Estimation of hourly solar radiation on an incline south facing surface in Port Harcourt city, Nigeria

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Abstract— The paper presents a simple method for estimating hourly solar radiation on an incline south facing surface. The method used is the Duffie and Beckman approach for estimating hourly solar radiation on an incline surface using some climatic data in Port Harcourt city, Nigeria. The key climatic data used are latitude, declination and clear index. The results show enormous potential of solar radiation from sunrise to sunset per day in the city. For the estimated days, December showcases highest radiation with lowest in June and if it is utilized for energy, it will reduce carbon dioxide (CO_2) level in the city.

Keywords: Carbon dioxide (CO_2), Duffie and Beckman, solar radiation, declination, latitude, clear index.

1 Introduction

Global warming has raised issues and interest concerning the rising CO_2 emission globally by conventional plants and systems. These interests are geared towards alternative sources of energy such as solar and wind energy that are environmentally friendly. Solar energy reaching the earth each year is approximately 10000 times the world energy consumption. It is a huge resource, renewable, clean and safe, available in all regions of the world, which today raise new hopes to answer energy crisis and climatic issues [1]. Solar energy reaching the earth in tropical zones is about 1kW/m2 giving approximately 5 to 10 kWh/m2 per day. In countries within 3200km of the equator, uses of such energy can be economically significant [2]. The study of the available solar radiation on a particular location is essential for the application of devices that use solar energy. Solar radiation estimation is also a key for the design and determination of the amount of energy produce by solar energy devices. The crucial role played by information on solar radiation parameters in its exploitation necessitates the need to develop ways of estimating the incident solar radiation for the benefits of the region of the world like Africa, where such routine measurement is lacking despite the abundance of solar energy in the region [3]. Due to this fact, researchers have come up with different approaches in determining the amount of solar radiation reaching the earth atmosphere and surface. A self calibrating method using air tempertaure based equation was used for predicting daily and monthly radiation in [4] and regression coefficients of Angstrom type correlation is used for estimating solar radiation in [5,6] while in [7] a multiple linear regression models was developed to estimate the monthly average daily global solar radiation in Onne, Nigeria.

Port-Harcourt city is located at the southern part of Nigeria is the second most industrialized city in the country. Due to its position, there is daily influx of people and cars which has lead to increasing daily energy demand in the city. Most of the companies in the city are either exploring or burning of fossil fuel for energy or for production and this has resulted to constant increase of CO_2 emission in the city.

This paper is aimed at the estimation of hourly solar radiation of tilt (45˚) south facing surface in the city, for possible application by renewable energy devices so as to reduce the level of CO_2 emission and also play some part in the reducing dependency on conventional electricity generation in the city and the possible reduction in the increasing demand for energy. The simple approach used in this paper is the duffie and Beckman method in [8].

2 Methodology

The data used for the estimation include declination, clear index = 0.65, ground reflectivity= 0.6, location (lat = 4.43N, long 7.05E), n = day number of the year.

Declination, δ

$$\delta = 23.45 \sin (360(284+n/365) \qquad (1)$$

Sunset hour angle (W_s)

This is the solar hour angle corresponding to the time when the sun set and the day length are 2 W_s.

$$\cos W_s = -\tan\phi \tan\delta. \qquad (2)$$

Daylight hours (N)

$$N = 2\, W_s /15 \qquad (3)$$

$$N = 2/15 * \cos^{-1}(-\tan\Phi \tan\delta)$$

Then sunrise hour = 12.00(noon)-N/2

Sunset hour = 12.00(noon)+N/2

Solar hour angle is now given by ω = 15(12-t) degree, where t is solar time (24 Hrs format) from sunrise to sunset.

ISSN 2229-5518

Incident angle (θ) and solar zenith angle (θ_z) starting from sunrise hour to sunset hour

$$Cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega$$

$$+\cos\delta\sin\Phi\sin\beta\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega \quad (4)$$

$$Cos\ \theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega \quad (5)$$

Calculation of Beam radiation (R_b) on the tilted plane and horizontal plane is given by

$$R_b = Cos\theta /\ Cos\ \theta \quad (6)$$

Calculation of Global solar radiation (G_o)

$$G_o = G_{sc}[1+0.033\cos(360/365n)]\ Cos\ \theta_z \quad (7)$$

$$G_{sc} = 1367 W/m^2$$

The total daily extraterrestrial radiation on a horizontal plane H_o is given by integrating the above equation from sunrise to sunset. Hence $H_o = G_o$* time, time in every one hour [5].

Calculation of Solar radiation at earth surface with use of clear index K_t

$$Clear\ index\ K_t = H/H_o \quad (8)$$

Calculation of diffuse (H_d) and beam (H_b) radiation

When the solar hour angle is less than 81.4° and K_t lies in between 0.3 and 0.8

$H_d/H = 1.391-3.56K_t + 4.189K_T^2 - 2.137K_t^3$ and when solar hour angle is greater than 81.4 and K_t lies in between 0.3 and 0.8 we use this equation

$$H_d/H = 1.311-3.022K_t + 3.427K_T^2 - 1.821K_t^3$$

Therefore the average beam radiation

$$H_b = H - H_d \quad (9)$$

Calculation of solar radiation on an inclined surface (H_T)

$$H_T = H_bR_b + H_d(1+\cos\beta/2) + H\rho(1-\cos\beta/2) \quad (10)$$

Where ϱ is given as ground reflectivity which varies from 0.3 to 0.8

3 HOURLY ESTIMATED RESULTS

From the above equation (1) – (10), the hourly solar radiation and the application of the climatic datas, the results where estimated for different days of each month of 2011 as shown in figure 1 – figure 12.

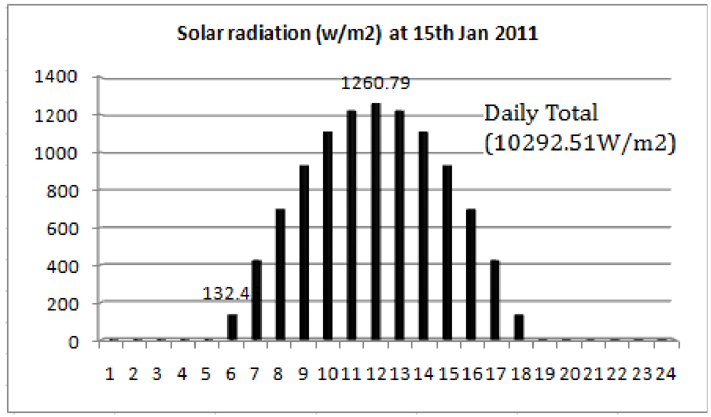


Figure 1

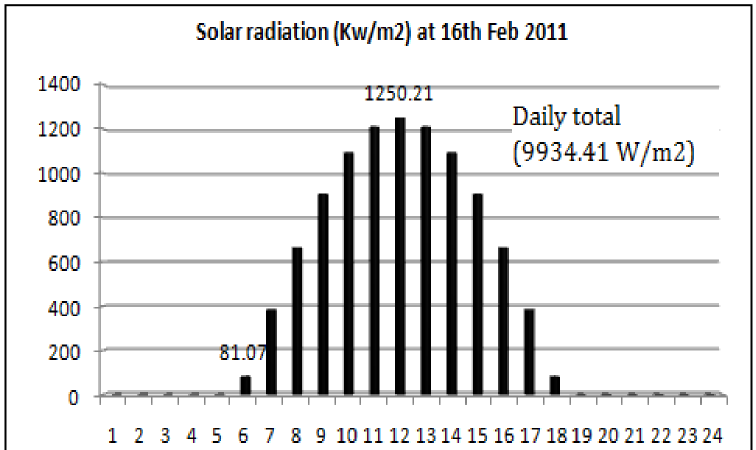


Figure 2

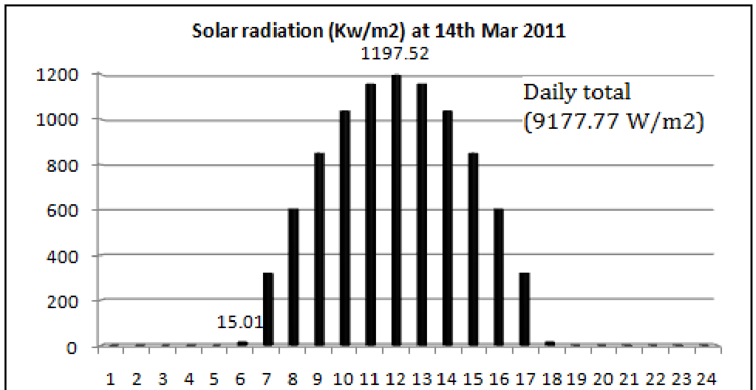
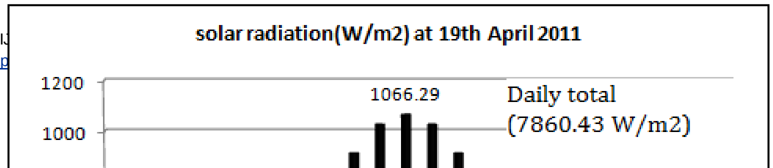


Figure 3



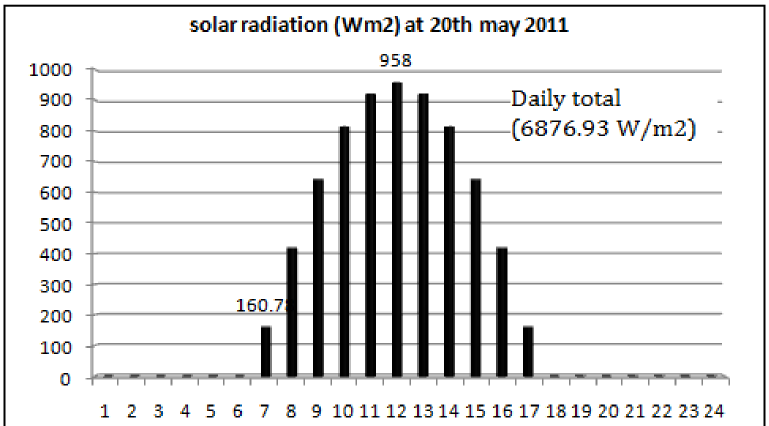


Figure 5

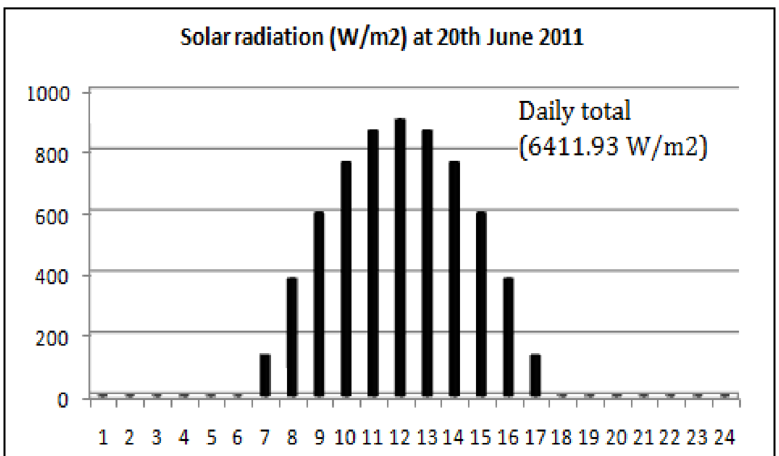
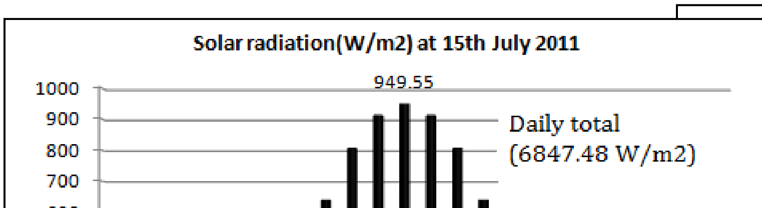


Figure 6



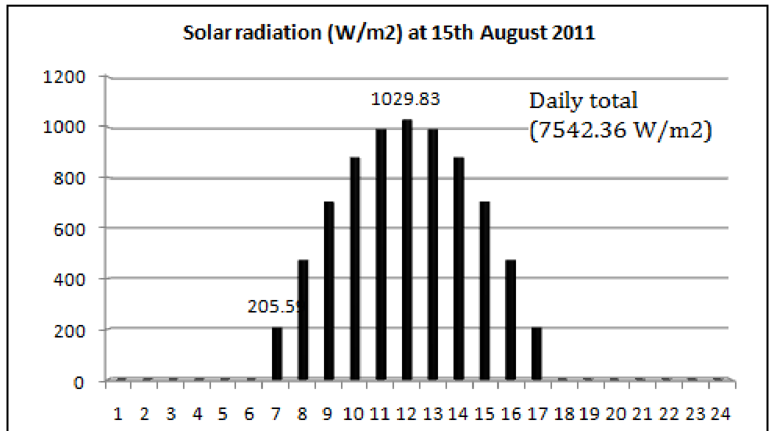


Figure 8

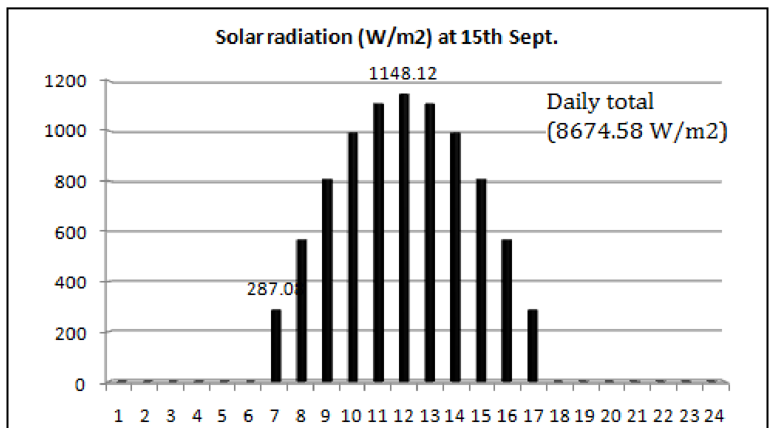
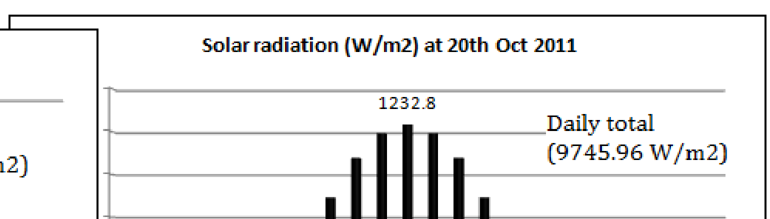


Figure 9



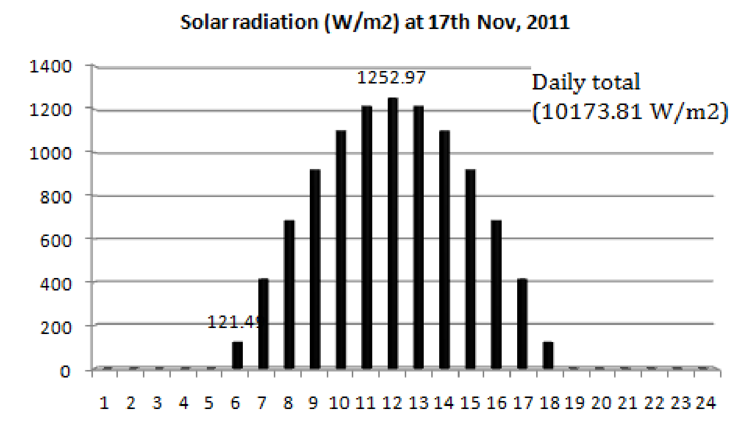


Figure 11

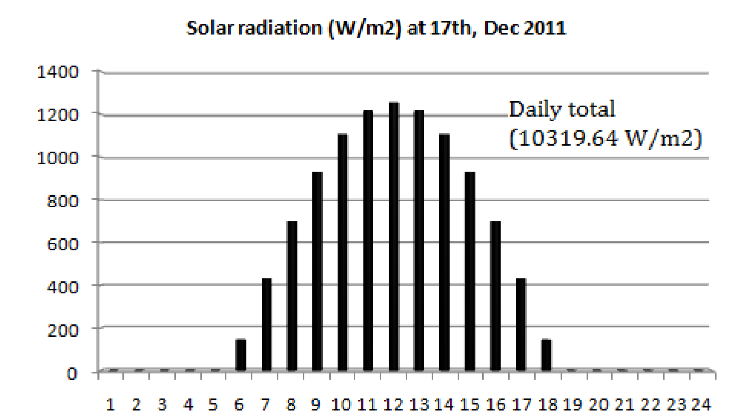


Figure 12

4 DISCUSSION

Nigeria which is situated at the tropical zone of Africa has two seasons namely dry and rainy. The dry season stretches from October - march while the rainy season is from April – September. The estimated hourly solar radiation results of Port – Harcourt city reveals that the dry season shows more solar radiation potential with December having highest radiation while the rainy season has lesser radiation with June having the lowest solar radiation. Each estimated day of the dry season shows radiation on incline south facing surface from 6AM to 6PM about 12 solar hours while the rainy season has lesser radiation due to the amount of clouds which reduce the penetration of this radiation. The solar hours for the rainy season are also less as shown in the estimated results which reveal the intensity of radiation from 7AM to 5PM. If the estimated days of each month of the 2011 are assumed to be the monthly average, then the trend of solar radiation in the city across the year is as shown in figure 13.

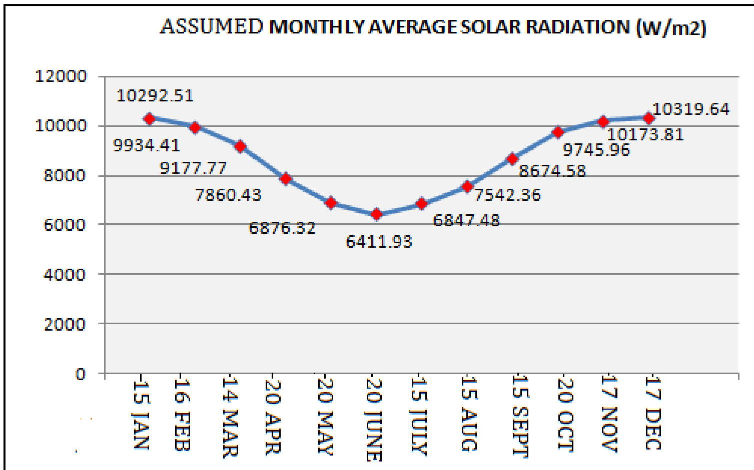


Figure 13

5. CONCLUSION

The estimated results show good potential of solar radiation in the city and why the government should invest heavily in solar energy so as to reduce dependence on conventional systems and CO_2 emission level in the city. Government can also provide fund for solar energy researchers and scientist with the view of establishing a solar energy industry and also provide incentives for users of solar energy devices which will increase the number of users in the city.

REFERENCES

[1]. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change (IPCC), 2007.
[2]. J.B. Gupta, 2004, A course in power systems, Tenth Edition, Sanjeev Kumar Kataria for S.K. Kataria And Sons.
[3]. E.O. Falayi, A.B. Rabiu "Modelling global solar radiation using sunshine duration data" Nigerian journal of physics, 17S (2005).
[4]. Richard G. Allen "Self-Calibrating method for estimating solar radiation from air temperature" Journal of Hydrologic

engineering/April 1997/57.
[5]. S.A. Khalil and A.M. Fathy "An empirical method for estimating Global solar radiation over Egypt". Acta Polytechnica Vol. 48 No. 5 2008.
[6]. A.Chukwuemeka, M.N.Nnabuchi "Solar radiation in Port Harcourt: Correlation with Sunshine Duration" the pacific Journal of science and technology (2009). Volume 10, Number 1. [7] Louis E. Akpabio, Sunny O. Udo, Sunday E. Etuk "Empirical correlations of Global solar radiation with a meteorological data for Onne, Nigeria" Turkish Journal of Physic 28 (2004), 205 -212.
[8]. John. A. Duffie, William. A. Beckham.1980, "Solar engineering of thermal process", John Wiley and Sons, INC, New York.