International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Comparative Valuation of Global Solar Radiation on Horizontal and Tilt Surfaces in Owerri, Nigeria

[1]Njoku, M.C., [2]Ezeadi, U.C., [3]Ezeka, J.O., [4]Ikonne, J.K., [5]Ezewuzie, U.J., [6]Godwin, D.U., and [7]Ezedeyimobi, S.O.

[1,2,3,4,5,6,7]Department of Mechanical Engineering, Federal Polytechnic Nekede, P.M.B. 1036 Owerri, Imo-State, Nigeria

Corresponding author:Njoku M.C., Department of Mechanical Engineering, Federal Polytechnic Nekede, P.M.B. 1036 Owerri, Imo-State, Nigeria. ***E-mail:*** mnjoku@fpno.edu.ng

DOI: https://doi.org/10.55248/gengpi.2022.31235

ABSTRACT

Comparative valuation of global solar radiation on horizontal and tilt surfaces with the use of Angstrom-Page and four isotropic models for Owerri has been carried out in this paper. Angstrom linear regression model is developed from thirty years (1992-2022) of sunshine hour and average monthly global solar radiation sourced from NIMET and NASA, respectively. The Angstrom regression coefficients a and $b$determined for Owerri is 0.210 and 0.696, respectively. The developed model is used to estimate average monthly global solar radiation on horizontal surface and consequently, the amount of incident solar radiation received on tilt surface by the isotropic models. The MBE, RMSE and MPE values are estimated to be 0.0083, 0.0029 and -0.0041%, respectively, for the developed Angstrom-Page model. A strong coefficient of determination of 76.6% was obtained and Analysis of Variance (ANOVA) significant of 100% was observed, which shows the goodness of fitness of the model. Among the isentropic models studied, one of the models poorly estimated solar radiation on horizontal and tilt surfaces for the study location.

Keywords: Angstrom-Page model, isotropic model, regression constant, solar radiation, statistical parameters

1.0 Introduction

Energy generation and supply are prerequisite for economic and sustainable development of a nation. Increase in consumption of conventional energy sources for power generation by most countries of the world have triggered serious environmental issues such as global warming, air-pollution and health related problems. As the need to save the planet has necessitated calls for change in types of energy sources usage that is environmentally friendly, readily available, abundant and safe [1-2].

Among the non-conventional energy sources, solar energy is perhaps the most feasible alternative and sustainable energy source in the world [3]. Solar energy is a form of renewable energy harness from the sun. The quantity of solar energy prediction in Nigeria makes it a vital alternative source of energy for domestic and industrial usage [4]. Solar radiation is fairly well distributed in Nigeria as average sunshine hour is estimated at 6hours per day and the mean average total solar radiation varies from 3.5 $kWhm^{-2}day^{-1}$ in the coastal latitudes to about 7 $kWhm^{-2}day^{-1}$ along the semi-arid areas in the far North [5]. The harvest of this large amount of energy will be essential for economic growth and reduce over-dependence on fossil fuel usage in Nigeria.

Optimal design and performance evaluation of solar collectors require the use of meteorological data of the location where solar appliances are to be installed. Among the meteorological data, incident solar radiation on horizontal surface and successively tilt solar radiation is of utmost importance. At present, the Nigeria Meteorological Agency (NIMET) which is a federal government agency that is responsible for measurement of meteorological parameters across the country does not measure solar radiation. This has led to the use of correlations to estimate solar radiation of any location within the country with the use of available measured meteorological data such as sunshine hour, temperature, relative humidity, etc.

The Angstrom-Page model is a linear relationship between the ratio of measured global solar radiation to the estimated extraterrestrial solar radiation of a given location and the ratio of measured sunshine hour to estimated sunshine duration of the same location. This model which uses sunshine for estimation of global solar radiation have been used by several researchers in Nigeria to predict the value of global solar radiation of different locations. Gana and Akpootu [6] estimated the global solar radiation of Kebbi in north-east Nigeria with the use of four sunshine base models. Kaltiya et al. [7] used the Angstrom-Page model to predict the global solar radiation of Markurdi in Benue state, Nigeria. Taura et al. [8] estimated global solar radiation and its derivate over two vegetation zones of Jigawa. Based on meteorological data, Auwal and Darma [9] estimated the global solar radiation of Kano, Nigeria. Isikwue et al. [10] used empirical models to estimate the global solar radiation of Makurdi, Nigeria. Augustine and Nnabuchi [11] studied global solar radiation and relationship between sunshine hours of three cities in Nigeria.

The main objective of this study is to evaluate Angstrom regression coefficients, thereby, develop a correlation and estimate monthly global solar radiation incident on horizontal surface for Owerri and subsequently, carryout a comparative evaluation of four isotropic models for the estimation of solar radiation on tilt surface for the study location.

2.0 Material

Owerri is the capital city of Imo-State, located in the south-eastern part of Nigeria at an elevation of 120 meters above sea level and suited on latitude 5.49^{o}N and longitude 7.03^{o}N. For the study location, thirty years (1992-2022) of measured sunshine hour and monthly global solar radiation are sourced from Nigerian Meteorological Agency (NIMET), Lagos [12] and National Aeronautics and Space Agency (NASA) [13], respectively. A conversion factor of 3.6 is used to convert the monthly global solar radiation measured in KWm^{-2}day^{-1} to MJm^{-2}day^{-1} as proposed by [13].

3.0 Methodology

3.1 Estimation of Monthly Average Solar Radiation

To predict the amount of incident solar radiation on horizontal surface from measured hours of bright sunshine, the Angstrom-Page model is employed. The Angstrom-Page model equation is based on extraterrestrial radiation on a horizontal surface and it is give as [14]

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{n}}{\bar{N}} \qquad (1)$$

Where $\bar{H}$ is the monthly global solar radiation on horizontal surface (MJm^{-2}day^{-1}), $\bar{H}_O$ is the monthly extraterrestrial radiation for the study location (MJm^{-2}day^{-1}), $\bar{n}$ is the monthly hours of bright sunshine, $\bar{N}$ is the monthly maximum possible hours of bright sunshine and a and b are empirical constants to be determined.

The monthly extraterrestrial radiation for the study location is given as [15]

$$\bar{H}_o = \frac{24\ x3600G_{sc}}{\pi}\left(+0.033cos\frac{360n}{365}\right)x\left(cos\emptyset cos\delta sin\omega_s + \frac{\pi\omega_s}{180}sin\emptyset sin\delta\right) (2)$$

where G_{sc} is the solar constant given as 1367W/m^2 [13], n is the day of the year, $\emptyset$ is latitude of study location, δ is the solar declination and ω_s is the sunset hour angle.

The declination (δ) and sunset hour angle (ω_s) can be calculated from the following equations [15]

$$\delta = 23.45sin\left[\frac{360}{365}(284+n)\right] \qquad (3)$$

$$\omega_s = cos^{-1}(-tan\emptyset tan\delta) \qquad (4)$$

The monthly maximum possible hours of bright sunshine is given as [15]

$$\bar{N} = \frac{2}{15}cos^{-1}(-tan\emptyset tan\delta) \qquad (5)$$

3.2 Estimation of Titled Solar Radiation

For maximum performance and effective harness of solar energy, flat plate solar collectors are usually tilt to an angle. Hence, the evaluation of the performance of solar collectors require the knowledge of the actual amount of solar radiation incident upon flat plate solar collector when in tilt position. Empirical methods are usually employed to predict the quantity of solar radiation incident on tilt solar collector from horizontal values. The average monthly global solar radiation incident on tilt surface $(\bar{H}_T)$ for an isotropic model consists of three components: beam radiation, diffuse radiation and ground reflected radiation. Thus, mathematically stated as

$$\bar{H}_T = \bar{H}_{Beam} + \bar{H}_{Diffuse} + \bar{H}_{ground} \quad (6)$$

Equation (6) can be written as [15]

$$\bar{H}_T = \bar{H}\left(1 - \frac{\bar{H}_d}{\bar{H}}\right)\bar{R}_b + \bar{H}_d\bar{R}_d + \bar{H}\rho_g\left(\frac{1 - \cos\beta}{2}\right) \quad (7)$$

Whereβ is the slope angle ofsolar collector.

Furthermore, for optimal performance of solar collectors, Ref. [15] suggested that the latitude of the study location should be the slope angle of the solar collector. Thus, the latitude of the study location is taken as solar collector slope tilt angle. Where ρ_g is the ground reflectance taken as 0.2 for the study location [15], $\bar{H}_d$ is the diffused radiation which depends on the value of clearness index$(K_T = \bar{H}/\bar{H}_o)$and it is given as [16]

For $\omega_s \leq 81.4^o \, and \; 0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 (8)$$

And for $\omega_s > 81.4^o \, and \; 0.3 \leq \bar{K}_t \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \quad (9)$$

Liu and Jordan [17] suggested that the geometric factor (R_b) which is a ratio of the average daily beam radiation on a tilt surface to that on a horizontal surface for the month can be estimated assuming that it has the value which would be obtained if there were no atmosphere. For solar collector in the northern hemisphere and sloped towards the equator, the geometric factor is given as

$$\bar{R}_b = \frac{cos(\emptyset - \beta)\, cos\delta sin\omega_s' + (\pi/180)\omega_s' sin(\emptyset - \beta) sin\delta}{cos\emptyset cos\delta sin\omega_s + (\pi/180)\omega_s sin\emptyset sin\delta} \quad (10)$$

Where ω_s' is the sunset hour angle for the tilt surface for the mean day of the month.

$$\omega_s' = min\begin{bmatrix} cos^{-1}(-tan\emptyset tan\delta) \\ cos^{-1}(-tan(\emptyset - \beta) tan\delta) \end{bmatrix} \quad (11)$$

The minimum value of the two quantities in Equation (11) is used.

Mainly, two types of models are used to estimate solar radiation incident on a tilt solar collector; isotropic and anisotropic models. The basic difference is the way each of the models treats the diffuse fraction of the solar radiation. The isotropic model assumes that the intensity of diffuse sky radiation is uniform over the sky dome. Hence, the diffuse radiation incident on a tilt surface depends on the fraction of the sky dome seen by it. The anisotropic model assumes the anisotropy of the diffuse sky radiation in the circumsolar region (sky near the solar disc) plus an isotropic distributed diffuse component from the rest of the sky dome. The isotropic diffuse model is conservative and makes calculation of radiation on tilt surface relatively easy [15]. Several authors have proposed different models for prediction of isotropic view factor of diffuse radiation incident on tilt surface. Among which are:

Model 1: Liu and Jordan Model [17]

$$\bar{R}_d = \frac{1 + cos\beta}{2} \quad (12)$$

Model 2: Koronakis Model [18]

$$\bar{R}_d = \frac{1}{3}[2 + cos(\beta)] \quad (13)$$

Model 3: Tian et al. Model [19]

$$\bar{R}_d = 1 - \beta/180 \quad (14)$$

Model 4: Badescu Model [20]

$$\bar{R}_d = \frac{3 + cos(2\beta)}{4} \qquad (15)$$

3.2 Statistical Evaluation

To test the accuracy of the Angstrom-Page model developed for the study location, the values of Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE) are estimated. The MBE values indicate the average deviation of the predicted values from the measured data. Ideally, a zero value of MBE should be obtained. However, a low MBE is desired. A positive value gives the average amount of overestimation, while, a negative value gives the average amount of underestimation. The RMSE values measures the variation of the predicted values around the measured data. The value of RMSE is usually positive, a zero value is ideal and the smaller the value, the better the model performance. The values of MPE is an indicator of the accuracy of the data expressed in percentage. MPE of low value or zero is ideal.

$$MBE = \frac{\sum(H_{i,cal.} - H_{i,mea.})}{n_p} \qquad (16)$$

$$RMSE = \left[\frac{\sum(H_{i,cal.} - H_{i,mea.})^2}{n_p}\right]^{1/2} \qquad (17)$$

$$MPE = \frac{\left[\sum\left(\frac{H_{i,mea.} - H_{i,cal.}}{H_{i,mea.}} x\ 100\right)\right]}{n_p} \qquad (18)$$

Where $H_{i,cal.} and\ H_{i,mea.}$ are the calculated and measured monthly average solar radiations, respectively, and n_p is the number of possible outcome.

4.0 Results and Discussion

The regression coefficients estimated from the regression analysis of the metrological data for Owerri is $a = 0.210$ and $b = 0.696$. Hence, the Angstrom-Page equation for Owerri can be written as

$$\frac{\bar{H}}{\bar{H}_o} = 0.210 + 0.696\left(\frac{\bar{n}}{\bar{N}}\right) \qquad (19)$$

From the statistical analysis of the Angstrom-Page equation developed from the study location, the values of MBE, RMSE and MPE estimated for the study location are 0.0083, 0.0029 and -0.0041 % respectively. A low value of MBE is obtained. This indicate that the deviation between global solar radiation calculated value and the measured value from NASA meteorological website is small and desirable. A positive and small value of RMSE is estimated. This reveals better performance of the model for the study location. The MPE value which indicates the accuracy of the model, recorded a very low value. This further reveal that the model developed for Owerri is accurate.

From the model summary of the IBM SPSS statistic result, the value of coefficient of determination (R^2) was observed to be 0.766. This result implies that 76.6 % of the variance was explained. This indicate that the model is efficient and strong. More also, from the Analysis of Variance (ANOVA) table, a significant of0.000^b is obtained. This means that the regression model developed for the study location is significant at 100 %. Hence, the Angstrom-Page of Equation (19) for Owerri is accepted.

Table 1 meteorological data for Owerri

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
$\bar{H}$	19.91	20.21	19.15	18.32	16.99	15.48	13.86	13.57	14.18	15.34	17.42	19.04
$\bar{n}$	5.26	5.58	4.53	5.10	5.78	4.54	3.08	2.46	3.20	4.16	5.66	5.66

The graph of Figure 1 shows the measured monthly global solar radiation and the calculated solar radiation estimated from the Angstrom-Page regression model of Equation (19) for each month in Owerri. The fall in both measured and calculated monthly global solar radiation between May and September represents the period of rainy season in Owerri during which solar radiation intensity is low. This is more obvious in August which recorded the lowest solar radiation for both measured and calculated solar intensity. This is attributed to the fact that Owerri is located in the rain belt of south east Nigeria during which August is observed to have the highest rainfall annually, hence, heavy overcast weather conditions periodically exist.

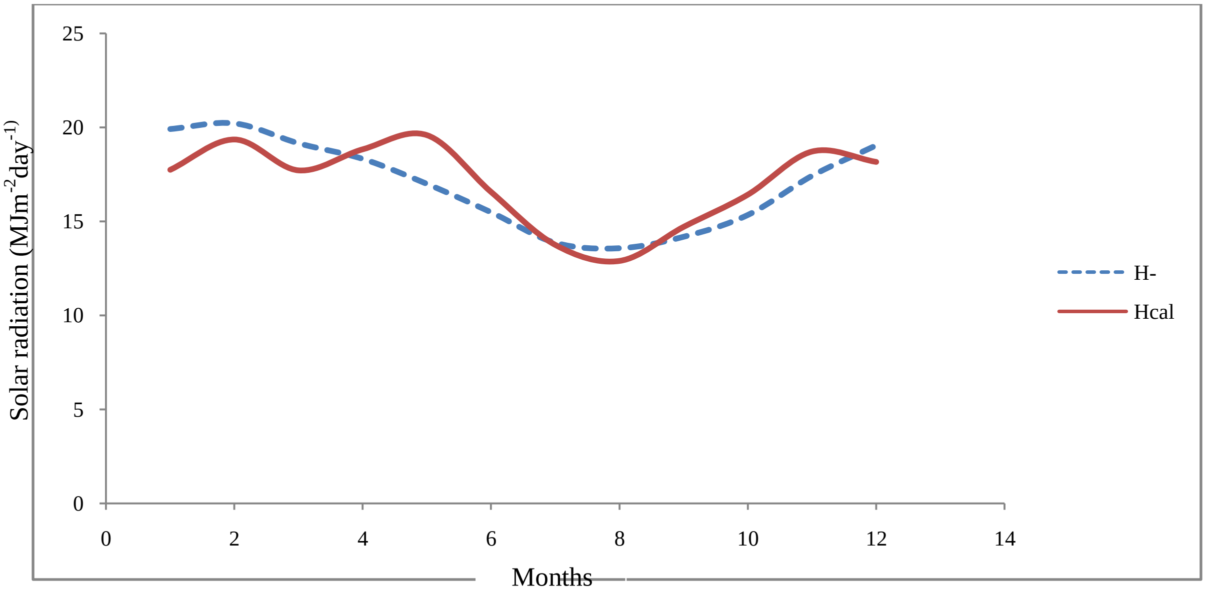

Figure 1 measured and calculated solar radiation for Owerri

Table 2 shows the calculated monthly global solar radiation on horizontal surface and monthly tilt solar radiation calculated from the isotropic models. The tilt solar radiation is calculated for each month of the year with the use of different isotropic view factor model as shown in Figure 2. The mathematical expression of Equation (7) shows that the calculated and diffuse monthly average solar radiation incident on horizontal surface has significant contributions to the monthly average solar radiation incident on a tilt surface. It is observed that for each month, Liuand Jordan [17], Koronakis[18] and Badescu [20] models estimated almost the same values and their annual tilt solar radiation values are within the same range. While, the isotropic model proposed by Tian et al. [17] estimated the lowest value for each month and subsequently low annual tilted solar radiation for the study location.The Tian et al. [19] model is observed to record lower value of tilt global solar radiation than the calculated monthly average global solar radiation on horizontal surface of Equation (19) i.e. the Angstrom-Page model for Owerri. This obviously points out that portion of the beam, diffuse and ground reflectance radiation incident on a tilted surface are not adequately accounted for by this model. Though, within the months of January, February and December, Tian et al. model showed slight increase than the calculated monthly average solar radiation. But the value for these months are small compared to those of Liu and Jordan, Koronakis and Badescu models as shown in Table 2. From Figure 2, it is seen that the value for Liu and Jordan, Koronakis and Badescu models exceeded the value of the calculated monthly average horizontal solar radiation for all the months of the year which is expected. Thisindicate that the diffuse and ground reflection have effective contribution to the total value of the tilted solar radiation.

Table 2 Horizontal and tilted solar radiation from the models

	$\bar{H}_{cal}$	**Liu and Jordan**	**Koronakis**	**Tian et al**	**Badescu**
January	17.74	25.12	25.13	19.50	25.11
February	19.35	26.29	26.29	19.64	26.27
March	17.71	23.22	23.22	16.31	23.20
April	18.83	24.23	24.23	16.51	24.21
May	19.58	25.31	25.32	16.88	25.29
June	16.56	21.50	21.51	13.82	21.49
July	13.75	17.79	17.79	10.57	17.77
August	12.90	16.63	16.64	9.52	16.61
September	14.71	19.10	19.10	11.19	19.08
October	16.42	21.84	21.84	13.84	21.82
November	18.71	25.92	25.92	18.62	25.90
December	18.16	26.03	26.04	19.96	26.02
TOTAL	204.42	272.98	273.03	186.36	272.77

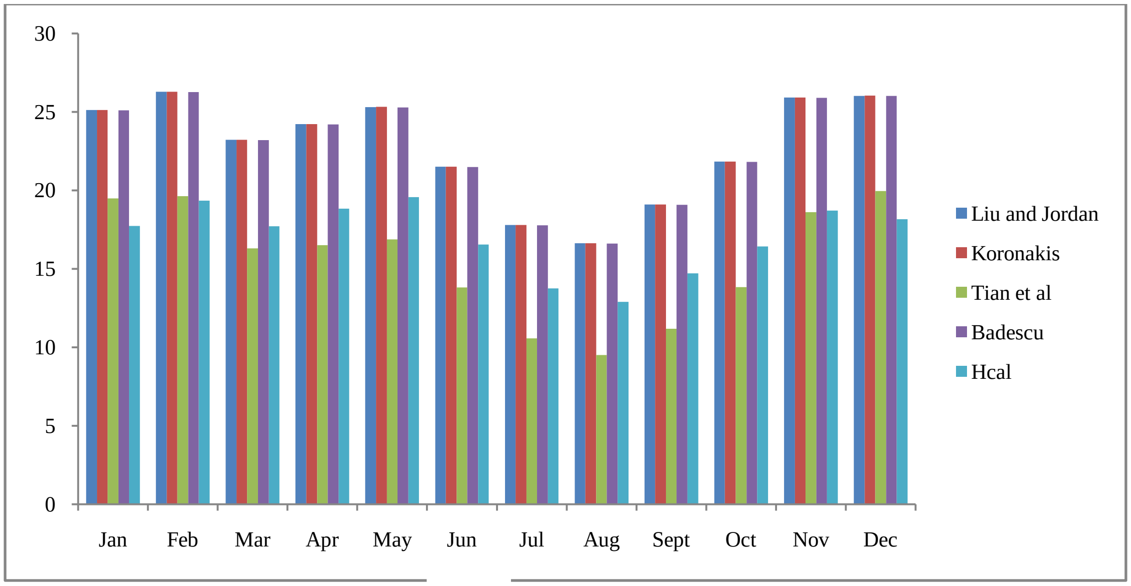

Figure 2 Horizontal and different model of tilted monthly solar radiation

5.0 Conclusion:

From the study of prediction of solar radiation incident on horizontal and comparative assessment of titled solar radiation for Owerri, it is established that the linear Angstrom-Page model developed can be used for the estimation of solar radiation values for Owerri and other locations with similar meteorological parameters. To evaluate solar radiation incident on a titled solar collector at the study location Liu and Jordan, Koronakis orBadescu models can be used as the three models haveshown to estimate the values of tilted solar radiation within similar range in comparison with the estimated solar radiation on a horizontal surface.

References:

[1] Li, H., Ma, W., Lian, Y. and Wang, X. (2010): Estimating daily global solar radiation by Day of Year in China. Appl. Energy., 87: 3011-3017.

[2] Jakhrani, A. Q., Raza, S., Rigit, A.R.H. and Kamboh, S.A. (2013): Selection of Models for Calculation of Incident Solar Radiation on Tilted Surface. World Appl. Sci. Journal, 22(9): 1334-1343

[3] Shukla, K.N., Sudhakar, K. and Rangnekar, S. (2015): Estimation and Validation of Solar Radiation Incident on Horizontal and Tilted Surface at Bhopal, Madhya Pradesh, India. American-Eurasian J. Agric. Environ. Sci., 15 (1): 129-139, 2015ISSN 1818-6769

[4] Sambo, A.S. (2009): Strategic Developments in Renewable Energy in Nigeria. International Association for Energy Economics. 15-19

[5] Njoku, M.C., Ofong, I., Ogueke, N.V., and Anyanwu, E.E. (2018): Charaterization of Sky Conditions at Benin City and Owerri in Nigeria. Journal of Fundamentals of Renewable Energy and Applications. 8:5, 1-8.

[6] Gana, N.N. and Akpootu, D.O. (2013): Estimation of Global Solar Radiation Using Four Sunshine Based Models inKebbi, North-Western, Nigeria. Pelagia Research Library, Advances in Applied Science Research, 4(5):409-421

[7] Kaltiya, M.S., Abubakar, M.S. and Itodo, I.N. (2014): Prediction of Global Solar Radiation Using Angstrom-Page Equation Model for Makurdi Benue State, Nigeria. American Journal of Engineering Research (AJER); 3(8), 145-150

[8] Taura, L.S., Musa, A.O. and Saleh, S. (2012): Estimation of the Global Solar Radiation and its Derivatives over the Two (2) Vegetation Zones of Jigawa State. European Journal of Scientific Research. 79(1), 99-109

[9] Auwal, M. and Darma, T.H. (2014): Estimation of Global Solar Radiation for Kano State Nigeria Based on Meteorological Data. IOSR Journal of Applied Physics (IOSR-JAP). 6(6), 19-23

[10] Isikwue, B.C., Amah, A.N. and Agada, P.O. (2012): Empirical Model for the Estimation of Global Solar Radiation in Makurdi, Nigeria. Global Journal of Science Frontier Research Physics & Space Science. 12(1) Version 1.0

[11] Augustine, C. and Nnabuchi, M.N. (2009): Relationship between Global Solar Radiation and Sunshine Hours for Calabar, Port Harcourt and Enugu, Nigeria. International Journal of Physical Sciences. 4 (4), 182-188

[12] Nigerian Metrological Agency (NiMET) Oshodi, Lagos

[13] National Aeronautics and Space Administration (NASA). http://power.larc.nasa.gov/data-access-viewerAccessed October 16, 2022

[14] Igbal, M. (1983): An introduction to solar radiation. Academy Press. New York.

[15] Duffie, J. A. and Beckman, W.A. (2013): Solar Engineering of Thermal Processes. John Wiley & Son Inc.

[16] Erbs, D.G., Klein, S.A. and Duffie, J.A. (1982) Estimation of the Diffuse Radiation Fraction for Hourly, Daily and Monthly- Average Radiation. Solar Energy 23: 293-295

[17] Liu, B.Y.H and Jordan, R.C. (1962): Daily Insolation on Surfaces Tilted Towards the Equator. Trans ASHRAE 67: 526–541

[18] Koronakis, P.S. (1986): On the Choice of the Angle of Tilt for South Facing Solar Collectors in the Athens Basin Area. Solar Energy; 36:217.

[19] Tian, Y.Q., Davies-Colley, R.J., Gong, P., and Thorrold, B.W. (2001): Estimating Solar Radiation on Slopes of Arbitrary Aspect. Agric. Forest Meteorol; 109:67–7

[20]. Badescu, V. (2002): A New kind of Cloudy Sky Model to Compute Instantaneous Values of Diffuse and Global irradiance. Theor. Appl. Climatol; 72:127–36.