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Variation of Mean Hourly Insolation with Time at Jos

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Abstract: *5year data on mean daily global radiation for Jos, Nigeria, were used to study how the hourly global radiation varies over a typical day at Jos. Empirical formulae were used in the analysis. The irradiance at solar noon was found to have a maximum value of 3.81 MJm^{-2} in February and a minimum value of 2.22 MJm^{-2} in July, with an average value of 3.07±0.55 MJm^{-2} over the 5year period examined. Within the same period, the hourly insolation varied from 0.25 MJm^{-2} at 7.00am to 3.07 MJm^{-2} at 12.00noon, with an assumption that the day was symmetrical about the solar noon. Its average is 1.70±1.01 MJm^{-2} over a daylength of 11hours. This equivalent to a power output of 470 Wm^{-2}, which implies that with a solar panel of 2 m^2, one could obtain a power output of about 1000W, corresponding to the power rating of an electric iron or water heater on a 240V AC supply. The values of insolation obtained in this work strongly suggest that solar energy could be utilized in Jos and its environs to meet some energy needs, at least at the domestic level.*
Key words: *global radiation, empirical formulae, irradiance, insolation, solar noon.*

I. Introduction

Solar radiation plays a very important role in our life. The knowledge of solar radiation reaching the earth's surface and its geographical distribution is very important for solar energy and other applications. The availability of solar radiation data is limited by the sparsity of the existing network. But measured data are rather scare, and so radiation data often have to be estimated from empirical formulae that are available for that purpose. In this paper, information about hourly global radiation is derived from daily global radiation in order to ascertain the viability of using solar devices and appliances in Jos and its environs.

II. Data Acquisition

The data set used in this paper was obtained from the Nigerian Meteorological Agency (NIMET), Lagos. These data contain records of monthly mean daily values of global radiation for the years 1995 and 1998-2001. The records were of Haipang airport, near Jos. These data are given in appendix A.

III. Method of Analysis

Values of mean hourly global radiation $\bar{I}$, were calculated from the mean daily values $\bar{H}$, of global radiation using empirical formulae through a conversion factor, $\bar{r_t}$, defined by:

$$\overline{r_t H} = \bar{I} \tag{1}$$

As demonstrated by Hottel and Whillier (1955), and by Liu and Jordan (1960), $\bar{r_t}$ depends essentially on the hour angle ω and the sunrise hour angle ω_s. ω is a unit of time, each hour equaling 15° of longitude, with mornings positive and afternoons negative while ω_s is calculated from

$$\omega_s = \cos^{-1}\{-\tan(\phi)\tan(\delta)\} \tag{2}$$

$\phi = latitude\ of\ location\ (north\ positive)$ and $\delta =$ solar declination, i.e. angular position of the sun at solar noon with respect to the plane of the equator (north positive). $\delta = 9.95^o$ for Jos. δ can be calculated from the approximate equation of Cooper (1969) as:

$$\delta = 23.45\sin\{360(n+284)/365\} \tag{3}$$

or from Molen (2009) as:

$$\delta = 23.45\sin(2\pi n/365 - 1.39) \tag{4}$$

n is the day number counting from January 1st as 1and ending with December 31st as 365, that is $1 \le n \le 365$. Collares-Pereira and Rabl (1979) improved this correlation, which allowed $\overline{r_t}$ to be expressed as a function of the extraterrestrial irradiation as:

$$\frac{\overline{r_t H_o}}{a + b\cos\omega} = \bar{I}_o \tag{5}$$

where ω is the hour angle calculated at the middle of the considered hour and the coefficients a and b are expressed as functions of ω_s by:

$$a = 0.409 + 0.5016\sin(\omega_s - \pi/3) \tag{6}$$

$$b = 0.6609 - 0.4767\sin(\omega_s - \pi/3) \tag{7}$$

$\overline{H}$ and $\bar{I}_o$ are respectively the monthly averages of daily and hourly extraterrestrial irradiations given by

$$\overline{H}_o = \sum_{i=1}^{n_d} H_o / n_d \tag{8}$$

$$\bar{I}_o = \sum_{i=1}^{n_d} H_o / n_d \tag{9}$$

where n_d is the number of days in the considered month and H_o is given by (Duffie & Beckman, 1991):

$$H_o = \frac{24\,x\,3600}{\pi} I_{sc}\left[1 + 0.033\cos(2\pi n/365)\right]\left[\cos(\phi)\cos(\delta)\sin(\omega_s) + \omega_s \sin(\phi)\sin(\delta)\right] \tag{10}$$

where the angles are expressed in radians.

For the hourly extraterrestrial horizontal irradiation, the expression is (Notton, Muselli & Louche, 1996).

$$I_o = \frac{12\,x\,3600}{\pi} I_{sc}\left[1 + 0.033\cos(2\pi n/365)\right]\left[\cos(\phi)\cos(\delta)\left\{\sin\left(\omega + \pi/24\right) - \sin\left(\omega - \pi/24\right)\right\} + \left(\pi/12\right)\sin(\phi)\sin(\delta)\right] \tag{11}$$

Note that $\overline{r_t}$ is simply the ratio of the hourly total to daily total horizontal irradiation. Tiwari (2006) expressed it as:

$$\overline{r_t} = \frac{\pi}{24}\left[a + b\cos(\omega)\right]\frac{\left[\cos(\omega) - \cos(\omega_s)\right]}{\sin(\omega_s) - \omega_s\cos(\omega_s)} \tag{12}$$

The monthly mean hourly total horizontal irradiation $\bar{I}$ has been calculated from the monthly mean daily total horizontal irradiation $\overline{H}$, using equations (1) to (12).

For simplicity, the hourly total and the daily total extraterrestrial irradiations, $\bar{I}_o$ and $\overline{H}_o$ respectively, were calculated from equations (10) and (11), using for n (the day of the year), values of the recommended days for which $\bar{I}_o$ and $\overline{H}_o$ are equal to the monthly averages. These recommended days are shown in table 1.

We adopted a value of I_{sc} = 1367 W/m^2 for the solar constant (Tiwari, 2006), and used the co-ordinates of Jos as {9.95°N, 8.88°E, 1159m}. The declination, δ, was taken from table 1 while the sunrise (or sunset) hour angle, ω_s, was calculated from equation (2).

The mean hourly insolation for the solar noon S_{tm} has been calculated for all months of the year for the 5 years. From this, the mean values of S_{tm} for the 5 years were deduced.

Table 1: Recommended Average Days for Months and Values of n By Months.

Month	n for ith day of month	For the average day of the month: Date i	Day of year n	Declination δ
January		17	17	-20.9
February	31 + i	16	47	-13.0
March	59 + i	16	75	-2.4
April	90 + i	15	105	9.4
May	120 + i	15	135	18.8
June	151 + i	11	162	23.1
July	181 + i	17	198	21.2
August	212 + i	16	228	13.5
September	243 + i	15	258	2.2
October	273 + i	15	288	-9.6
November	304 + i	14	318	-18.9
December	334 + i	10	344	-23.0

Source: Duffie and Beckman, 1991.

IV. Results and Discussion

Maximum irradiance at solar noon

Monthly mean hourly values of maximum irradiance at solar noon S_{tm} have been calculated throughout the 5-year period. The results are presented in appendix B. This is illustrated in fig.1.

It can be seen that S_{tm} is generally higher during the dry season. The maximum value occurs in February at about $3.81 MJ/m^2$. S_{tm} decreases progressively during the rainy season, reaching a minimum value of $2.22\,MJ/m^2$ in July, after which it rises again.

The lower values of S_{tm} during the rainy season can be attributed to the increased absorption of solar radiation by water vapor in the atmosphere and to the reflection of solar radiation back to space by clouds.

Variation of hourly insolation with time of the day

Values of average hourly insolation, $\bar{I}$, at solar noon and at each of the 5 hours on either side of the solar noon have been calculated, averaged and presented in appendix C. A graph of the variation of $\bar{I}$ with time of the day is shown in fig.2. It has its maximum of 3.07 MJm^{-2} at midday while the minima occur at the beginning and at the end of the day. Note the symmetry of $\bar{I}$ about the solar noon.

V. Conclusion

The hourly insolation at Jos was found, on the average, to be 1.70 MJm^{-2}, equivalent to a power rating of about 470 Wm^{-2}. This value of insolation is high enough to encourage the use of solar energy devices and appliances in Jos and its environs, at least at the domestic level.

VI. Recommendations

- In view of the significance of radiation to our biotic environment, we should equip our observatories with the latest and most reliable instruments for measurement of solar radiation and other related quantities.
- Further research should be conducted on solar radiation on tilted surfaces at Jos.

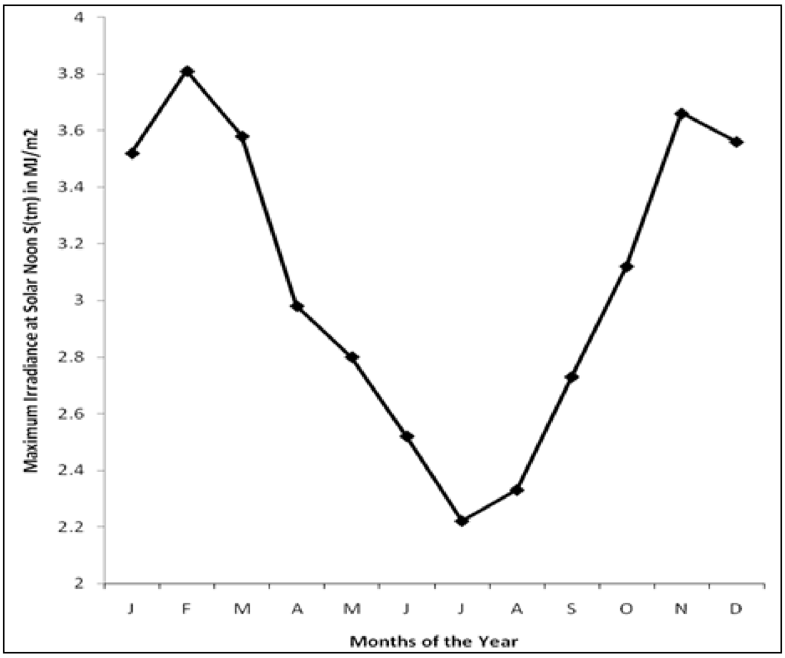

Fig. 1: Variation of S_{tm} with months

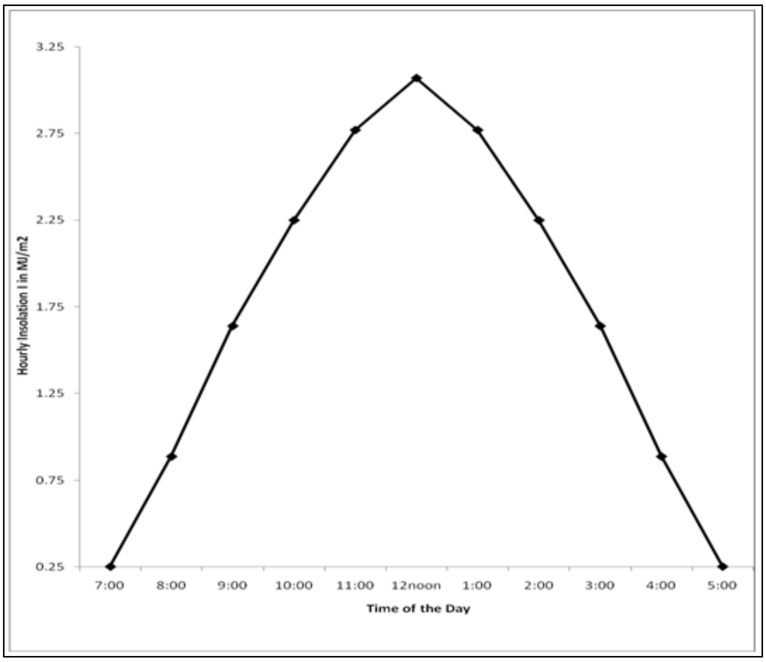

Fig. 2: Variation of $\bar{I}$ with time of day

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Appendix A
Average Daily Insolation at Jos

Global radiation $\overline{H}_G$ in $MJm^{-2}day^{-1}$ converted from ml of $Gunbellani$

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year
1995	23.4	26.0	25.1	23.1	19.5	19.2	15.1	17.5	19.2	21.7	24.2	23.2	21.4
1998	24.6	27.2	25.2	23.7	19.8	18.7	16.1	15.6	18.1	20.2	24.3	23.8	21.4
1999	23.4	24.7	25.3	22.6	19.7	18.6	17.6	15.4	19.9	21.9	24.4	24.4	21.5
2000	24.3	24.3	26.0	21.7	21.9	17.9	16.5	19.5	20.4	21.7	25.6	24.1	22.0
2001	25.8	26.0	26.2	22.6	22.6	20.4	17.3	17.4	20.5	24.6	28.4	26.8	23.2
Mean	24.3	25.6	25.5	22.7	20.7	19.0	16.5	17.1	19.6	22.0	25.4	24.5	21.9

Appendix B
Average Hourly Insolation at Jos

Variation of maximum irradiance at solar noon S_{tm} in MJm^{-2} with time of the day

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year
1995	3.39	3.87	3.52	3.03	2.64	2.57	2.03	2.39	2.67	3.08	3.49	3.38	2.97
1998	3.56	4.04	3.53	3.12	2.68	2.51	2.17	2.13	2.52	2.87	3.51	3.46	3.01
1999	3.39	3.67	3.55	2.96	2.67	2.49	2.37	2.10	2.77	3.11	3.52	3.55	3.01
2000	3.52	3.61	3.65	2.84	2.97	2.40	2.22	2.66	2.84	3.08	3.69	3.51	3.081
2001	3.74	3.87	3.67	2.96	3.06	2.74	2.33	2.38	2.85	3.49	4.10	3.90	3.26
Mean	3.52	3.81	3.58	2.98	2.80	2.54	2.22	2.33	2.73	3.12	3.66	3.56	3.07

Appendix C:
Variation of mean hourly insolation $\overline{I}$ in MJm^{-2} with time of the day

Time	7:00	8:00	9:00	10:00	11:00	12noon	1:00	2:00	3:00	4:00	5:000	$\overline{I}_{dh}$
JAN	0.156	0.897	2.01	2.54	3.17	3.52	3.17	2.54	2.01	0.897	0.156	1.92
FEB	0.207	0.988	1.85	2.66	3.30	3.81	3.30	2.66	1.85	0.988	0.207	1.98
MAR	0.217	1.04	1.86	2.64	3.26	3.58	3.26	2.64	1.86	1.04	0.297	1.98
APR	0.225	0.875	1.57	2.21	2.71	2.98	2.71	2.21	1.57	0.875	0.225	1.65
MAY	0.346	0.915	1.53	2.06	2.56	2.80	2.56	2.06	1.53	0.915	0.346	1.60
JUN	0.338	0.851	1.41	2.00	2.32	2.54	2.32	2.00	1.41	0.851	0.338	1.49
JUL	0.286	0.737	1.22	1.68	2.03	2.22	2.03	1.68	1.22	0.737	0.286	1.29
AUG	0.265	0.739	1.62	1.74	2.13	2.33	2.13	1.74	1.62	0.739	0.265	1.39
SEP	0.249	0.812	1.43	2.04	2.48	2.73	2.48	2.04	1.43	0.812	0.249	1.52
OCT	0.341	0.866	1.59	2.28	2.82	3.13	2.82	2.28	1.59	0.866	0.341	1.72
NOV	0.178	0.947	1.81	2.64	3.30	3.66	3.30	2.64	1.81	0.947	0.178	1.95
DEC	0.137	0.888	1.74	2.56	3.20	3.56	3.20	2.54	1.74	0.888	0.137	1.87
Mean	0.252	0.887	1.64	2.25	2.77	3.07	2.77	2.25	1.64	0.887	0.252	1.70