



Analysis of Optimum Tilt Angles and Their Effects on Receptors of Solar Radiation in Some Locations in Nigeria

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ABSTRACT

Tilt angle is considered as one of the critical parameters in optimizing the amount of captured solar radiation by solar collectors. In this work, optimum tilt angles for three selected locations in Nigeria: Maiduguri (11.9°N, 13.2°E), Abuja (9.2°N, 7.2°E) and Port Harcourt (4.9°N, 7.0°E) were evaluated. Global Solar Radiation Data at Horizontal Surface for the three locations were obtained from the data provided by National Aeronautics Space Administration (NASA). Klein and Theilacker (KT) method was adopted for determination of optimum orientation of the collectors and the computation was carried out using 'Solver-add-in' obtained from Microsoft excel options. The analysis showed that if the collectors are to be fixed permanently, the best orientation is southward tilted slightly above the latitudes of the locations. However, for optimal performance of periodically adjustable collector, the collectors should be oriented southward during the months of September to February and oriented northward during the months of April to August. The gains of energy as a result of changing the orientation were also investigated which showed that the effect of tilt is more significant at locations farther away from the equator as compared to locations nearer to the equator. In addition, monthly adjustment of collector orientation resulted in energy gain of approximately 1.79MJ/m²day while for a permanently fixed system (annual optimization) the maximum energy gain is about 0.45MJ/m²day as compared to that available at horizontal surface. The result will be useful for Solar Installers (both thermal and photovoltaic) in making decisions on the orientation of the collectors thereby maximizing the solar radiation available to solar collectors and, hence, minimizing the overall cost of the system.

Keywords: Orientation, Optimum Tilt, Solar Radiation, Latitude, Nigerian locations

INTRODUCTION

Solar radiation data is critical in the design and performance evaluation of reliable solar energy systems. Nigeria is located between 4°N and 14°N latitude and as a result, the country receives a vast supply of solar radiation all year round with daily solar radiation ranging between 3.5kWh/m² (12.6MJ/m²) at the coastal area and 7.0kWh/m² (25.2MJ/m²) at the Northern boundary (Dike *et al.*, 2012; Nik *et al.*, 2012; Ohunakin *et al.*, 2013; Argungu and Dabai, 2017; Dike *et al.*, 2017).

Solar radiation received by a solar collector is dependent on the orientation of the collector. Therefore it is desirable to find an angle known as optimum tilt angle (β_{opt}) at which the solar collector will receive the greater quantity possible of incident solar radiation. Tilt angle optimization for solar collector can be categorized either as periodically adjustable

type or permanently fixed (Yang and Lu, 2005; Wang and Hong, 2015; Torres-Perez and Rodriguez-Puente, 2016).

Many studies revealed that for a permanently fixed collector, the optimum tilt angle (β_{opt}) is suggested to be equal to the latitude of the location (El-Sebaii *et al.*, 2010; Agarwal *et al.*, 2012; Eka Dewi *et al.*, 2013; Duffie and Beckman, 2013); but some authors have different suggestions: Jafarkazemi and Saadabadi (2013) reported $\beta_{opt}=22^\circ$ (i.e. lat-2.4°) for Abu Dhabi whose latitude is 24.4°N; Li and Lam (2007) reported $\beta_{opt}=20^\circ$ (i.e. lat-2.3°) for Hong-Kong with 22.3°N. Some reports on Nigerian locations include: Udoakah and Okpura (2015) found $\beta_{opt}=6^\circ$ (i.e. lat+0.68°) for Enugu whose latitude is 6.68°N;

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Orizu *et al.* (2017) reported $\beta_{opt}=12.74^\circ$ (i.e. $lat+6.54^\circ$) for Onitsha with latitude of $6.2^\circ N$; Eke (2011) found $\beta_{opt}=22.5^\circ$ (i.e. $lat+11.3^\circ$) for Zaria with latitude of $11.2^\circ N$; Ajao *et al.* (2013) reported $\beta_{opt}=22^\circ$ (i.e. $lat+13.54^\circ$) for Ilorin whose latitude is $8.46^\circ N$; while Fagbenle (1991) proposed that for $lat < 8.5^\circ$ $\beta_{opt}=lat+10^\circ$, while for $8.5^\circ < lat < 15^\circ$ $\beta_{opt}=lat+5^\circ$.

For collector that is to be adjusted half yearly, many authors recommended $lat-15^\circ$ during summer and $lat+15^\circ$ during winter (Agarwal *et al.*, 2012; Duffie and Beckman, 2013). Other different reports include: Ibrahim (1995) determined $\beta_{opt}=lat-21^\circ$ during summer and $\beta_{opt}=lat+13^\circ$ during winter for Guzeluro-Cyprus, latitude of $35.2^\circ N$; Ahmad and Tiwari (2009) found $lat-16^\circ$ during summer and $lat+19^\circ$ during winter for New-Delhi, latitude $28.6^\circ N$; Asowata *et al.* (2012) recommended β_{opt} in Vaal Triangle in South Africa as $lat-10^\circ$ during summer and $lat+15^\circ$ during winter; Orizu *et al.* (2017) found β_{opt} for Onitsha as 0° during rainy season and 25.5° i.e. $lat+19.36^\circ$ during dry season.

Reports for other periodic adjustments are: Ulgen and Hepbasli (2002) reported β_{opt} for the city of Izmir in the western part of Turkey ($38.3^\circ N$) as 4.3° , 43.0° , 55.7° and 18.3° during Summer, Autumn, Winter and Spring respectively. Idowu *et al.* (2013) predicted β_{opt} for locations between $1^\circ N$ to $14^\circ N$ as $lat+25^\circ$ for Nov, Dec and Jan; $lat+15^\circ$ for Feb, Sep and Oct; $lat-15^\circ$ for Aug; $lat-25^\circ$ for May, Jun and Jul; and equal to lat for Mar and Apr.. Udoakah and Okpura (2015) reported β_{opt} for Enugu ($6.48^\circ N$) as: 30° , 24° , 6° for Jan to Mar; 0° for Apr to Sep and 18° , 30° and 36° for Oct to Dec respectively. Waziri *et al.* (2014) reported β_{opt} for Kano ($12.1^\circ N$) as: 35° , 45° , 35° , 25° , 15° and 15° for Nov to Apr respectively. Eke (2011) reported β_{opt} for Zaria ($11.2^\circ N$) as: 26.5° , 24.5° , 10.0° , 19.5° , 26.0° , 30.0° , 24.0° , 21.0° , 11.5° , 19.5° , 27.0° and 30.0° for Jan to Dec respectively.

It can be seen from the literatures that there are many variations for proposed optimum tilt angles in various locations. This study investigated optimum orientation (azimuth and tilt angles) of solar collectors for three selected locations in Nigeria with latitudes, Longitudes, altitude respectively given as: Maiduguri ($11.9^\circ N$, $13.2^\circ E$, 337m), Abuja

($9.2^\circ N$, $7.2^\circ E$, 573m) and Port-Harcourt ($4.9^\circ N$, $7.0^\circ E$, 18m); after which the gain of energy as a result of changing the orientations were determined.

Theoretical Background

Several research works have been conducted to calculate monthly average daily radiation on a tilted surface, \bar{H}_T ; and many models were developed. In this work, Klein and Theilacker (KT) method was adopted for this work. It is given by (Duffie and Beckman, 2013; Goswani, 2015; Maleki *et al.*, 2017):

$$\bar{H}_T = \bar{H} \times \bar{R} \quad (1)$$

Where: \bar{H} is the long-term monthly daily average solar radiation on a horizontal surface; and \bar{R} is a long term geometric conversion factor given by:

$$\bar{R} = \bar{B} + \frac{\bar{H}_d}{\bar{H}} \left(\frac{1 + \cos \beta_t}{2} \right) + \rho_g \left(\frac{1 - \cos \beta_t}{2} \right) \quad (2)$$

Where: β_t is the tilt angle (inclination); and ρ_g is the reflectance factor (albedo) and is usually taken as 0.2 for normal surfaces (Torres-Perez and Rodriguez-Puente, 2016); \bar{B} is the fraction of beam solar radiation on inclined surface to total radiation; $\frac{\bar{H}_d}{\bar{H}}$ is the diffuse fraction and can be evaluated using Erbs correlation which is valid for long term average which is valid for $0.3 \leq \bar{K}_T \leq 0.8$. It is given by (Duffie and Beckman, 2013):

$$\frac{\bar{H}_d}{\bar{H}} = \begin{cases} A, & h_{so} \leq 81.4^\circ \\ B, & h_{so} > 81.4^\circ \end{cases} \quad (3a);$$

where:

$$A = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \quad (3b);$$

$$B = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \quad (3c)$$

h_{so} is the sunset hour angle on horizontal surface; and \bar{K}_T is the average daily clearness index given by:

$$\bar{K}_T = \bar{H} / \bar{H}_o \quad (4)$$

Where: \bar{H} is the monthly average measured solar radiation; and \bar{H}_o is the monthly average extraterrestrial radiation on a horizontal

surface which can be computed from the equation (Grewel and Grewel, 2004; Duffie and Beckman, 2013; Goswami, 2015):

$$\bar{H}_o = I_{sc} \left(\frac{24}{\pi} \right) E_o \left[\left(\frac{2\pi h_{so}}{360} \right) \sin \Phi \sin \delta + \cos \Phi \cos \delta \sin h_{so} \right] \quad (5)$$

Where: I_{sc} is solar constant (solar radiation intensity received above the earth's atmosphere at mean earths-sun distance, $I_{sc}= 1367Wm^{-2}$); E_o , δ_s , Φ and h_{so} are the Earth's Eccentricity Factor, Angle of declination, Latitude of the location and sunset hour angle on horizontal surface respectively given by (Duffie and Beckman, 2013; Goswami, 2015):

$$E_o = 1 + 0.033 \cos\left(\frac{2\pi d_n}{365}\right) \quad (6)$$

$$\delta_s = 23.45 \sin[2\pi(284 + d_n)/365] \quad (7)$$

$$h_{so} = \cos^{-1}(-\tan \delta_s \tan \Phi) \quad (8)$$

Where: d_n is the n^{th} day of the year (*Jan. 1 = 1; Dec. 31 = 365*); ($1 \leq d_n \leq 365$).

The fraction of beam solar radiation on inclined surface to total radiation \bar{B} is given as:

$$\bar{B} = \frac{\cos(\Phi - \beta_t)}{d \cos(\Phi)} \left\{ \left(a - \frac{\bar{H}_a}{\bar{H}} \right) (\sin h_{ot} - h_{ot} \cos h_{st}) + \frac{b}{2} (h_{ot} + (\sin h_{ot})(\cos h_{ot} - 2 \cos h_{st})) \right\} \quad (9)$$

Where: h_{ot} sunset hour angle on horizontal surface; h_{st} sunset hour angle on sloped surface; a , b and d are the monthly average radiation to long term daily average radiation commonly known as Collares-Pereira and Rablempirical coefficients. They are evaluated as (Wong and Chow, 2001; Duffie and Beckman, 2013; Goswami, 2015):

$$a = \left[0.4090 + 0.5016 \sin(h_{so} - \frac{\pi}{3}) \right] \quad (10)$$

$$b = 0.6609 - 0.4767 \sin\left(h_{so} - \frac{\pi}{3}\right) \quad (11)$$

$$d = \sin h_{so} - h_{so} \cos h_{so} \quad (12)$$

$$h_{st} = \cos^{-1}[-\tan \delta_s \tan(\Phi - \beta)] \quad (13)$$

$$h_{ot} = \min \left\{ \begin{matrix} \cos^{-1}(-\tan \delta_s \tan \Phi) \\ \cos^{-1}[-\tan \delta_s \tan(\Phi - \beta)] \end{matrix} \right. \quad (14)$$

The “*min*” is indicating the smaller of the two expressions; while h_{so} is as shown by equation 8.

METHODOLOGY

Materials used for this work were: Global Solar Radiation Data and a Computer System with office application.

Global solar radiation data at horizontal surface for all the three locations were obtained from National Aeronautics Space Administration (NASA). The data was analysed and monthly average values are as shown in Table 1.

Table 1: Global Solar Radiation Data at Horizontal Surfaces in MJ/m²-day

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Maiduguri	20.20	22.68	24.12	23.83	22.90	21.49	19.55	18.50	20.05	21.20	21.02	19.26	21.22
Abuja	21.17	21.92	22.57	21.82	20.09	18.22	15.98	15.08	17.03	19.12	21.53	21.10	19.62
PortHarcort	14.87	15.55	15.23	15.44	14.87	13.75	12.64	11.84	13.64	14.00	14.33	14.94	14.25

Source: National Aeronautics Space Administration (NASA)

Table 2: Monthly Average Days and their Day Numbers

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
i th Day	i	31+i	59+i	90+i	120+i	151+i	181+i	212+i	243+i	273+i	304+i	334+i
Ave Day	17	16	16	15	15	11	17	16	15	15	14	10
Day No	17	47	75	105	135	162	198	228	258	288	318	344

Source: Klein, 1977 as cited in Duffie and Beckman(2013)

For obtaining the monthly average values of some meteorological variables (declination angle, sunset hours, earth’s eccentricity factor, extraterrestrial radiation, etc.), recommended average days suggested by Klein (1976) as cited in Duffie and Beckman, (2013) shown in Table 2 was adopted for this work.

Optimum tilt angles were evaluated based on various options of collector orientations as follows:

- i. Annual Optimization (Permanently fixed)
- ii. Seasonal Optimisation (Adjusted twice per annum)
 - a. Summer Months (March to August)
 - b. Winter Months (September to February)
- iii. Quarterly Optimisation (Adjusted four times per annum)
 - a. Winter (December, January, February)
 - b. Spring (March, April, May)
 - c. Summer (June, July, August)

- d. Autumn (September, October, November)

iv. Monthly Optimization

The analysis was simplified by using a spread sheet (Microsoft Excel) in which three sheets were used for the analysis:

- i. Data base sheet: where all the data about the locations (geographical co-ordinates and solar radiation) are stored;
- ii. Manipulation sheet: where all the calculations of the meteorological variables are carried out;
- iii. Input/output sheet: where the user will select the location and the collector orientation type after which the result will be displayed on the same sheet. In this sheet, the computation was carried out using ‘solver-add-in’ obtained from excel options as shown in Figure 1.

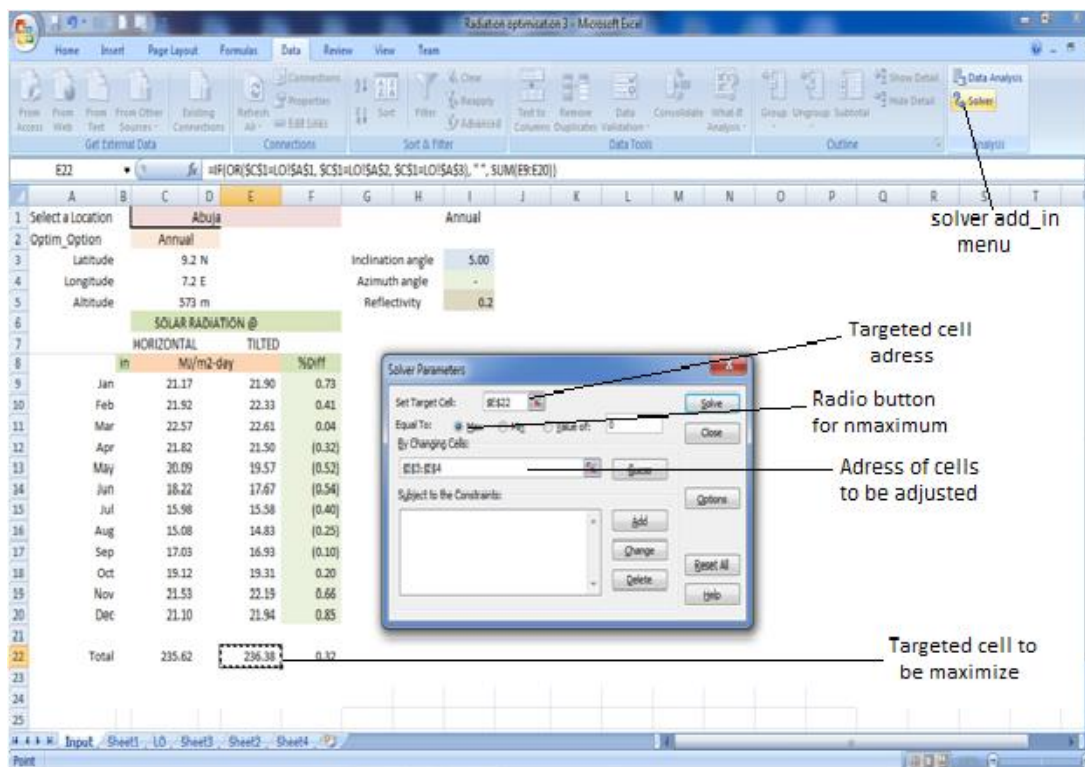


Figure 1: Determination of Optimum Orientation using Solver add-in

RESULTS AND DISCUSSIONS

Results of the analysis showed that if the collectors are to be fixed permanently, the best orientation is the collectors to face southward tilted at 13.8° (i.e. lat+ 4.5°), 13.7° (i.e. lat+ 1.9°) and 6.0° (i.e. lat+ 1.1°) for Maiduguri (11.9°N), Abuja (9.18°N) and Port Harcourt (4.9°N) respectively. From the result, it can be deduced that, for collectors that are to be fixed permanently, the optimum optimum tilt angle should be slightly greater than the latitude of the location.

Global solar radiation obtained based on permanently fixed collector at the optimum orientations are as shown in Table 3.

From global solar radiation data obtained at horizontal surface for the locations (Table 1), as expected, Maiduguri which is among the semi-arid areas has the highest average solar

radiation of $21.22\text{MJ/m}^2\text{-day}$ ($5.89\text{ kWh/m}^2\text{-day}$); while Port Harcourt which is among the coastal region has least average solar radiation of $14.25\text{MJ/m}^2\text{-day}$ ($3.96\text{ kWh/m}^2\text{-day}$).

Comparing Table 1 with Table 3, it can be seen that when a collector is to be fixed permanently at the optimum tilt angle, there is decrease of solar radiation in the months of Apr to Aug but increase in the remaining months; but the net effect is increase in daily average of 0.45 , 0.40 and $0.06\text{MJ/m}^2\text{-day}$ representing 2.10% , 2.05% and 0.40% as compared to that available at horizontal surface for Maiduguri, Abuja and Port Harcourt respectively.

For collectors that are to be adjusted half-yearly, results for optimum orientation and the corresponding global solar radiation available are as shown in Table 4 and Table 5 respectively.

Table 3: Global Solar Radiation Data based on Annual Optimum Orientation in $\text{MJ/m}^2\text{-day}$

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Maiduguri	22.78	24.55	24.75	23.12	21.30	19.65	18.13	17.74	20.08	22.45	23.49	21.96	21.67
Abuja	23.61	23.41	22.93	21.05	18.68	16.72	14.90	14.47	16.92	19.95	23.76	23.87	20.02
PortHarcort	15.37	15.87	15.29	15.26	14.49	13.34	12.32	11.68	13.61	14.19	14.74	15.52	14.31

Table 4: Half-Yearly Optimum Tilt Angles for the Locations

Location	Latitude	Sep to Feb (Winter months)	Mar to Aug (Summer months)
Maiduguri	11.9°N	31.6° (i.e. lat+ 19.7°)	-7.8° (i.e. lat- 19.7°)
Abuja	9.18°N	30.0° (i.e. lat+ 20.8°)	-8.8° (i.e. lat- 18.0°)
Port-Harcourt	4.9°N	21.2° (i.e. lat+ 16.3°)	-11.6° (i.e. lat- 16.5°)

Table 5: Global Solar Radiation based on Collectors Adjusted Half-Yearly in $\text{MJ/m}^2\text{-day}$

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Maiduguri	24.58	25.32	23.30	23.79	23.38	22.15	20.02	18.62	18.91	22.62	25.09	23.96	22.65
Abuja	25.15	23.85	21.84	21.84	20.59	18.83	16.39	15.20	15.97	19.89	25.04	25.77	20.86
PortHarcort	16.14	16.15	14.81	15.50	15.30	14.29	13.01	11.95	13.13	14.22	15.31	16.46	14.69

From Table 4, it can be seen that collectors whose orientations are to be changed half yearly, for the month of Sep-Feb (Winter), the collectors are to be oriented southward at optimum angle (β_{op}) of about 16° to 21° above the latitudes of the locations; while for the month of Mar-Aug (Summer), β_{op} collectors are to be oriented northward at β_{op} of about 16° to 20° less than the latitudes of the locations.

Comparing Table 1 with Table 5, it can be seen that when a collector is to be changed half yearly, there is decrease of solar radiation in the months of Mar and Sep but increase in the remaining months; but the net effect is increase in daily average of 1.43 , 1.24 and $0.44\text{ MJ/m}^2\text{-day}$ representing 6.72% , 6.34% and 3.08% as compared to that available at

horizontal surface for Maiduguri, Abuja and Port Harcourt respectively.

For collectors that are to be adjusted quarterly: Dec-Feb(winter), Mar-May(spring), Jun-Aug(summer), and Sep-Nov(autumn); results for optimum orientation and the corresponding global solar radiation available are as shown in Table 6 and Table 7 respectively.

It can be seen from Table 6 that for a collector whose orientation is to be changed quarterly: for the month of Sep-Nov (Autumn), β_{op} is about 10° to 13° above the latitudes of the location; for the month of Dec-Feb (Winter), β_{op} is about 22° to 26° above the latitudes of the location; for the month of Mar-May (Spring), β_{op} is about 11° to 13° less than the latitudes of the locations; for the month of Jun-

Aug (Summer), β_{op} is about 23° to 28° less than the latitudes of the locations.

Comparing Table 1 with Table 7, it can be seen that when a collector is to be adjusted quarterly, there is increase of solar radiation in all the months with the exception of Mar and the net effect is increase in daily average of 1.55, 1.34 and 0.49 MJ/m²-day representing 7.30%, 6.85% and 3.43% as compared to that available at horizontal surface for Maiduguri, Abuja and Port Harcourt respectively.

Results for optimum orientation and the corresponding global solar radiation available for collectors that are to be adjusted monthly are as shown in Table 8 and Table 9 respectively.

Table 6: Quarterly Optimum Tilt Angles for the Locations

Locations	Dec-Feb (winter)	Mar- May (spring)	Jun – Aug (summer)	Sep – Nov (Autumn)
Maiduguri	37.3° (i.e. lat+25.4°)	-0.9° (i.e. lat-12.8°)	-16.4° (i.e. lat-28.0°)	24.9° (i.e. lat+13.0°)
Abuja	35.2° (i.e. lat+26.0°)	-2.8° (i.e. lat-12.0°)	-17.0° (i.e. lat-26.2°)	23.0° (i.e. lat+13.8°)
Port_Harcourt	26.7° (i.e. lat+21.8°)	-6.5° (i.e. lat-11.4°)	-17.8° (i.e. lat-22.7°)	14.6° (i.e. lat+9.7°)

Table 7: Available Solar Radiation based on Quarterly Optimum Tilt Angles in MJ/m²-day

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Maiduguri	24.76	25.17	24.05	23.84	22.97	22.54	20.23	18.48	19.50	22.75	24.71	24.22	22.77
Abuja	25.31	23.69	22.38	21.86	20.29	19.13	16.54	15.10	16.48	20.06	24.69	26.03	20.96
PortHarcort	16.22	16.07	15.04	15.53	15.16	14.42	13.08	11.89	13.41	14.29	15.15	16.61	14.74

Table 8: Monthly Optimum Tilt Angles for the Locations

Month	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maiduguri	11.9°	39.8°	29.9°	14.8°	-2.8°	-15.8°	-21.1°	-17.9°	-7.7°	7.3°	24.5°	37.6°	42.2°
Abuja	9.2°	37.5°	26.8°	11.9°	-5.0°	-17.2°	-21.9°	-18.3°	-8.8°	4.6°	20.9°	35.0°	40.4°
PortHarcort	4.9°	28.8°	19.3°	6.5°	-7.4°	-18.2°	-22.3°	-19.1°	-10.2°	1.0°	14.4°	25.8°	31.6°

Table 9: Available Solar Radiation based on Monthly Optimum Tilt Angles in MJ/m²-day

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Maiduguri	24.78	25.33	24.75	23.85	23.56	22.60	20.24	18.62	20.17	22.75	25.20	24.29	23.01
Abuja	25.33	23.88	22.93	21.88	20.75	19.18	16.54	15.20	17.06	20.07	25.12	26.12	21.17
PortHarcort	16.23	16.16	15.29	15.53	15.37	14.45	13.08	11.96	13.65	14.29	15.35	16.65	14.83

From Table 8, it can be seen that for a collector that is to be adjusted monthly, the values for β_{op} are positives for the months of Sep to Feb and negative for the months of Apr to Aug.; which implies that the collector should be oriented southwards and northwards during the months of Sep to Feb and Apr to Aug respectively.

Comparing Table 1 with Table 9, it can be seen that when a collector is to be adjusted monthly, there is increase of solar radiation in all the months and the net effect is increase in daily average of 1.79, 1.55 and 0.58 MJ/m²-day representing 8.44%, 7.91% and 4.10% as compared to that available at horizontal surface for Maiduguri, Abuja and Port Harcourt respectively

Conclusion

The analysis for determination of optimum orientation for solar collectors indicate that collectors that are to be fixed permanently, the best orientation for all the locations is to face southward tilted at an angle slightly above the latitudes of the locations. However, for collectors that are to be adjusted periodically, the best orientation is southward during the winter months(September to February) and northward during the summer months (March to August) tilted at variable angle depending on the frequency and period of the adjustments.

The results show that effect of tilt is more at places far away from the equator as compared to places very close to the equator. From the results obtained, it can be concluded that adjustment of solar collectors periodically at optimum orientation results in increase in the availability of global solar radiation and the availability increases with frequency of adjustment. A gain of up to 1.79 MJ/m²-day can be obtained above that available on horizontal surface, therefore it is advisable to adjust the orientation of a collector to its optimum orientations on monthly or quarterly basis where possible.

It can be recommended that if it is not possible to be changing the orientation of the solar collector, the tilt angle of the critical month (i.e. the month with the greatest demand as compared to the available radiation in the month) should be used where possible. It is also recommended that in situations where changing the tilt angle result in extra cost of the material, it is advisable to compare the extra cost with the additional energy obtainable before making final decision.

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