Solar Radiation in Port Harcourt: Correlation with Sunshine Duration.

A. Chukwuemeka, M.Sc.* **and M.N. Nnabuchi, Ph.D.**

Department of Industrial Physics, Ebonyi State University, Abakaliki, Nigeria.

E-mail: emmyaustine2003@yahoo.com

ABSTRACT

Measurement of global solar radiation and sunshine duration during the period of 1990 – 2007, at Port Harcourt were used to establish an Angstrom type correlation equation. This equation is given by:

$$\overline{H}_P = \left(0.2946 + 0.3059\frac{\overline{n}}{\overline{N}}\right)\overline{H}_O.$$

The correlation coefficient and coefficient of determination are 0.852 and 0.726, respectively. The accuracy of the model was tested by applying the Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE) statistical methods. The results shows that the model can be used for estimating global solar radiation in Port Harcourt and other locations with similar latitudinal variations.

(Keywords: sunshine, clearness index, solar radiation)

INTRODUCTION

In any solar energy conversion system, the knowledge of global solar radiation is extremely important for the optimal design and the prediction of the system performance. The best way of knowing the amount of global solar radiation at a site is to install a pyranometer at many locations in the given region and look after their day-to-day maintenance and recording, which is a very costly exercise. The alternative approach is to correlate the global solar radiation with the meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics for which solar radiation data are not available.

The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface using the sunshine duration data is due to Angstrom (1924). Prescott (1940) had put the Angstrom correlation in a more convenient form as:

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\frac{\overline{n}}{\overline{N}} \qquad \textbf{(1)}$$

where $\overline{H}_M$ is the measured global solar radiation ($MJm^{-2}day^{-1}$), $\overline{H}_O$ is the monthly mean daily extraterrestrial radiation ($MJm^{-2}day^{-1}$), $\overline{n}$ is the monthly mean daily bright sunshine hours, $\overline{N}$ is the maximum possible monthly mean daily sunshine hours or the day length, and (a) and (b) are regression constants.

A number of correlations involving global solar radiation and sunshine duration for different locations in Nigeria have been studied by different researchers. For example, Sambo (1985) developed a correlation with solar radiation using sunshine hours for Kano with the average regression coefficients a = 0.413 and b = 0.241 for all the months between 1980 – 1984. Arinze and Obi (1983) developed a correlation with solar radiation using sunshine hours in Northern Nigeria with regression coefficients a = 0.2 and b = 0.74. Burari, et at. (2001) developed a model for estimation of global solar radiation in Bauchi with regression coefficients a =0.24 and b = 0.46.

Other researchers (Ojosu, 1984), (Fagbenle, 1990), (Folayan, 1983), (Adebiyi, 1988), (Turton, 1987), and (Bamiro, 1983) developed theoretical and empirical correlations of broad applicability to provide solar data for systems designed in most Nigeria cities. We observed that the regression coefficients are not universal, but depend on the climatic conditions. Hence, in this study, we derive the regression coefficients for Port Harcourt, Nigeria.

The converted insolation data are correlated with sunshine hours and global solar radiation and regression equations are obtain with the aid of the SPSS computer software program. The results obtained compared favorably well with the results obtained by Fagbenle (1984) and Turton (1987).

METHODOLOGY

The sunshine duration hours data (1990 – 2007) for Port Harcourt (lat 4.85^0N, long 7.02^0E, and altitude 19.55m), which are the input data for the analysis was collected from the Nigerian Meteorological Agency, Oshodi, Lagos State. The solar radiation data was collected courtesy of the *Renewable Energy for Rural Industrialization and Development in Nigeria* published in Abuja by UNIDO in December, 2003.

DATA ANALYSIS

The global solar radiation data measured in ($Kwhm^{-2}day^{-1}$) was converted to ($MJm^{-2}day^{-1}$) using a factor of 3.6 proposed by Iqbal (1983). The data is presented in Table 1.

The Angstrom–Page linear regression model used in correlating the measured global solar radiation data ($\overline{H}_M$) with the fraction of sunshine ($\frac{\overline{n}}{\overline{\overline{N}}}$) is already given in Equation (1).

The possible daily maximum number of hours of insolation, also called the length of day, is given by Iqbal (1983):

$$\overline{N} = \frac{2}{15} w_s \quad \textbf{(2)}$$

where w_s is the hour angle, expressed as:

$$w_s = Cos^{-1}\left(-\tan\phi\tan\delta\right) \quad \textbf{(3)}$$

where ϕ and δ are the latitude and declination angles, respectively. The declination δ is given by:

$$\delta = 23.45 Sin\left(360\left(\frac{N+284}{365}\right)\right) \quad \textbf{(4)}$$

where N is the day number of the year. The mean monthly daily extraterrestrial radiation $\overline{H}_O$ on horizontal surface is given by the expression:

$$\overline{H}_O = \frac{24}{\pi} I_{sc} E_O \left(\frac{\pi}{180} w_s Sin\phi Sin\delta + Cos\phi Cos\delta Sin w_s\right) \quad \textbf{(5)}$$

Table 1: Meteorological Data and Global Solar Radiation for Port Harcourt.

$\overline{n}$ (hours)	$\overline{N}$ (hours)	$\frac{\overline{n}}{\overline{\overline{N}}}$	$\overline{H}_M$ ($MJm^{-2}day^{-1}$)	$\overline{H}_O$ ($MJm^{-2}day^{-1}$)	$\overline{K}_T = \frac{\overline{H}_M}{\overline{\overline{H}}_O}$
4.72	11.75	0.4017	14.40	34.28	0.4201
4.81	11.84	0.4063	16.26	36.06	0.4509
4.32	11.94	0.3609	15.16	37.52	0.4041
4.70	12.11	0.3881	16.68	37.48	0.4450
4.99	12.22	0.4083	15.16	36.24	0.4183
4.12	12.28	0.3355	13.96	35.13	0.3974
2.56	12.25	0.2089	12.99	35.61	0.3506
2.41	12.11	0.1990	12.52	37.05	0.3516
3.33	11.98	0.2779	14.02	37.26	0.3763
4.22	11.87	0.3555	14.29	36.18	0.3949
5.48	11.77	0.4656	14.00	34.38	0.4072
5.72	11.72	0.4881	14.37	33.19	0.4329

where I_{sc} is the solar constant in ($MJm^{-2}h^{-1}$). The value of I_{sc} used in this work is 4.921MJ/m2/day

E_O is the eccentricity correction factor of the Earth's orbit. The value of E_O is given by Liou (1980):

$$E_O = 1 + 0.033 Cos\left(\frac{360N}{365}\right) \quad \textbf{(6)}$$

The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), the Root Mean Square Bias Error (RMSE), and the Mean Percentage Error (MPE). The expressions for the MBE ($MJm^{-2}day^{-1}$), RMSE ($MJm^{-2}day^{-1}$), and MPE (%) is stated by El – Sebaii et al. (2005) as follows:

$$MBE = \left[\sum\left(\overline{H}_{i,cal} - \overline{H}_{i,meas}\right)\right]/n \quad \textbf{(7)}$$

$$RMSE = \left[\sum\left(\overline{H}_{i,cal} - \overline{H}_{i,meas}\right)^2 / n\right]^{\frac{1}{2}} \quad \textbf{(8)}$$

$$MPE = \left[\sum\left(\frac{\overline{H}_{i,meas} - \overline{H}_{i,cal}}{\overline{H}_{i,meas}} X100\right)\right]/n \quad \textbf{(9)}$$

where $\overline{H}_{i,cal}$ and $\overline{H}_{i,meas}$ is the calculated (predicted) and measured values, respectively, and n is the total number of observations.

Iqbal (1983), Halouani (1993), Almorox (2005), and Che et al. (2007) have recommended that a zero value for MBE is ideal and a low RMSE is desirable. The RMSE test provides information on the short-term performance of the studied model as it allows a term–by–term comparison of the actual deviation between the calculated values and the measured values.

The MPE test gives long-term performance of the examined regression equations, a positive MPE values provide the averages amount of overestimation in the calculated values, while the negative values gives the underestimation. A low value of MPE is desirable according to Akpabio et al. (2002).

RESULTS AND DISCUSSION

The regression constants (a) and (b) for Port Harcourt were determined by correlating the solar radiation with sunshine duration hours. The constants (a) and (b) were found to be 0.2946 and 0.3059, respectively. A comparison of these constants with those determined by Fagbenle (1990), (a = 0.31, b = 0.42), shows that there is agreement. Similarly, there is agreement with those estimated by Turton (1987), (a = 0.30 , b = 0.40).

The results of the regression analysis shows that the correlation coefficient (R) and coefficient of determination (R^2) are 0.852 and 0.726, respectively. The value of (R) shows a clear linear correlation between the sunshine hours and measured solar radiation. The value of (R^2) shows that 72.6% of the clearness index can be account for using sunshine hours. The values of the MBE, RMSE, and MPE are given as follows: MBE = -0.0108, RMSE = 0.5861 and MPE = 0.5080% .

The variations of sunshine hours and solar radiation are presented in Figures 1 and 2. From Figure 1, The highest and lowest levels of sunshine hours occurs in the month of December and August, respectively. The Monthly mean daily solar radiation pattern can be better explained in terms of dry and rainy seasons of Port Harcourt. The highest global solar radiation level (16.68$MJm^{-2}day^{-1}$) occurs in the dry season in the month of April and the radiation is generally lower (12.52 $MJm^{-2}day^{-1}$) in the rainy season in the month of August (Figure 2). This low value is due mainly to the prevailing rainy/cloudy conditions during this month.

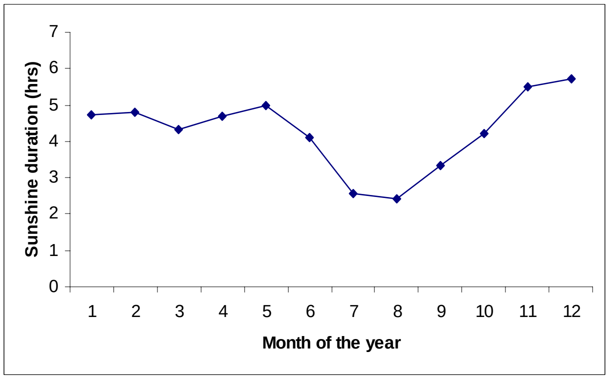

Figure 1: Monthly Variation of Sunshine.

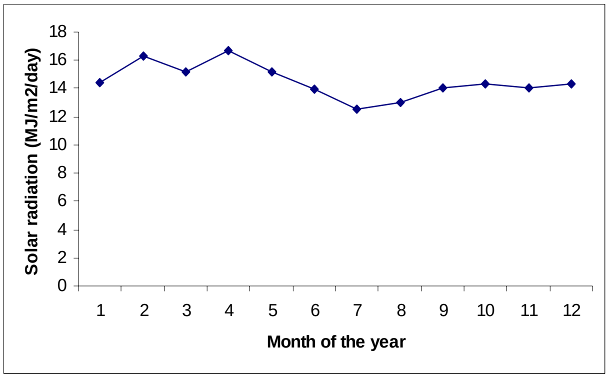

Figure 2: Monthly Variation of Solar Radiation.

A comparison of the monthly distribution of the measured with the predicted global solar radiation is presented in Figure 3. Figure 4 shows a scatter diagram of the clearness index and sunshine duration.

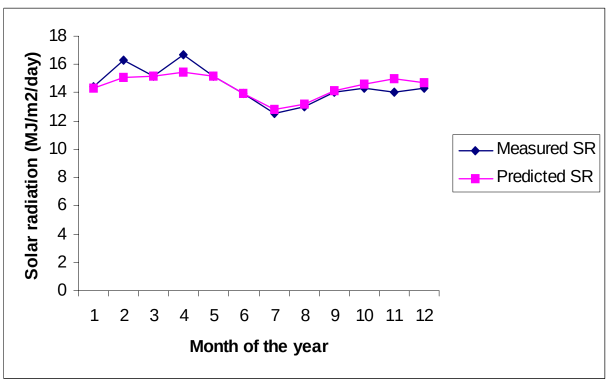

Figure 3: Comparison Between Measured and Predicted Solar Radiation.

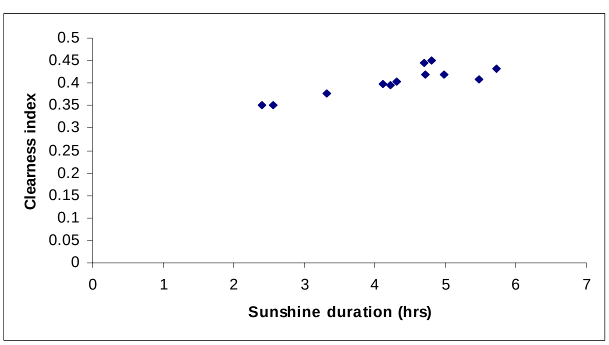

Figure 4: Scatter Diagram Showing Clearness Index and Sunshine.

CONCLUSION

The SPSS computer software program has been employed for estimating the climatic constants (a) and (b), and the monthly mean daily global solar radiation for the city of Port Harcourt. A comparison between the constants (a) and (b) obtained from this work and other research investigators, including Fagbenle (1990) and Turton (1987), shows satisfactory agreement.

Global solar radiation generally increases with latitude. The month of April experiences the highest global solar radiation in the city of Port Harcourt with the value of 16.68MJm^{-2}day^{-1} while the month of August recorded the least value (12.52 MJm^{-2}day^{-1}) of global solar radiation in the same location. The model:

$$\overline{H}_P = \left(0.2946 + 0.3059\frac{\overline{n}}{\overline{N}}\right)\overline{H}_O$$

is recommended for use in computing the design values of global solar radiation in any location in Nigeria.

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ABOUT THE AUTHORS

Augustine Chukwuemeka, M.Sc., is an Assistant Lecturer in the Department of Industrial Physics, Ebonyi State University, Abakaliki, Nigeria. His research interests are in developing models for estimating global solar radiation.

M.N. Nnabuchi, Ph.D. serves on the faculty of the Department of Industrial Physics at Ebonyi State University in Abakaliki, Nigeria. Dr. Nnabuchi’s research interest center on the application of chemical bath deposition techniques and the characterization of novel materials for solar cells and other optical applications.

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