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Estimation of insolation of flat plate solar collectors in selected cities in Nigeria

A. A. Dare[1] K. M. Odunfa[1] L. O. Ajuka[2] S. O. Oyedepo [3] O. A. Adeaga[4]
[1]Department of Mechanical Engineering, University of Ibadan, Oyo State, Nigeria
[2]Monitoring and Evaluation Unit, Vice-Chancellor's Office, University of Ibadan, Oyo State, Nigeria
[3]Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria
[4]Department of Mechanical Engineering, The Ibarapa Polytechnic, Eruwa, Oyo State, Nigeria
Correspondence authors: m.odunfa@mail.ui.edu.ng; lo.ajuka@ui.edu.ng; engr.adeaga@gmail.com

ABSTRACT
This paper examines the insolation and efficiency of flat plate collectors across selected locations of the six geopolitical zones of Nigeria at different tilts. The performance of a flat plate collector in relation to heat transfer fluid in the absorber was evaluated using standard equation known as the Hottel -Whillier- Bliss Equation. This equation takes into account the liquid collector's plate efficiency factor as 0.9, the least factor value. At tilt equals Latitude, the least incidence angle occurs in August/September at 2.5^o with corresponding insolation of about 1000W/m^2, while the highest incidence angle is on the average of 23.47^o in December with a corresponding least average insolation value of 854.38W/m^2. In Abuja, Bauchi, results shows that on January, November and December insolations were highest when collector tilt is at Latitude+ 15degrees, Latitude +10degrees on February and October. In Kano, for months November through January the tilt for highest insolation is at Latitude +15^o, Latitude +10^o in February and October, Latitude +5^o in May. In Enugu and Benin, the highest insolation in January, November and December is at a tilt of Latitude+15^o, Latitude+10^o in February,June and October, Latitude+5^o in May and July. In Ikeja, the highest insolation in November through January is at Latitude+15^o, Latitude+10^o in February, June and October, Latitude+5^o in March, April, May and July, and Latitude in August and September. Results revealed that as the incidence angle approaches 0^o, insolation become maximum and as incidence angle approaches 90^0, insolation becomes minimum. The study has therefore established the optimum tilt for maximum insolation and efficiency of a flat plate collector.
Keywords: Environmental pollution, Insolation, Chlorofluorocarbons, efficiency, solar energy

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I. INTRODUCTION

Energy is fundamental to human activities and the economic development of any country, Nigeria inclusive. Nigeria with its increasing population needs energy, alternative energy if the need for threats of gases from fossil fuel is to be faced out. Environmental pollution caused by fossil fuel combustion, Chlorofluorocarbons, and other chemicals and organic materials has been a thing of global concern, Nigeria inclusive. Research are being conducted towards addressing this problem; these includes the use of solar energy through collectors, followed by optical, thermal and thermodynamic analysis of these collectors, coupled with the use of optimum tilt for maximum insolation across different locations. The irradiative energy from the Sun that keeps our planet warm exceeds by far the current primary energy supply used by mankind for its comfort, leisure and economic activities. It also exceeds vastly other energy sources at ground level such as geothermic or tidal energy, nuclear power and fossil fuel burning. Sunrays also drive hydraulics, wind and wave power and biomass growth. The global warming crisis as a result of the depletion of the ozone layer caused by the emissions of CFC'S, halon (chlorinated and brominates organic compounds) and NOx has led to many researches on alternative renewable sources of energy like the sun energy. Most countries in the world have realized the need for reduction of gas emissions to contrast the adverse global climatic change, encouraging the use of renewable and fully sustainable sources of energy (Dincer, I. and Rosen, M.A, 1998). Indeed, large quantities of carbon dioxide, nitrogen, and

sulfur-oxides are emitted in the world by conventional energy sources, which are released to the earth's atmosphere contributing to climate change.
The sun's total energy output is 3.8 x10^{20}MW which is equal to 63MW/m^2 of the sun's surface. This energy radiates outwards in all directions. Only a tiny fraction, 1.7Kw of the total radiation emitted is intercepted by the earth (Kreith, F. and Kreider, J.F., 1978). However, even with this small fraction it is estimated that 30minutes of solar radiation falling on earth is equal to world energy demand for one year. The earth surface temperature has increased by 0.6^0c in the last century, and as a consequence the sea level is estimated to have risen by perhaps 20cm (Colombo, U., 1992). These changes can have a wide range of effects on human activities.
Solar radiation can be widely used for water heating in hot water systems, swimming pools as well as a supporting energy sources for central heating installations. The energy of the solar radiation is in this case converted to heat with the use of solar panel (Zima and Dziewa, 2010). Using the sun's energy to heat water is not a new idea. More than one hundred years ago, black painted water tanks were used as simple solar water heaters in a number of countries. However, the solar water heating technology has greatly improved during the past century. Today there are more than 30 million square meters of solar collectors installed around the globe (RETscreen, 2012). A typical flat-plate collector consists of an absorber in an insulated box together with transparent cover sheets (glazing). The absorber is usually made of a metal sheet of high thermal conductivity, such as copper or aluminum, with integrated or attached tubes. Its surface is coated with a special selective material to maximize radiant energy absorption while minimizing radiant energy emission. The insulated box reduces heat losses from the back and sides of the collector. These collectors are used to heat a liquid or air to temperatures less than 80°C (Strutckmann, 2008). The performance and operation of a flat-plate collector is governed by the fundamental laws of thermodynamics and relationships from heat transfer and fluid mechanics. While there is a tube for the inlet and outlet of the fluid (Liquid Flat-plate collector type) to be heated, the insulations prevent heat losses, the absorber collects the heat that is radiated through the glass cover sheet. This is shown in figure 1.2 below,

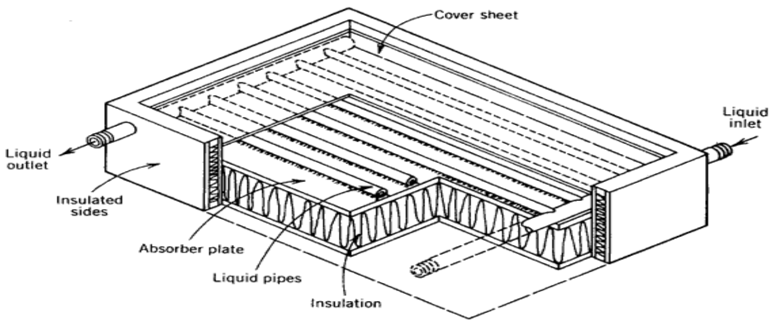

Figure 1.2: Cross-section of a typical liquid flat plate collector (Source: Lunde, P.,1980).

Owing to the many parameters affecting the solar collector performance, a relatively simple analysis will yield very useful results (Duffie, J. and Beckmann, W., 1991). The solar collectors stationary models presented by Hottel, H.C. and Woertz, B.B., 1942; Hottel, H.C and Whillier, W., 1955 were based on a zero-capacitance model. A test method that incorporates dynamic solar collector properties yields more information about the collector and makes collector testing easier to perform experimentally, while experimental expense must be made for on each test. (Muschaweck, J. and Spirkl W., 1993).
In An effort to include the capacitance effects on the collector performance, Close, D. 1967, developed the one-node capacitance model. Klein, S. et al., 1974 suggested a 2-node model in which nodes are positioned at the collector plate and at a single glass cover. The collector mean temperature assumed to be the algebraic average of the inlet and outlet fluid temperatures. De Ron, A., 1980 presented a dynamic model of a single glass cover flat-plate collector.
Adding to assumptions made by [15]. [16] Derived analytic approximations of the temperatures within a flat-plate solar collector under transient conditions. Based on the fact that some of the heat resistances of a conventional flat-plate solar collector are smaller than others [17.] proposed a discrete numerical model to calculate the flow
and temperature distribution to analyze the performance of flat-plate solar collector arrays.

The objectives to determine what optimum tilt angle of flat plate collector to be chosen to obtain maximum solar radiation, pattern of distribution of insolation in the geopolitical Zones in Nigeria are shown in this paper.

NOMENCLATURE

^{0}, deg	Degree
vs	versus.
Lat	Latitude
+, @	Plus, at
θ, β	The Incidence Angle, Altitude Angle

II. METHODOLOGY

The theoretical performance of a flat plate collector under steady state conditions, where the rate of energy extracted from the collector per unit of collector area(Qu./Ac), is equal to the rate of radiative energy absorbed, minus the rate of heat loss to the surroundings(Qs=0)

The geopolitical zones of Nigeria, from the North Central (NC), North West (NW), North East (NE), South East(SE), South South(SS), to South West(SW) parts of Nigeria are the major focus, therefore in the estimation carried out on the insolations, and the efficiencies of a typical flat plate solar collector in Nigeria, and establishing its pattern of distribution using comparative analysis, the following equations below were adopted.

2.1 Assumptions

The Basic assumptions made are;

a. There is an ideal flow of fluid in the collector;

b. No shading for the flat plate solar collector.

2.2 Working Equations

The widely used Hottel Whiller-Bliss Equation is itemized in the following equations explained below to obtain the insolations, and efficiencies of the flat plate collector in each of the locations which make up the zones.

Determination of the Latitude of the Locations

The Latitude (ℓ) of the under listed selected locations were obtained as stated below;

The Latitude of Abuja 9.07^{0}N(North Central), Bauchi 10.31^0 N(North East), Kano12.00^0 N(North West), Enugu6.5^{0}N(South East) ,Benin6.34^0 N(South South), Ikeja6.45^0 N(South West), and Plateaux 9.17^0 N(North Central), Borno11.5^0 N(North East), Sokoto13.07^0 N (North West), Imo5.48^0 N(South East), Rivers N(South South),Oyo8.00^0 N(South West).

Determination of Tilt of Collector

The Tilt of the collector is made to be latitude dependent by observing an interval of 5deg until 15deg. That is, tilt at Latitude, Latitude +5deg, Latitude +10 deg, Latitude +15 deg. For example, tilts at Abuja are shown below:

Tilt of Abuja at Latitude equals 9.07^0, at Latitude +5deg (9.07 +5) equals 14.07^0, at Latitude +10deg (9.07 +10) equals 19.07^0, at Latitude +15deg (9.07 +15) equals 24.07^0.

This step is carried out for all the respective locations mentioned above to determine the Tilt with which the irradiance and efficiencies of such location is determined using a flat plate solar collector.

Determination of Declination Angle (δ)

The declination angle is the same for the whole globe on any given day. It shows the change in the declination angle throughout a year. Because the period of the Earth's complete revolution around the Sun does not coincide exactly with the calendar year the declination varies slightly on the same day from year to year. It is measured in the deg (°), minutes ('), and seconds ("). The equation used to calculate the declination angle in radians on any given day is given as:

$$\delta = 23.45^o \sin (360^o (284+ n)/ 365) \quad \text{(2.0)}$$

Where δ = declination angle (degrees); n = the day number, such that n = 21st day on every month.

Determination of Altitude Angle (β)

The angle of the sun above the respective locations mentioned, measured in degrees, were calculated using equation 3.1 below,

$$\sin\beta = \cos\ell \cosh \cos d + \sin\ell \sin \delta \quad \text{(2.1)}$$

Where β is the altitude Angle, h is the solar hour angle equal to zero at solar noon, ℓ is the Latitude and δ is the declination Angle.

The Incidence Angle (θ)
The angle that the beam of radiation makes with the normal to the collector surface at the point of incidence when inclined away from the sun is given by:

$$\cos\theta = \cos\beta \cos\alpha \cos\varphi + \sin\beta \sin\varphi \quad \ldots\ldots(2.2)$$

Where θ is the incidence Angle, α is the Azimuth Angle and φ is the angle of Tilt.

The Normal Solar Radiation Intensity (I_n)
The amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky can be determined by the equation below

$$I_n = 1082\, e^{-0.182/\sin\beta} \quad \ldots\ldots (2.3)$$

Where I_n is the Normal Solar Radiation Intensity inW/m2, β is the Altitude Angle.

The Direct or Beam Radiation (I_D)
Direct (Beam) Radiation is estimated when the intensity normal to the sun's rays I_n and the angle of incidence θ at the point of consideration is known. It is given by the equation (W/m^2);

$$I_D = I_n \cos\theta \quad \ldots\ldots (2.4)$$

Where I_D is Direct Solar Radiation normal to a surface, θ is the incidence angle the surface.

h. Diffuse Sky Radiation Angle Factor (FSS)
This is the angle factor between the between the surface and the sky. It is given by the equation

$$F_{ss} = ½(1 + \sin\varphi) \quad \ldots\ldots (2.5)$$

Determination of Diffuse Radiation (I_d)
The diffuse radiation on a clear day is though small, but cannot be neglected. It is as a result of scattered radiation by earth constituent. The Diffuse sky radiation for clear days is given approximately by the equation in W/m^2;

$$I_d = C\, I_n F_{ss} \quad \ldots\ldots (2.6)$$

Where C is a dimensionless coefficient derived by Stephenson.

Determination of Total Radiation ($I_D + I_d$)
This is the sum of the Direct or Beam Radiation (I_D) and the Diffuse Radiation (I_d).
Where Total Solar Irradiance; $I_T = I_d + I_D$ (I_D is the direct incident radiation).

Table 2.0: Dimensionless Coefficient for Sky Radiation

Date	C	Date	C
Jan. 21	0.058	Jul. 21	0.136
Feb.21	0.060	Aug. 21	0.122
Mar. 21	0.071	Sept. 21	0.092
April. 21	0.097	Oct. 21	0.073
May. 21	0.121	Nov.21	0.063
Jun. 21	0.134	Dec. 21	0.057

Source: Arora, C.P. (2001).

Determination of Efficiencies of the Flat Plate Collector
The basic equation used in Efficiency calculation is the Hottel Whiller-Bliss Equation.
The Hottel Whiller-Bliss Equation;

$Q_u = FA_C\ [\ I\ (\tau\alpha)_C - U_L\ (T_i - Ta)]$ ……………………………………… (3.2)

Collector Efficiency $(\eta_c) = (Q/A\ I_T)$

$= F'\ [(\tau\alpha)_C - U_L(T_i - Ta)/\ I_T]$ ……………………………………… (3.3)

Where; Q_u is the useful thermal power output by Collector (Watts).
A_C is the area of the collector (m^2); τα is the effective transmittance-absorptance product.
U_L= Overall heat loss coefficient; Where, F' = is the plate efficiency factor , and numerical values range typically from about 0.8 to 0.9 for air collectors, from 0.9 to 0.95 for liquid collectors, and from 0.95 to 0.99 for evacuated collectors. But this study has used 0.9 the least.

Also, Ti (Inlet temperature) is taken as 25^0C, Ta (Ambient temperature) is taken as 40^0C.
The transmittance τ(θ) of a glass cover for solar radiation depends on the angle of incidenceθ. Typical values for clear glass are given in **Table 2.1** below;

Table 2.1 Transmittance of a Glass Cover.

***θ*:**	0°	60°	70°	80°	90°
***τ*(*θ*):**	0.9	0.8	0.65	0.35	0

Absorptance *α*(*θ*) of the black plate for solar radiation also depends on the angle of incidence ***θ***.

Table 3.3 shows typical values for *α*(*θ*) and the product *τ*(*θ*).*α*(*θ*).

Table 2.2 Absorptance of a Black Plate.

***θ*:**	0°	60°	70°	80°	90°
***α*(*θ*):**	0.92	0.85	0.75	0.60	0
***τ*(*θ*).*α*(*θ*):**	0.83	0.68	0.49	0.21	0

Where **θ** is the angle of incidence with respect to latitude of zones of interests.
Using the stated Hottel Whiller-Bliss Equation, and by interpolation the value of **τ(θ).α(θ) (**Transmittance of a Glass Cover and Absorptance of a Black Plate**)** is determined, and the result obtained is shown.

III. RESULTS AND DISCUSSION

The solar insolation on a clear 21^{st} day of every month in Abuja, Bauchi, Kano, Enugu, Benin, Ikeja which can be collected using a flat plate solar collector is represented on charts and tables 4.6a through 4.8d, and table4.9 through 4.10d respectively at Latitude, Latitude + 5deg, Latitude + 10deg, Latitude + 15deg.
Observation from the Tables and graphs shows the pattern of distribution of solar radiation which can be captured with a flat plate solar collector and its efficiencies in the six geopolitical zones of Nigeria and the comparative analysis is discussed below;
The corresponding results estimated in the calculations from the equations are presented in this section.

3.1 Tilt of Collector at Latitude through Latitude + 15 deg.:
The tilt of the collector was raised from latitude to Latitude + 15 deg at an interval of 5 deg and the corresponding values were shown in the table below;
The Table 3.1and 3.2 shows the variation of Latitude with the least at Rivers and the highest at Sokoto.

There are slight differences in the latitudes of same geopolitical zones; Abuja and Plateaux, Bauchi and Borno, Kano and Sokoto, Enugu and Imo, Benin and Rivers, Oyo and Ikeja. These differences have its direct effect on the overall insolations in this zones.

Table 3.1: Tilt of Collector across the locations.

Tilt at Latitude through Latitude +15 deg.

Location	Latituide	Latituide + 5deg.	Latituide + 10deg.	Latituide + 15deg.
Abuja	9.07	14.07	19.07	24.07
Bauchi	10.31	15.31	20.31	25.31
Kano	11.59	16.59	21.59	26.59
Enugu	6.5	11.5	16.5	21.5
Benin	6.34	11.34	16.34	21.34
Ikeja	6.45	11.45	16.45	21.45
Plateaux	9.17	14.17	19.17	24.17
Borno	11.5	16.5	21.5	26.5
Sokoto	13.07	18.07	23.07	28.07
Imo	5.48	10.48	15.48	20.48
Rivers	4.75	9.75	14.75	19.75
Oyo	8	13	18	23

3.2 Estimated Declination Angle (δ)

The result of the declination on the 21st day of every month is observed to have decreased from September to March and highest in June, a case typical of the declination chart.

Table 3.2 with respect to insolation shows that the higher the declination, the lower the insolation, and the lower the declination, the higher the insolation in each of the locations (This is inferred from Table 3.8a through 3.8d).

Table 3.2: Estimated Declination Angle (δ) through the Months (deg.)

Months	Jan.	Feb.	Mar	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Declination Angles	-19.9	-11.24	-0.4	11.59	20.16	23.47	20.46	11.76	-0.2	-11.8	-20.46	-23.47

3.3 The Altitude Angle (β) at the Locations.

The angle of the sun above the respective locations in each of the months is observed to be highest in April at Kano and lowest in December at Bauchi as shown in Table 3.3a. In Table 3.3b, the highest altitude is at Borno and Imo on April and the Least is at Borno and Imo in January. This is an indication that the lowest altitudinal locations will experience more radiation than the highest one.

Table 3.3a:The Altitude Angle (β) across the different Locations (deg.)

	Abuja	Bauchi	Kano	Benin	Enugu	Ikeja	Plateau	Borno	Sokoto	Imo	Rivers	Oyo
January	61.03	59.79	58.51	63.59	63.76	63.65	60.93	57.03	64.62	57.03	65.36	62.1
February	69.7	68.5	67.17	72.26	72.42	72.31	69.59	65.69	73.27	65.69	74.02	70.76
March	80.54	79.28	78	83.07	83.27	83.12	80.43	76.53	84.11	76.53	84.82	81.58
April	87.53	88.74	89.51	84.9	84.74	84.85	87.59	88.45	83.87	88.45	75.25	86.43
May	78.91	80.16	81.43	76.34	76.18	76.29	79.01	82.89	75.31	82.9	74.59	77.84
June	75.6	76.85	78.13	73.04	72.88	72.99	75.69	79.6	72.01	79.6	71.28	74.52
July	78.61	79.85	81.13	76.04	75.88	75.99	78.7	82.59	75.01	82.59	74.29	77.54
August	87.35	88.54	89.41	84.73	84.57	84.68	87.41	88.57	83.7	88.57	82.97	86.26
September	80.73	79.47	78.41	83.32	83.47	83.37	76.73	76.73	84.33	76.73	85.08	81.82
October	69.18	67.93	66.64	71.74	71.9	71.79	69.07	65.16	72.75	65.16	73.48	70.24
November	60.47	59.23	57.95	63.04	63.2	63.09	60.37	56.47	64.06	56.47	64.8	61.54
December	57.46	56.22	54.94	60.03	60.19	60.08	57.36	53.46	61.05	53.46	61.78	58.53

3.4 The Incidence Angle (θ)

The angle which the solar rays make with the surface of the collector at different tilts (i.e Latitude through Latitude + 15 degrees) at the point of incidence in the respective zones is shown in the table in Table 4.4a through 4.4d below; Table 4.4a through 4.4d also shows that as the incidence angle approaches zero (0^0), insolation becomes maximum and as incidence angle approaches ninety degrees (90^0), insolation becomes minimum. Also, Latitude has its effect on the incidence angle of each locations. The incidence angle is observed to be highest in December and least in September and March.

Table3.4: Incidence Angle (θ) across the locations.

	Table 3.4a: Locations at Tilt Equals Latitude						Table 3.4 b: Locations at Tilt Equals Latitude +5deg.					
	Abuja	Bauchi	Kano	Benin	Enugu	Ikeja	Abuja	Bauchi	Kano	Benin	Enugu	Ikeja
Jan.	19.9	19.91	19.91	19.91	19.9	19.9	14.9	14.9	14.92	14.91	14.89	14.9
Feb.	11.22	11.22	11.28	11.23	11.25	11.25	6.25	6.23	6.21	6.23	6.29	6.26
Mar.	0.44	0.44	3.03	0	0.7	0	4.61	4.56	4.6	4.65	4.51	4.55
Apr.	6.58	9.03	11.1	1.03	1.63	0	11.59	14.04	16.1	6.07	6.43	6.29
May	2.14	0.24	13.68	7.45	7.18	7.27	2.97	5.48	8.05	2.37	2.15	2.27
Jun.	5.32	2.83	0.47	10.77	10.47	10.57	0	2.14	4.73	5.82	5.44	5.57
Jul.	2.37	0	2.77	7.79	7.45	7.54	3.89	5.15	7.75	2.73	18.47	2.5
Aug.	6.42	8.83	11.12	0.76	1.15	1.15	11.43	13.84	16.03	5.92	6.22	6.12
Sep.	0.51	0	0	0	0	0.34	4.83	4.72	4.83	4.82	4.82	4.84
Oct.	11.76	11.77	11.74	11.85	11.77	11.77	6.75	6.78	6.74	6.77	6.77	6.77
Nov.	20.46	20.46	20.46	20.46	20.47	20.47	15.46	16.42	15.46	15.46	15.46	15.47
Dec.	23.47	23.41	23.45	23.47	23.48	23.46	18.47	18.47	18.34	18.46	18.47	18.46

	Table 3.4 c: Locations at Tilt Equals Latitude + 10deg.						Table 3.4d: Locations at Tilt Equals Latitude + 15deg.					
	Abuja	Bauchi	Kano	Benin	Enugu	Ikeja	Abuja	Bauchi	Kano	Benin	Enugu	Ikeja
Jan	9.94	9.88	9.91	9.91	9.9	9.9	4.93	4.93	4.93	4.92	4.85	4.91
Feb	1.06	1.22	1.3	1.17	1.45	1.4	1.99	1.79	1.76	1.76	1.75	1.65
Mar	9.61	9.59	9.63	9.63	9.56	9.58	1.99	14.61	14.61	14.61	14.59	14.58
April	16.6	19.05	21.11	8.71	11.43	11.3	21.6	24.04	26.1	16.07	16.41	16.3
May	8	10.47	13.04	2.46	2.82	2.77	12.97	15.46	17.19	7.5	7.83	7.73
June	4.63	7.09	9.72	0.8	0.76	0.9	9.67	12.16	14.72	4.31	4.55	4.46
July	7.69	10.13	12.74	2.25	2.52	2.32	12.69	15.16	17.71	15.92	7.53	7.43
August	16.43	18.85	21	10.92	11.22	11.11	21.31	23.92	26	7.2	16.22	16.13
September	9.82	9.78	9.8	9.81	9.84	9.82	14.8	14.8	14.79	14.8	14.83	14.83
Oct	1.81	1.81	1.65	1.8	1.82	1.78	3.21	3.24	3.14	3.21	3.32	3.14
Nov	10.46	10.46	10.47	10.47	10.46	10.45	5.47	5.48	5.42	5.44	5.45	5.17
Dec	13.48	13.46	13.46	13.46	13.46	13.46	8.47	8.46	8.43	8.46	8.46	8.44

3.5 The Diffuse Sky Radiation Factor (FSS)

The radiation factor which is estimated from the scattered direct beam on each locations is shown in Table 4.5a and 4.5b below: It can be inferred that the higher the diffuse sky factor, the higher the indirect radiation, and vice versa.

Table 3.5: The Diffuse Sky Radiation Factor (FSS) for the zones at Latitude through Latitude +15deg

	Table 3.5a: FSS for the zones at Lat. through Lat. +15 deg.						**Table 3.5b: FSS for the zones at Lat. through Lat. +15deg.**					
	Abuja	Bauchi	Kano	Enugu	Benin	Ikeja	Plateau	Borno	Sokoto	Imo	Rivers	Oyo
Latitude	0.9937	0.9919	0.9898	0.9968	0.9969	0.9968	0.9936	0.99	0.987	0.9977	0.9986	0.9951
Latitude +5 deg.	0.985	0.9823	0.9792	0.99	0.9902	0.99	0.9848	0.9794	0.9753	0.9917	0.9928	0.9872
Latitude +10 deg.	0.9726	0.9689	0.9649	0.9794	0.9798	0.9795	0.9723	0.9652	0.96	0.9819	0.9835	0.9755
Latitude +15 deg.	0.9565	0.952	0.9471	0.9652	0.9657	0.9654	0.9562	0.9475	0.9412	0.9684	0.9706	0.9603

3.6. Insolation at same geopolitical zones (Abuja vs Plateau, Bauchi vs Borno, Kano vs Sokoto, Enugu vs Imo, Benin vs Rivers, and Ikeja vs Oyo) at a tilt of latitude + 15 deg. This is the result obtained by comparing different locations in the same geopolitical zone, and the result shows the difference in insolation as captured using a flat plate solar collector , this pattern of distribution in the insolation is shown at latitude + 15 degrees, which also agrees with latitude, Latitude + 5degrees, and Latitude +10degrees.

3.6.1 **Insolation at Abuja vs Plateaux (at Tilt equal Latitude + 15 deg)**.

The Figure4.6.1 shows that insolation in this two locations are relatively close. However, apart from February where insolation in Abuja (933.84W/m2) is lesser than Plateaux (940.15W/m2), the insolation in Abuja is higher than Plateaux throughout the remaining months.

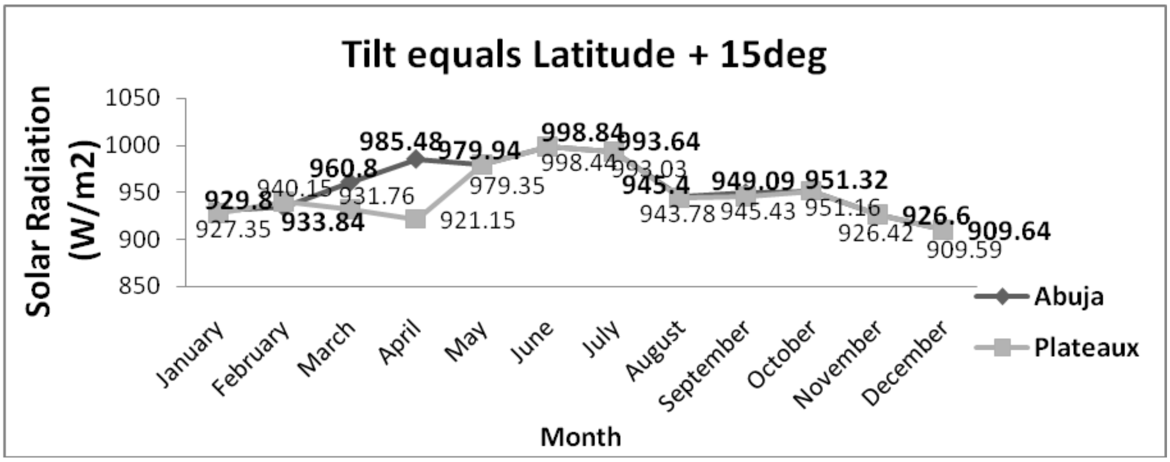

Figure 3.6.1: Insolation of Abuja vs Plateaux

3.6.2 Insolation at Bauchi vs Borno (at Tilt equal Latitude + 15 deg).

According to the Figure 4.6.2., only in May and September is captured insolation in Borno (997.01W/m2) higher than Bauchi (970.56W/m2), while captured insolation at Bauchi is higher in the other remaining months of the year. This result also shows to a reasonable extent that the higher the Latitude, the higher the tendencies for more insolation in some specific months of the year.

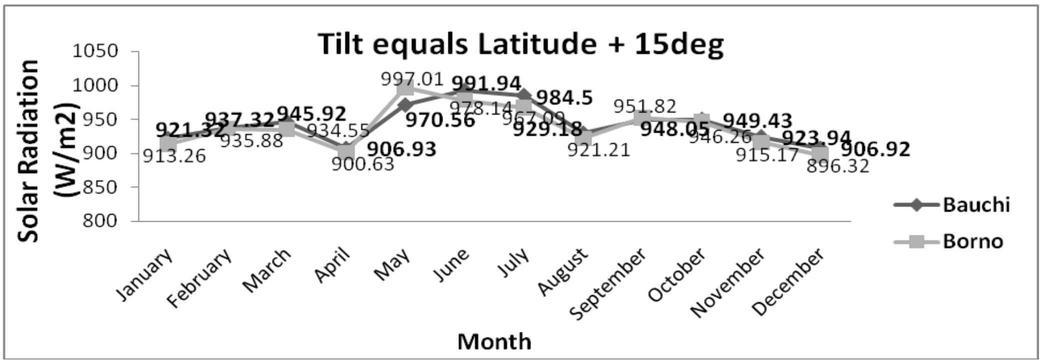

Figure 3.6.2: Insolation of Bauchi vs Borno

3.6.3 Insolation at Kano vs Sokoto (at Tilt equal Latitude + 15 deg).

In the Figure4.6.3, the insolation captured by collector in May at Kano (959.04W/m2) is lesser than in Sokoto (1003.25W/m^2). However, the other months are in favour of Kano. Meanwhile, the highest insolation in Sokoto is in May (1003.25W/m2), and the least is in December (899.54W/m^2).

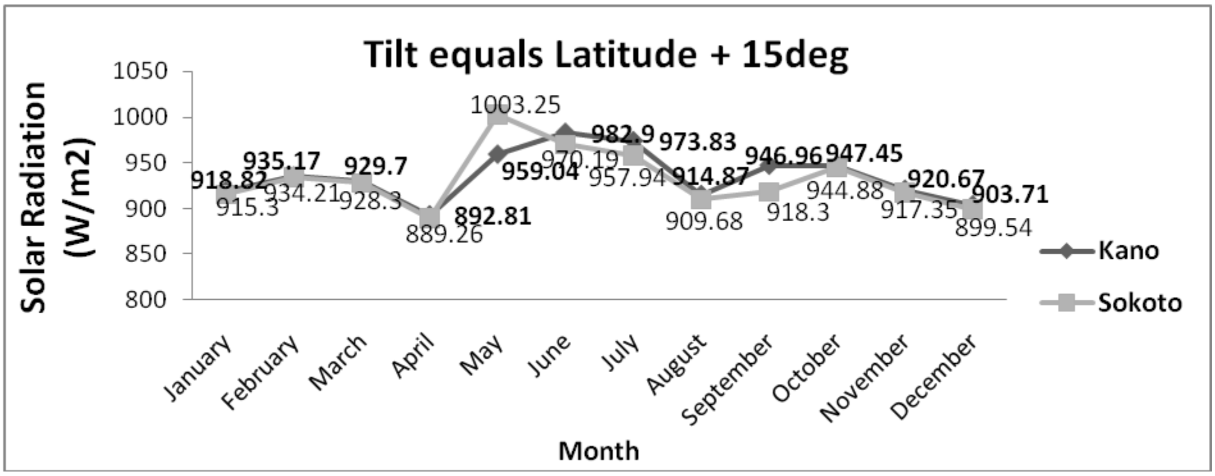

Figure 3.6.3: Insolation of Kano vs Sokoto

3.6.4 Insolation at Enugu vs Imo (at Tilt equal Latitude + 15 deg).

Figure4.6.4 shows the Insolation from January through November in Enugu is slightly lesser than in Imo except on December when the value of insolation in Enugu (915.67W/m^2) is higher than at Imo (909.59W/m2). The highest insolation is in July at Enugu while the least is in December at Imo.

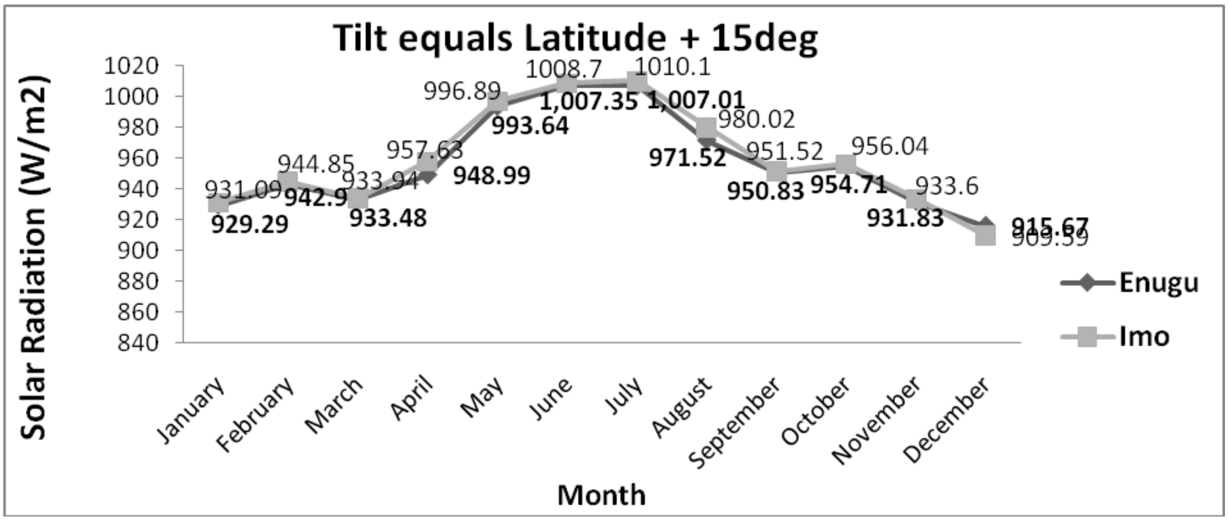

Figure 3.6.4a: Insolation of Enugu versus Imo

3.6.5 Insolation at Benin versus Rivers (at Tilt equal Latitude + 15 deg).

The Figure4.6.5 shows the highest insolation in Benin is in June (1007.62W/m2) while the lowest is in December (916W/m2) as shown in the Figure4.6.5. The figure also shows that insolation in Rivers is relatively higher than insolation captured in Benin except on March when insolation in Benin (933.49W/m2) is higher than at Rivers (872.26W/m^2).

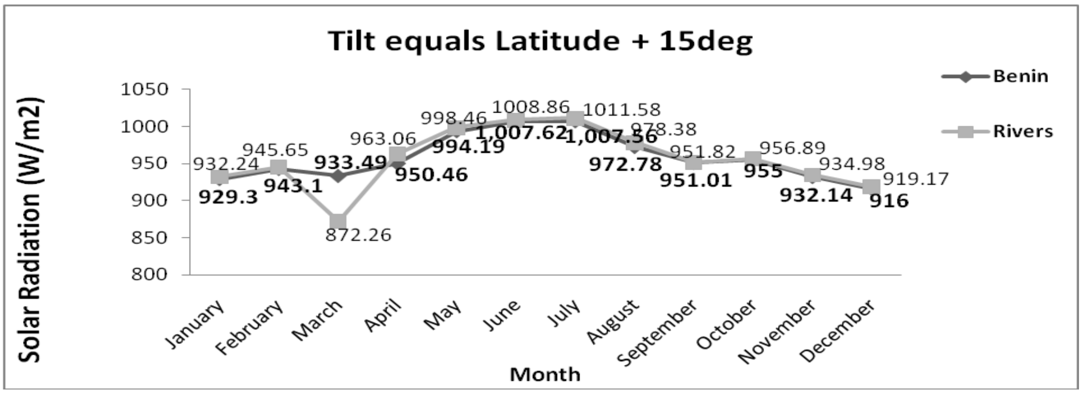

Figure 3.6.5: Insolation of Benin versus Rivers.

3.6.6 Insolation at Ikeja vs Oyo (at Tilt equal Latitude + 15 deg).

From the graph Figure4.6.6, it has been established that the insolation in Ikeja is higher than in Oyo throughout the year. For example, Ikeja (929.31W/m^2) is higher than Oyo (926.4W/m^2) in January.

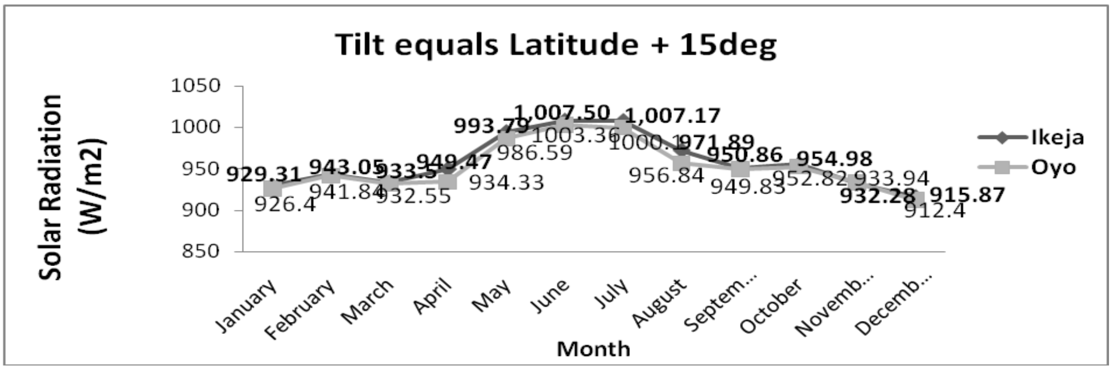

Figure 3.6.6: Insolation of Ikeja vs Oyo

3.7 INSOLATION AT ABUJA, BAUCHI, KANO, ENUGU, BENIN, IKEJA AT DIFFERENT TILT OF COLLECTOR.

This involves comparing each of the set of different locations at different tilts to establish the optimum tilts associated with the insolations at each months of the year.

3.7.1 Insolation of Abuja at Latitude, Latitude +5deg, Latitude +10deg, Latitude +15deg.

Figure4.7.1 shows that on January, November and December collected insolation at Abuja is highest when collector tilt is at Latitude+ 15deg (929.8W/m2), Latitude +10deg (942.3W/m2) on February and October. Meanwhile in March, and May through September highest insolation is at Latitude, and Latitude +15deg on April.

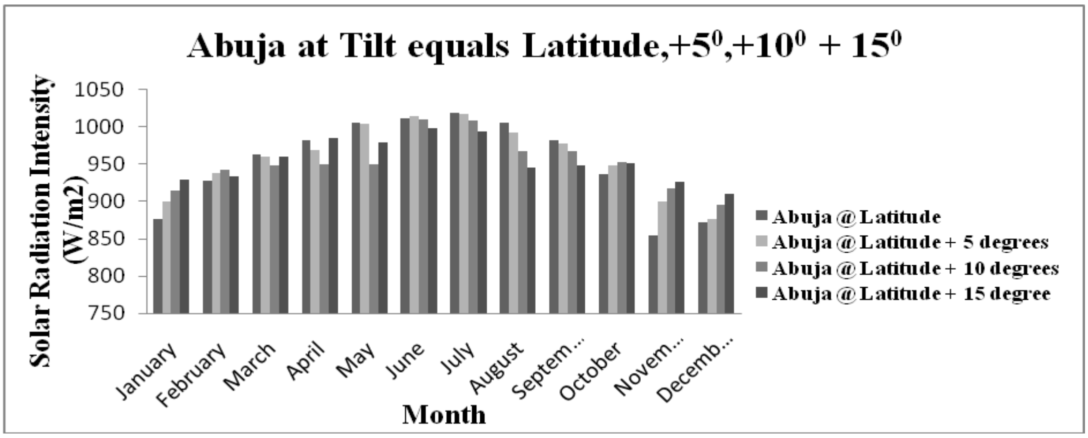

Figure 3.7.1: Insolation of Abuja at Latitude, Latitude +5 deg, Latitude +10deg, Latitude + 15deg.

3.7.2 Insolation of Bauchi at Latitude, Latitude +5deg, Latitude +10deg, Latitude+15deg. According to the Figure 4.7.2 below, the highest captured insolation in Bauchi (using flat plate collector) is in July (1,020.68W/m2) and the least is in December (846.83W/m2) when the collector tilt at Latitude (921.32W/m2). However, the highest insolation in January, November and December is at Latitude +15deg, in February and October, it is at Latitude+ 10deg, in March through September highest insolation is at Latitude.

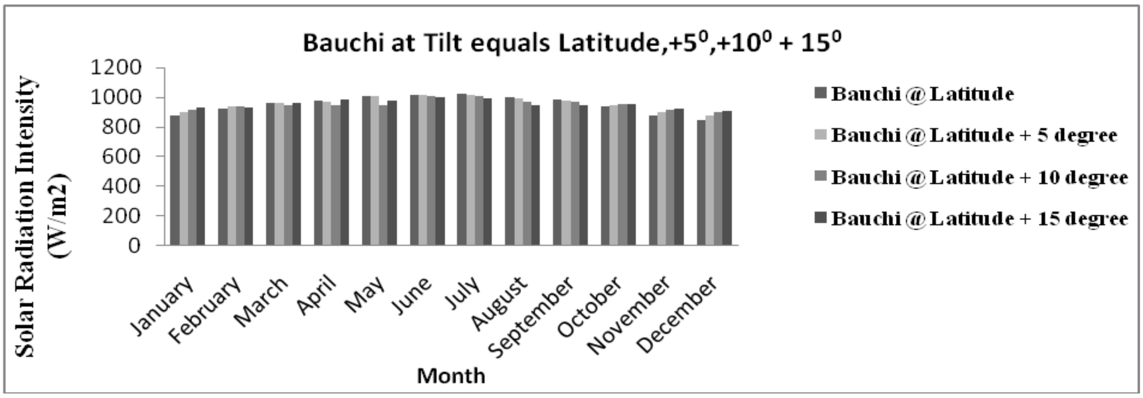

Figure 3.7.2: Insolation of Bauchi at Latitude, Latitude +5 deg, Latitude +10deg, Latitude + 15deg.

3.7.3 Insolation of Kano at Latitude, Latitude +5deg, Latitude +10deg, Latitude +15deg
In the Figure 4.7.3 below, the highest insolation in Kano is at Latitude (1020.04W/m2), and the least in December at Latitude (843.62W/m2). In Kano, the Figure also shows that in November through January the tilt for highest insolation is at Latitude +15degrees, Latitude +10degrees in February and October, , Latitude +5 degrees in May, while in March, April and June through September tilt for highest insolation is at Latitude only.

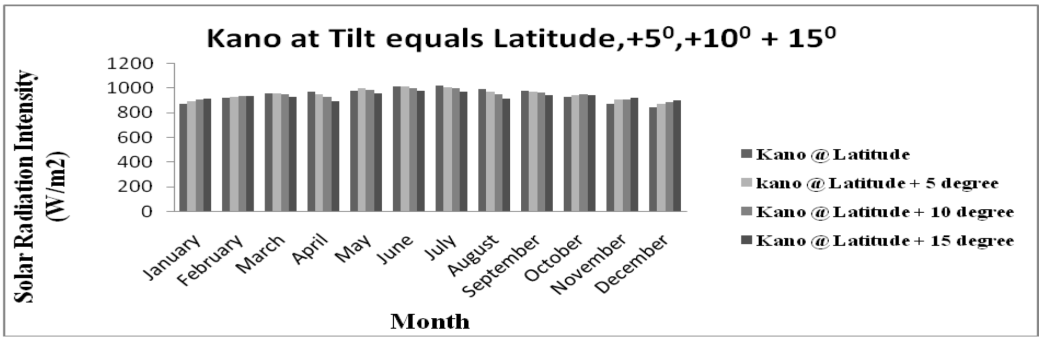

Figure 3.7.3: Insolation of Kano at Latitude, Latitude +5 degrees, Latitude +10degrees, Latitude + 15degrees.

3.7.4 Insolation of Enugu at Latitude, Latitude+5degrees, Latitude+10degrees, Latitude +15degrees
According to the Figure 4.7.4, the highest insolation captured in Enugu is at Lat + 5degrees (1016.94W/m2), and least is at latitude(854.19 W/m2). In January, November and December a tilt of Latitude +15degrees is highest, Latitude +10degrees in February, June and October, Latitude +5degrees in May and July, Latitude in March, April, August and September.

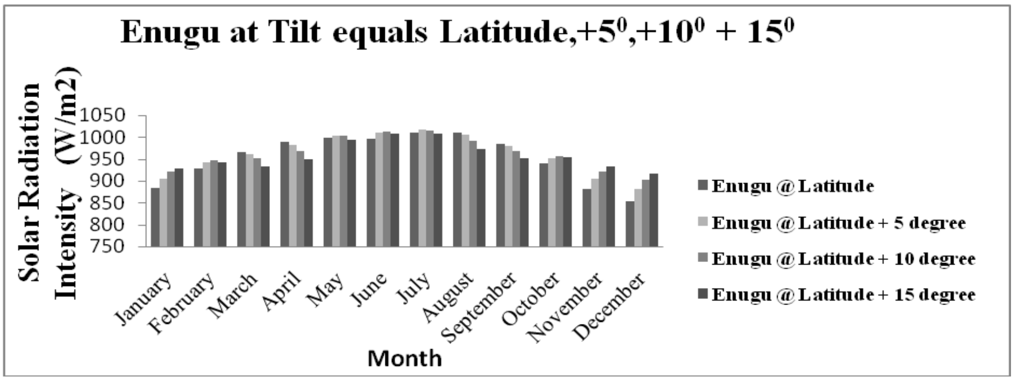

Figure 3.7.4: Insolation of Enugu at Latitude, Latitude +5 degrees, Latitude +10degrees, Latitude + 15degrees.

3.7.5 Insolation of Benin at Latitude, Latitude +5degrees, Latitude +10degrees, Latitude +15degrees

Figure 4.7.5 shows the highest insolation in Benin is (1016.82W/m2) in July at Latitude +5degrees, least is December at Latitude(854.57W/m2). The figure also shows that the highest insolation in November through January is at Latitude +15degrees, Latitude +10degrees in February, June and October, Latitude +5 degrees in May and July, Latitude in March, April, August and September.

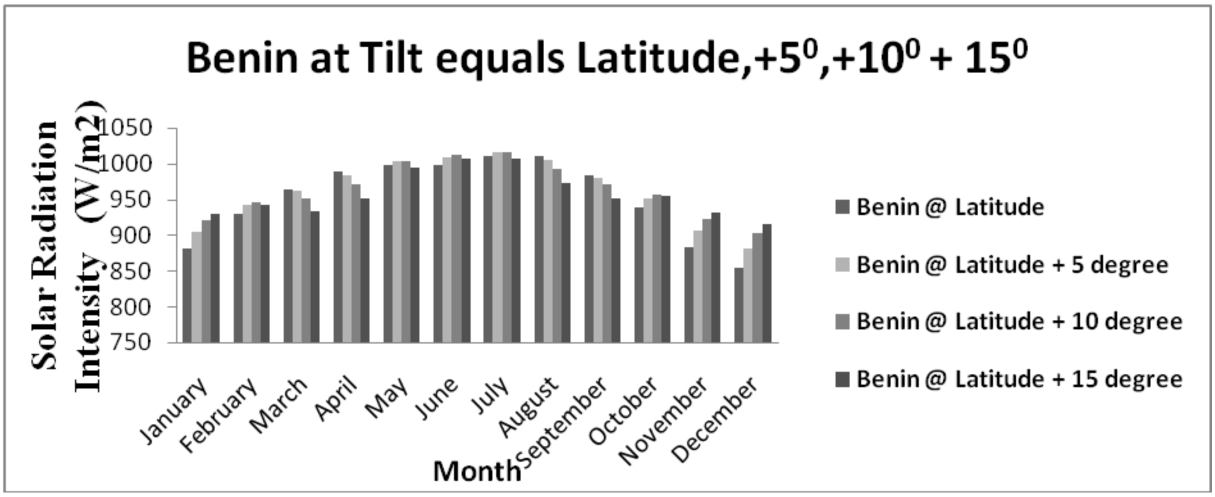

Figure 3.7.5: Insolation of Benin at Latitude, Latitude +5 degrees, Latitude +10degrees, Latitude + 15degrees.

3.7.6 **Insolation of IKeja at Latitude, Latitude +5degrees, Latitude +10degrees, Latitude +15degrees**

Figure 4.7.6 shows the highest insolation in Ikeja is at Latitude +5degrees(1016.82W/m2) on July, and least is at Latitude +5degrees(881.4W/m2) on December. Also, in November through January, the highest insolation is at Latitude +15degrees, Latitude +10degrees in February, June and October, Latitude +5degrees in March, April, May and July, and Latitude in August and September.

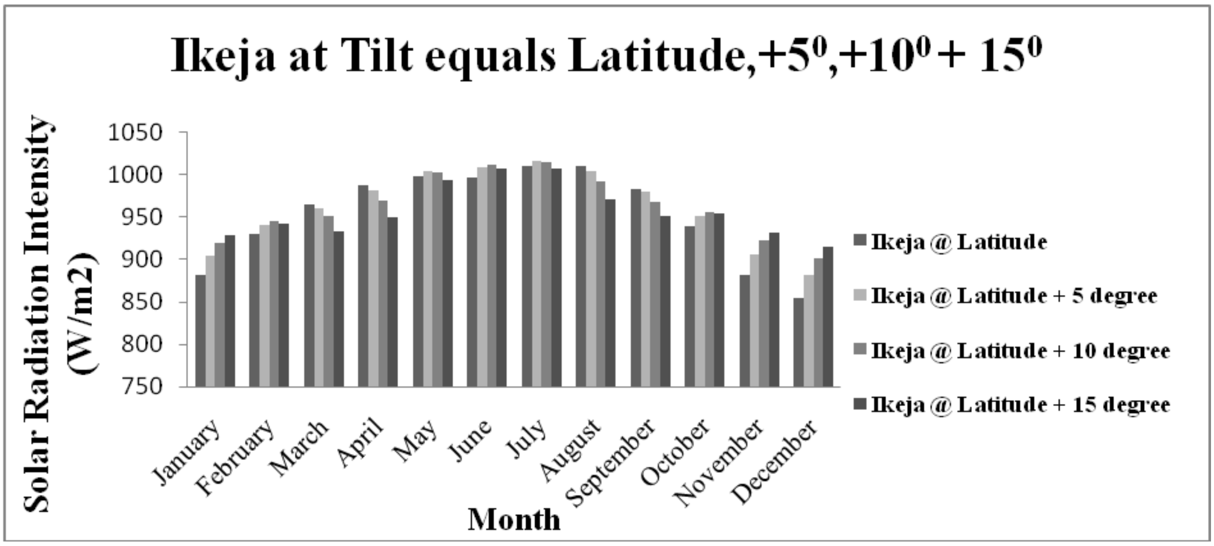

Figure 3.7.6: Insolation of Ikeja at Latitude, Latitude +5 deg, Latitude +10deg, Latitude + 15deg.

3.8.1 Total Radiation Absorbed (IT = Id +ID)

The distribution of radiation across the geopolitical zones for each of the months is presented in Table 3.8a through 3.8d, at Latitude through Latitude + 15deg.

From the Tables mentioned above, generally the highest insolations is collected across the northern zones around May through September, and the highest insolation is at Kano in June and the least is in November at Abuja at Latitude.

Also, at Latitude + 5deg, the highest insolation is at Abuja in July and the least is at Bauchi in January. At Latitude + 10deg, the highest insolation is at Enugu in June and the least is at Kano in December. At Latitude + 15deg, the highest insolation is at Benin in July, and the least is at Kano in April.

Table 3.8a: Total Insolation (IT = Id +ID) for respective locations, for a tilt equal to latitude of the location (W/m^2).

Month	δ	Locations with Tilt equals Latitude.					
		Abuja	Bauchi	Kano	Enugu	Benin	Ikeja
January	-19.90	876.97	874.52	871.95	883.13	881.53	881.46
February	-11.24	927.26	925.48	923.79	928.30	930.35	930.14
March	-0.40	962.91	961.09	961.44	964.50	964.51	964.52
April	11.59	982.78	977.52	971.68	988.09	989.03	988.45
May	20.16	1,006.27	1,007.46	982.34	998.40	997.76	998.19
June	23.47	1,012.19	1,015.77	1,017.50	995.70	997.85	996.33
July	20.46	1,019.31	1,020.68	1,020.04	1,011.05	1,010.20	1,010.82
August	11.76	1,005.41	1,000.09	993.83	999.03	1,010.73	1,010.67
September	-0.20	982.00	981.21	980.24	983.44	983.50	983.44
October	-11.76	936.46	934.77	933.00	939.54	939.44	939.59
November	-20.46	854.37	874.92	872.27	881.89	882.16	881.97
December	-23.47	872.11	846.83	843.62	854.19	854.57	854.38

Table 3.8b: Total Insolation; (IT = Id +ID) for respective locations, for a tilt equal to lat. of the location + 5 deg. (W/m2).

Tilt equal Latitude + 5^0						
Month	Abuja	Bauchi	kano	Enugu	Benin	Ikeja
January	899.35	847.08	894.23	904.07	904.25	904.16
February	938.57	936.89	932.73	941.52	941.79	941.57
March	959.74	958.77	957.88	961.27	961.17	961.2
April	969.57	960.9	952.17	982.17	982.79	982.44
May	1004.8	1002.28	998.29	1004.04	1003.76	1003.91
June	1015	1014.97	1013.2	1009.17	1008.38	1008.92
July	1018.06	1015.91	1011.63	1016.94	1016.51	1016.82
August	992.29	983.75	974.7	1004.8	1005.31	1004.96
September	978.17	977.27	976.22	979.73	979.79	979.66
October	948.56	947.47	944.65	951.59	951.77	951.65
November	900.47	897.94	907.39	905.24	905.53	905.33
December	875.94	873.13	870.04	881.3	881.69	881.4

Table 3.8c: Total Insolation; (IT = Id +ID) at the respective locations in Nigeria, for a tilt equal to latitude of the location + 10 deg. (W/m2).

Tilt equal Latitude + 10^0						
Month	Abuja	Bauchi	kano	Enugu	Benin	Ikeja
January	915.15	921.84	908.62	920.05	920.32	920.13
February	942.3	941.25	939.16	946.04	946.32	946.19
March	949.23	947.61	948.72	950.87	1002.63	950.89
April	949.37	932.62	928.88	969.08	1011.76	967.78

May	949.77	989.95	983.94	1002.43	950.79	1002.38
June	1010.55	1007.08	1003.05	1011.89	970.16	1011.78
July	1009.45	1003.75	997.84	1015	1015.65	1015.71
August	967.62	960.08	951.21	991.74	992.63	992
September	967.06	966.27	966.46	968.76	970.38	968.79
October	953.35	951.5	949.42	956.71	956.9	956.77
November	916.99	914.36	910.09	921.94	922.15	922.03
December	896.17	893.33	888.47	901.82	902.22	901.93

Table 3.8d: Total Insolation; (IT = Id +ID) at the respective locations in Nigeria, for a tilt equal to latitude of the location + 15 deg. (W/m2).

Month	**δ**	**Locations with Tilt equals Latitude + 15 degrees.**					
		Abuja	**Bauchi**	**Kano**	**Enugu**	**Benin**	**Ikeja**
January	-19.90	929.80	921.32	918.82	929.29	929.30	929.31
February	-11.24	933.84	937.32	935.17	942.90	943.10	943.05
March	-0.40	960.80	945.92	929.70	933.48	933.49	933.50
April	11.59	985.48	906.93	892.81	948.99	950.46	949.47
May	20.16	979.94	970.56	959.04	993.64	994.19	993.79
June	23.47	998.84	991.94	982.90	1,007.35	1,007.62	1,007.50
July	20.46	993.64	984.50	973.83	1,007.01	1,007.56	1,007.17
August	11.76	945.40	929.18	914.87	971.52	972.78	971.89
September	-0.20	949.09	948.05	946.96	950.83	951.01	950.86
October	-11.76	951.32	949.43	947.45	954.71	955.00	954.98
November	-20.46	926.60	923.94	920.67	931.83	932.14	932.28
December	-23.47	909.64	906.92	903.71	915.67	916.00	915.87

IV. CONCLUSION

For schemes to harness the highest amount of insolation using a flat plate solar collector, this research has shown that it is better if provisions are made for rotation of collector axis periodically as the declination, altitude, and incidence angle affects and varies the value of insolation and efficiencies of collector irrespective of clearness index. Hence, the above mentioned factors determine the effect and degrees by which the collectors should be tilted for maximum solar energy collection. It can be deduced from this research work that improvement on the properties of the flat plate collector components such as transmissivity of glass covers, absorptivity of the absorber and an adequate insulation can directly improve collector thermophysical properties. However, for flat plate collector utilization, users should adopt the following tilts for maximum collection of insolation, In Abuja, collector tilt should be at Latitude +15degrees in October through April (however, in February and March collector tilt at Latitude +15degrees is only slightly lower than at Latitude + 10degrees, and Latitude only respectively), while a Tilt at Latitude should be adopted in May through September. In Bauchi, same recommendation above for Abuja also holds. In Kano, maximum insolation would be obtained at a tilt of Latitude +15 from October through February, a tilt of Latitude only in March and April, and a tilt at Latitude + 5degrees for the remaining months of the year. In Enugu, a tilt at Latitude+15degrees should be adopted from October through February, a tilt at Latitude in March, April, August and September, while a tilt at Latitude +5 degrees should be adopted in May through July for maximum insolation. In Benin, a tilt of Latitude +15degrees should be adopted from October through February, while the other months are good at Latitude for maximum insolation. For maximum insolation in Ikeja, a collector tilt at Latitude + 15degrees should be adopted from October through February, and a collector tilt at Latitude alone for march, April, August, and September, while a collector tilt at Latitude +10degrees is best for May through July.

For other non-selected locations (that were not captured directly in this project) but in the same geopolitical zones of this research project, the recommendations given for the nearest location in that geopolitical zones can be adopted since there will be only slight difference in their Latitude.
Finally, from the Hottel-Whillier Bliss equation, observation shows that a reasonable difference between the inlet and the ambient temperature can considerably affect the efficiency of the flat plate collector.

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