparable with our calculated results. Thus our results can be considered as useful results for rapid mechanism for initial design of solar power generation system in these locations. Also method of calculations can be extended for remote and inaccessible regions also.

Keywords: *Solar Energy, direct normal irradiance, global horizontal irradiance, sun shine hour.*

Introduction

The Solar energy is the most potential renewable energy sources among the other non conventional energy sources. However the solar insolation is not uniform all over the world. The radiation incident on a surface varies from moment to moment depending on its geographic location (latitude and longitude of the place), orientation and season, time of day and atmospheric conditions. Knowledge of monthly-mean values of the daily global and diffuse radiation on a horizontal surface is essential to design any solar energy system. Hourly values of radiation enable us to derive very precise information about the performance of solar energy systems. In India, the Meteorological Department measures sunshine duration, global radiation, and diffuse radiation at some selected places [1, 2]. The measured data of 21 years have been compiled and is available in the form of tables giving the monthly average values of hourly global and hourly diffuse values [3]. For locations where no measurements exist, monthly-mean values of the daily global and diffuse radiation and hourly radiation on an horizontal surface can be estimated by using empirical correlation developed from the measured data of nearby locations having similar climatological conditions. Various climatic parameters such as humidity, temperature, rainfall, total amount of coverage and in particular, number of sunshine hours, etc., have been used in developing empirical relations as a substitute for the measurement of solar radiation. Several attempts have been made to analyze the hourly global radiation data of widely separated locations to obtain the curves of hourly to daily radiation ratio against the sunset hour angle [4, 5]. No general formula is available for prediction of the solar radiation reaching the Earth's surface over a given period of time at any location. The direct incidence radiance, global horizontal radiance and diffuse radiance was calculated by Sukhatme for Indian locations using constants given by ASHRAE [6, 7, 9]. Following the similar procedure solar radiation has been calculated for Jodhpur, New Delhi, Vishakhapatnam, Shillong, Guwahati, Sibsagar and Silchar. Parishwad et al. [8] developed a procedure for estimating hourly global (I_g) and diffuse (I_d) radiation on a horizontal surface at any location in India where measured data is not available. But the result has been found identical for the locations having close latitude value even though the longitude and altitudes are different. The method proposed by Collares-Pereira and Rabl [5] to estimate the hourly average radiation has been found to be more appropriate. Hourly average radiation was measured for Jodhpur and Guwahati and the measured data available for Jodhpur was compared with our result.

Methodology

The calculations are based on the empirical equations for predicting the availability of solar radiation given by Sukhatme [6]. The following relation is used to calculate monthly average daily global radiation $\frac{H_g}{H_0} = a + b[\frac{S}{S_{max}}]$ (1)

where H_g is the monthly average of the daily global radiation and H_0 is the monthly average of the daily extraterrestrial radiation on a horizontal surface at a location. S is the monthly average of the sunshine hours per day and S_{max} is the monthly average of the maximum possible sunshine hours per day at the location and is equal to $\frac{2}{15}w_s$, where w_s is the hour angle. a, b are the constants obtained for 17 Indian cities [6,9]. For a particular place for which these constants are not available, a and b can be taken for a nearby location with a similar geography and climate. The nearest place to our considered cities is Shillong and the values of the constants a and b are available for Shilong. But the climatological conditions are not same as that of our considered cities. Gopinathan [10] has suggested the correlation as

$$\frac{H_g}{H_0} = a_1 + b_1[\frac{S}{S_{max}}] \quad (2)$$

Where $a_1 = -0.309 + 0.539\cos\varphi - 0.0693E_L + 0.290\left(\frac{S}{S_{max}}\right)$ (3)

and $b_1 = 1.527 - 1.027\cos\varphi + 0.0926 E_L - 0.359\left(\frac{S}{S_{max}}\right)$ (4)

The constants a_1 and b_1 are related to three parameters, the latitude (φ), the elevation (E_L) and the sunshine hours. In our calculations equations (2), (3) and (4) have been used. H_0 can be calculated using

$$H_0 = \frac{24}{\pi} I_{Sc}\left(1 + .033\frac{360n}{365}\right)(w_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos w_s \quad (5)$$

where I_{sc} is the solar constant and is the rate at which energy is received from the sun on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun and its value is 1.367 kW/m^2. n is the day in each month on which extraterrestrial radiations nearly equal to the monthly mean value and for each month the value of n is shown in the Table1. φ is the latitude of the place, hour angle w_s and solar declination δ can be determined by the following equations

$$w_s = \cos^{-1}(-\tan\varphi \tan\delta) \text{ and } \delta = 23.45\sin\left[\frac{360}{365}(284 + n)\right] \quad (6)$$

The value of latitude (φ), longitude (l) and altitude (E_L) were taken from Wikipedia [11] for the selected cities.

Months	N for *i*th day of month	For average Day of month		
		Date	n	δ
Jan	*i*	17	17	-20.9
Feb	31 + *i*	16	47	-13.0
Mar	59 + *i*	16	75	-2.4
Apr	90 + *i*	15	105	9.4
May	120 + *i*	15	135	18.8
Jun	151 + *i*	11	162	23.1
Jul	181 + *i*	17	198	21.2
Aug	212 + *i*	16	228	13.5
Sep	243 + *i*	15	258	2.2
Oct	273 + *i*	15	288	-9.6
Nov	304 + *i*	14	318	-18.9
Dec	*334 + i*	10	344	-23.0

Table 1: Recommended average days for months and values for n [12]

Garg and Garg [12] have examined radiation data for 11 Indian cities and proposed the equation for average daily diffuse radiation H_d as

$$\frac{H_d}{H_g} = 0.8677 - 0.7365\left(\frac{S}{S_{max}}\right) \quad (7)$$

Using the procedure described above, global (H_g) and diffuse radiation (H_d) were calculated for all the months of the year. The monthly average hourly global radiation at a location can be calculated by using the relation proposed by Collares-Pereira and Rabl [5]

$$\frac{I_g}{H_g} = \frac{I_0}{H_0}(a + bcosw) \quad (8)$$

where $a = 0.409 + 0.5016 \sin(w_s - 60^0)$ and $b = 0.6609 - 0.4767\sin(w_s - 60^0)$ (9)

I_g = monthly average of the hourly global radiation a horizontal surface (kW-h/m^2), I_0 = monthly average of the hourly extraterrestrial radiation a horizontal surface (kW-h/m^2)). Gueymard [13] modified eq. (8) by incorporating a normalizing factor f_c

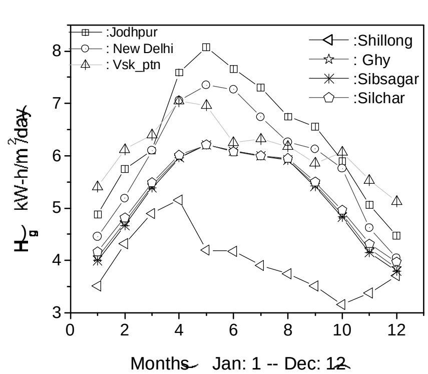
$$\frac{I_g}{H_g} = \frac{I_0}{H_0}(a + bcosw)/f_c \quad (10)$$

where $$f_c = a + 0.5\, b \left(\frac{\frac{\pi w_s}{180} - sinw_s cosw_s}{sinw_s - \frac{\pi w_s}{180} cosw_s}\right) \qquad (11)$$

Hourly average of global radiation (I_G) for two different locations (Jodhpur and Guwahati) having similar latitude (26.28° N and 26.11° N) values but different longitude (73.02° E and 91.72° E) and altitude values were calculated for January, April, July and October (from 9 hrs to 16 hrs) by employing the procedure proposed by Collares-Pereira and Rabl[5]

Result And Discussions

The daily average global horizontal (H_g) and diffuse radiance (H_d calculated for each month in different locations of India are shown as in Fig.1. Our calculated results are comparable with the measured data available for Jodhpur, New Delhi and Vishakhapatnam [1]. Thus our result can be accepted for other locations such as Guwahati, Sibsagar, Silchar etc., for which no measured data are available.



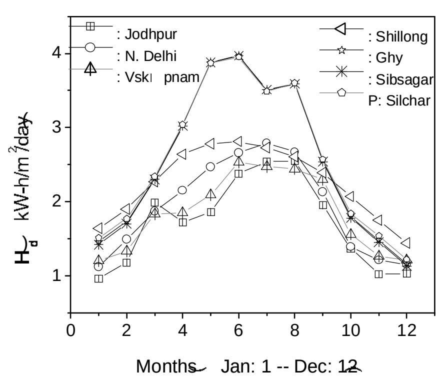


Figure1(a): Daily average of Global (H_g)

Figure 2: Diffuse (H_d) radiance Calculated for each month

By following the method proposed by Parishad et.al [8] it was found that hourly average radiation for Jodhpur, New Delhi, Vishakhapatnam and Guwahati are very close to each other. These results are quite contradictory with the available measured data. Hence this method was discarded in our calculations. By using the method proposed by Collares-Pereira and Rabl[5] hourly average radiation was calculated for all the above mentioned locations and it was observed that results are within the error of 2% to 18%. The hourly average radiation of Jodhpur and Guwahti are shown as in Fig 2a and Fig 2b. It is highest for the month of April in both the locations; but lowest during July in Guwahati and during January in Jodhpur. This result is justified as due to rainy season sunshine hours are less during July in Guwahati. Hourly average for the other places of north eastern region have not been calculated as no appreciable difference will be observed for the location having close latitude, longitude and altitude with similar climatic condition.

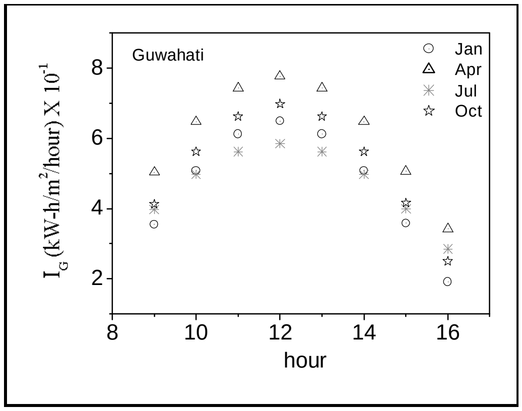


Figure 2(a) :Hourly average of global radiation for Guwahati

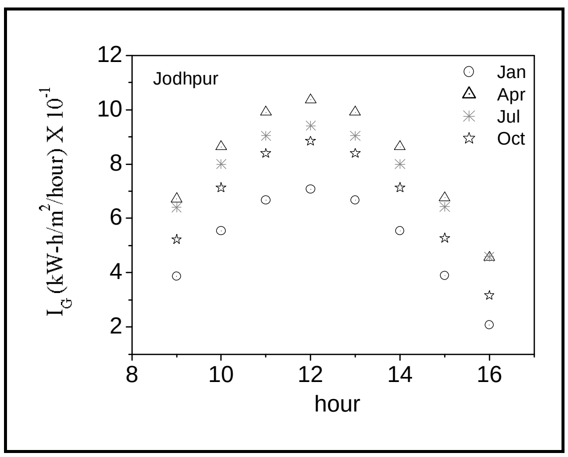


Figure 2: Hourly average of global radiation for Jodhpur

Conclusions

The direct incident solar radiation, global horizontal solar radiation and diffuse radiation incidence have been calculated for different places of India including the different locations of north-east India. The calculated results are compared with the measured data available for certain locations of India and found to be acceptable within limited error range. The hourly average of global solar radiation was estimated for Guwahati and Jodhpur. The percentage of error between measured and calculated results for Jodhpur lies within the range of 2% – 18%. The maximum error (18%) has been observed for the time 9.00 and 16.00 hr corresponding to the maximum positive and negative hour angles considered in our study. In all other time error was found to be within 10%. This result may not be useful in present scenario as maximum efficiency of the solar cell was reported around 15%. But in future if we can design solar cell with much higher efficiency this kind of solar insolation data will be much useful for the location where no measured data are available. Extension of these calculations to remote and inaccessible regions would provide rapid mechanism for initial design of solar power generation system in these locations.

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