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Determination of Optimum Tilt Angle and Orientation of a Flat Plate Solar Collector for Different Periods in Kano

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***Abstract*- The importance of collector tilt angle and orientation in solar systems cannot be overemphasized. It determines the intensity of the radiation on a collector and its ability to reflect, transmit and absorb the radiation. In this study, collector tilt angle and orientation for Kano, Nigeria which lies on latitude 12.1^{0}N was determined experimentally. A solarimeter mounted on a plane of a simply constructed flat plate solar collector was used to measure the solar radiation and determine the angle at which the record is high. The optimum collector tilt angles for the months of November to April were found to lie between (Φ + 3^o) ≤ β_{opt} ≤ (Φ + 33^o). At these inclinations, the mean monthly solar radiation recorded were about 6%, 3% and 11% higher than at latitude Φ, Φ+15^0 and Φ -15^0 respectively**

***Index Terms*— Flat plate, Collector, Tilt angle, Orientation, Latitude**

I. Introduction

The performance of a solar collector is highly influenced by its orientation and its angle of tilt with the horizontal. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the collector. Therefore in the design, simulation and operation of solar collectors, it is very essential to know the optimum tilt angle. Optimum tilt angle is applied to a variety of systems, such as flat or parabolic collectors, photovoltaic (PV)-systems, solar houses and solar greenhouses installed in a fixed position. In addition to these, it is crucial in the determination of the lengths of the shading elements to be placed above the windows in buildings as well as in the right selection of the angles of these elements if they are located angular.

According to Bala et al. (2000) and Sambo, (2009), Nigeria is endowed with an annual average daily sunshine of 6.25 hrs, ranging from 3.5 hrs at the coastal areas to 9 hrs at the far northern boundary. Similarly it has an annual daily radiation of about 5.25 kWm^{-2} day -^{1} at the coastal area and 7.0 Kwm^{-2} day^{-1} at the northern boundary. Nigeria is also characterized by some cool and dusty atmosphere during the harmattan in the northern part for a period of about four months (i.e November –February). It has been confirmed by Garba and Bashir (2002) that, the dust has an attenuating effect on the solar radiation intensity. Despite the harmattan, Nigeria has average solar insulation greater than the world average. Kano located on latitude 12.1^{o}N where this research had been carried out has a sunshine hours ranging from 6.9hrs in March to 8.2 hrs in June. A number of studies have been carried out by various investigators in order to optimize the tilt angle and orientation of solar collectors around the world, while studies related to Nigeria are few in number and utilization efficiency of most solar energy appliances in Nigeria is very low. This study intends to address these shortcomings.

The slope or tilt angle (β) is defined as the angle between the plane of the solar collector and the horizontal. When β is positive, the orientation of the surface is towards the equator, and when β is negative, it is towards toward the pole (Goswami et al, 2000). On the basis of literature survey, a thumb rule for Indian conditions has been made. According to this rule, the optimum inclination of the surface receiving maximum radiation is given as $\beta = \Phi \pm 15^o$, (Tiwari, 2006). Where positive sign refers to winter condition and negative sign refers to summer conditions. Many authors (Grassie and Sheridan, 1977, chaim, 1982 and Bairi, 1990), have suggested the use of different slope angles for different seasonal applications. They suggested adjusting the slope angle at least twice a year; once in summer and once in winter.

Many investigations have been carried out to determine or at least estimate the best slope angle for solar systems. Some of these are, for example, $\Phi + 20^o$, Hottel, (1954), $\Phi + (10^o\text{-}30^o)$, lof and Taybout, (1973), $\Phi + 10^o$, Kern and Haris, (1975), and $\Phi - 10^o$, Hyewood, (1971). Some researchers suggested two values for the tilt angle, one for the summer and one for the winter, such as $\Phi \pm 20^o$, yellot, (1973), $\Phi \pm 8^o$, lewis, (1987) where Φ is latitude, "+" for winter and "-" for summer. Computer programs have also been used and the results have shown that the optimum tilt angle is almost equal to the latitude (Gopinathan, (1991), Soulayman, (1991), El-Kassabay, (1987) and Marcos, (1994).

From the above reviews it could be said that, a stationery solar collector cannot receive maximum solar energy on a year round basis because of the wide separation of optimum slope angles and orientation. Certain applications like crop or fruit drying, salt distillation etc, needs to use the solar collector for certain period of the year. Saiful (1999) found that when compared to fixed slope angle for the whole year, the seasonal adjustments of the solar collector receive up to 40% more solar energy. He used ASHRAE standard model atmosphere and the isentropic diffuse model to compute the direct and diffuse component of the solar radiation respectively.

Adnan et al, (2000) used solar fraction of the system (the fraction of energy supplied by the solar energy) as an indicator to find the optimum inclination angle for the thermosyphon solar water heater installed in the northern and southern parts of Jordan. His results showed that the optimum tilt angle for maximum solar fraction was about $\Phi + (0^o\text{-}10^o)$ for the northern region represented Amman and about $\Phi + (0^o\text{-}20^o)$ for the southern region represented by the town of Aqaba.

According to literature survey, most of the solar collectors constructed and installed in Nigeria are based on the findings of Gopinathan (1991), soulayman (1991) and El-Kassaby (1987) respectively, while few are based on the findings of Kern and Haris (1975)

Muhammad (1995) used frosted Dome Solarimeter, mounted on a bracket to experimentally determine the optimum collector orientation for Bauchi which lies on 10.3^o N and 9.8^o E. He found that, the optimum collector orientation for Bauchi for the month of January was 30^o. At this inclination, the total insulation recorded was about 24 percent more than at inclination of 90^0 and 9 percent more than at zero degree orientation.

II. MATERIAL AND METHODS

In order to determine the optimum tilt angle, six flat plate collectors were constructed in the workshop of Mechanical Engineering Department, Bayero University, Kano. The collectors measured $56cm^2$ each. The materials for the collector includes, low iron glass (4.0mm thickness) used as glazing, galvanized steel sheet (1.0mm thickness) painted black and used as the absorber, fiber glass with an operating temperature of 50^o to 230^o used as insulation, ply wood used as frame and ¾ inch square pipe and 1 inch angle bar used to construct the supporting frame. Five of the supporting frames were inclined at angles of 15^o, 25^o, 35^o, 45^o, and 55^o to house the collectors at the same time. One of the frames was constructed to rotate through -90^o to $+90^o$. A digital multi-meters was used to measure the output of the solarimeter in milli-volts (mV), which was then converted into solar radiation in watts per meter square (Wm^{-2}) using a multiplier of $90.34Wm^{-2}$ per mV with a sensitivity of $4.76 \times 10^{-6}Wm^{-2}$.

III. EXPERIMENTAL PROCEDURE

The standard procedure for flat plate solar collector testing is to operate the collector on a stand, under conditions in which operation is nearly steady i.e. the radiation and other conditions are essentially constant for a long time enough for the outlet temperature and useful gain to become steady. The global solar radiation was measured using a Solarimeter on the plane of the collector. To achieve maximum solar radiation, the collectors were rotated to face the sun (i.e. south facing) to reduce the angle of incidence and capacitance effect. A digital multi-meters was used to measure the output of the solarimeter in milli-volts (mV), which was then converted into solar radiation in watts per meter square (W/m^2) using a multiplier of $90.34Wm^{-2}$ per mV with a sensitivity of $4.76 \times 10^{-6}Wm^{-2}$. The other collector which has a variable tilt angle was used randomly and solar radiation and surface temperature of the absorber were recorded. Angles such as 0^o, 12.1^o 12.1 ± 15^o were randomly chosen. Figure 1 presents a typical test rig for the studies. The tests were conducted for a period of six months spanning from November, 2008 to April, 2009. Readings were taken for solar radiation, absorber surface temperature and ambient temperature from 10:00am to 3:00pm on an hourly basis. The results are presented in the next section.

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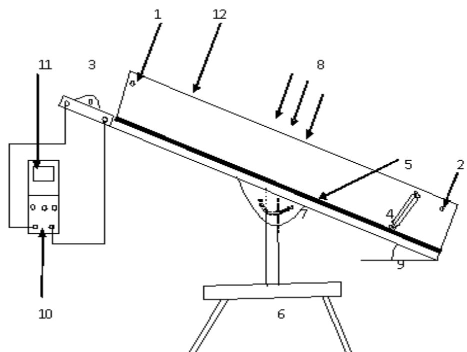

Figure 1: Flat plate solar collector arrangement

1, 2-Connection to next panel, 3-Solarimeter, 4-Thermometer, 5-Absorber Surface, 6-Collector Stand, 7-Adjuster, 8-Solar radiation, 9-Tilt angle, 10-Digital Multimetre, 11-Digital Display (mV), 12-Glazing

IV. RESULT AND DISCUSSION

Tables 1 and 2 show the mean monthly solar radiation and absorber temperature record at various collectors tilt angles for the months of November, 2008 to April, 2009 respectively. Table 3 gives the comparison between the optimum mean monthly solar radiations at the optimum tilt angle for the present study and the mean monthly solar radiations at the tilt angles of well-established literatures such as Tiwari (2006), Morcos (2004), El-kassabay, (1994), Gopinathan (1991) and Soulayman (1991).

Figure 3-9 were plotted for the months of November to April to show the mean daily solar radiation. From these plots, the optimum mean solar radiations for these months were found to be 958.7W/m^2, 880.34W/m^2, 863.28W/m^2, 913.54W/m^2, 867.34W/m^2 and 880.34W/m^2 respectively. These optimum radiations occurred at 35^o, 45^o, 35^o, 25^o, 15^o and 15^o tilt angles respectively. Hence, these angles gave the optimum tilt angles (β_{opt}) for these months respectively. Also from Table 2, Figures 2 and 9 was plotted. The graphs in the figures conformed with the result already established in figures 3-9 indicating the optimum tilt angles for the months.

Figures 3-9 shows the variation of the mean daily radiations according to the days of the month at (β_{opt}) respectively. From these figures the daily optimum solar radiations for these months were found to be 1039 W/m^2 on 20th and 21st November, 1005 W/m^2 on 1st December, 1012 W/m^2

on 30th January, 1077 W/m^2 on 8th February, 1053 W/m^2 on 18th March, 1003 W/m^2 on 5th April and the minimum daily radiations were found to be 635wm^2 on 18th November, 623W/m^2 on 21st December, 542 W/m^2 on 24th January, 647W/m^2 on 1st February, 488W/m^2 on 6th March and 461W/m^2 on 21st April. From these results, it could be inferred that the average radiation collected daily for each month were 837W/m^2, 814W/m^2, 777W/m^2, 862W/m^2, 771W/m^2 and 732wm^2 respectively.

From table 3, it was found that the solar radiation at (β_{opt}) for the present study was higher than the reading obtained at latitude Φ and Φ ± 15^0 by 6%, 3% and 11% respectively. These percent differences could have been higher if the whole year was considered. This is because the tilt angle was found to increase linearly towards the end of the year and decreases linearly from January.

Table 1: Mean monthly solar radiation (W/m^2) for November, 2008 – April, 2009

Month	**Collector Tilt Angle (β) in Degree**								
	-2.9	**0**	**12.1**	**15**	**25**	**27.1**	**35**	**45**	**55**
November	800	82	864.	928.	951.	953.	958.	926.	866.7
December	737	76	801.	857.	879.	850.	879.	880.	805.4
January	758	76	796.	836.	855.	859.	863.	842.	795.3
February	828	84	888.	902.	913.	895.	889.	851.	800.4
March	785	81	848.	867.	854.	841.	813.	758.	701.7
April	845	84	852.	880.	830.	815.	765.	685.	613.7

Table 2: Mean monthly Absorber temperature (^{o}C) for November, 2008 – April, 2009

Month	**Collector Tilt angle in degrees (β)**								
	-2.9	**0**	**12.1**	**15**	**25**	**27.**	**35**	**45**	**55**
Novemb	92.	94.	95.6	98.	99.	99.	108.	99.4	72.1
Decemb	88.	89.	90.1	90.	93.	94.	97.0	99.4	70.9
January	89.	90.	90.5	90.	91.	92.	94.9	89.2	71.7
February	97.	97.	98.7	99.	100	97.	96.5	94.1	87.2
March	98.	98.	98.9	10	96.	95.	93.4	87.8	80.9
April	99.	99.	100.	10	94.	93.	91.4	84.1	74.3

Table 3: Comparison of mean monthly solar radiation (W/m^2) at tilt angle of the present and past studies

Month	**β_{opt} present study**	**β_{opt} at lat. (Φ)**	**β_{opt} at Φ +15^o**	**β_{opt} at Φ -15^o**
Novemb	958.70	864.85	953.76	800.65
Decemb	880.34	801.53	850.63	737.42
January	863.28	796.52	859.57	757.98
February	913.54	888.63	895.73	828.52
March	867.34	848.91	841.04	785.28
April	880.34	852.93	815.66	845.14

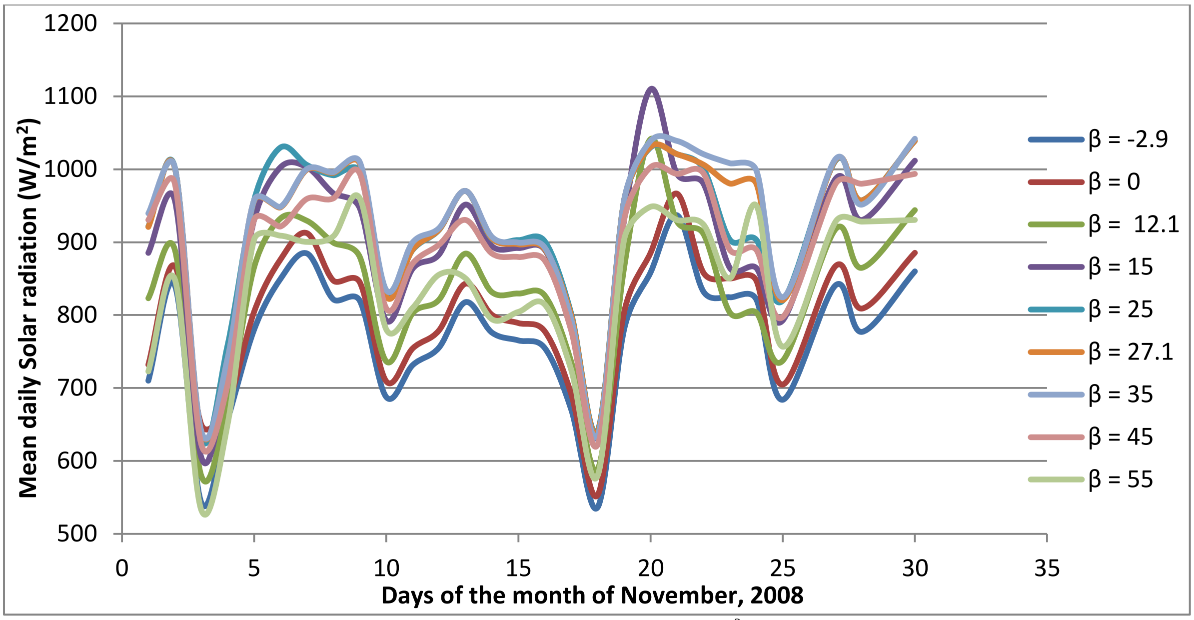

Figure 3: Variation of mean daily solar radiation (W/m^2) for November, 2008

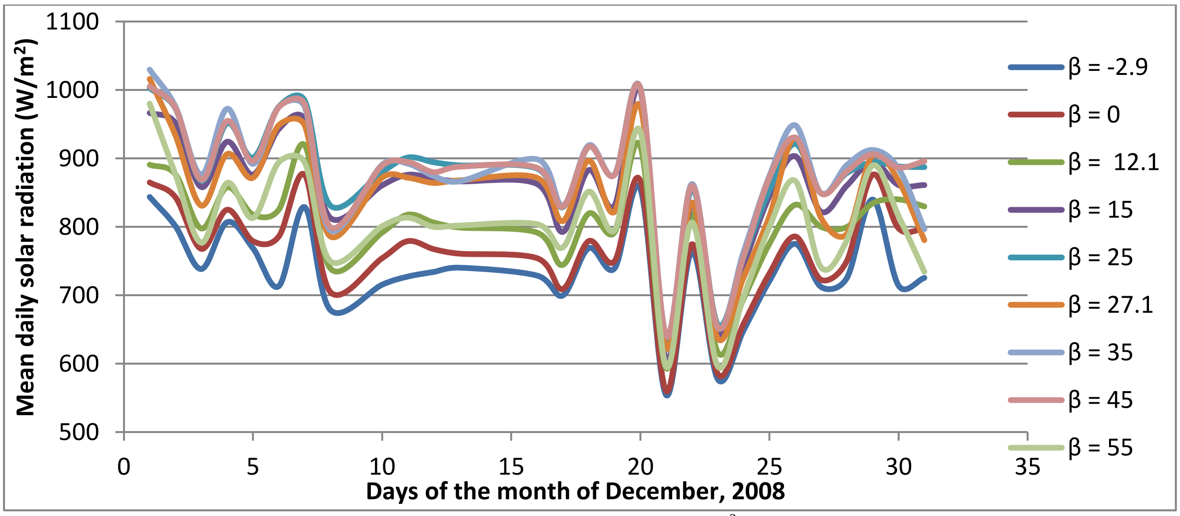

Figure 4: Variation of mean daily solar radiation (W/m^2) for December, 2008

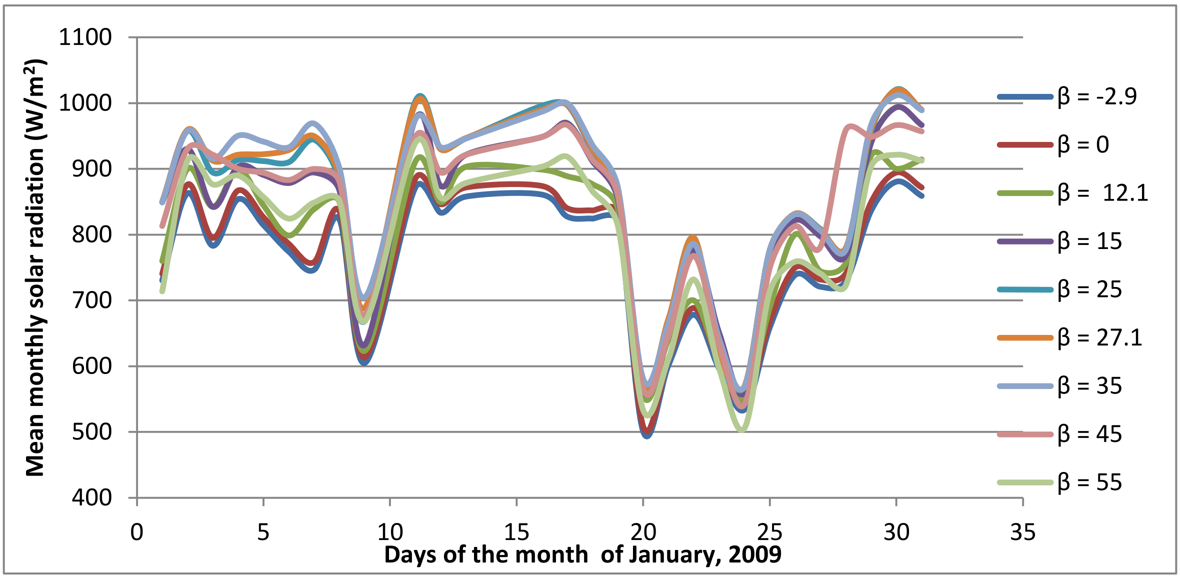

Figure 5: Variation of mean daily solar radiation (W/m^2) for January, 2009

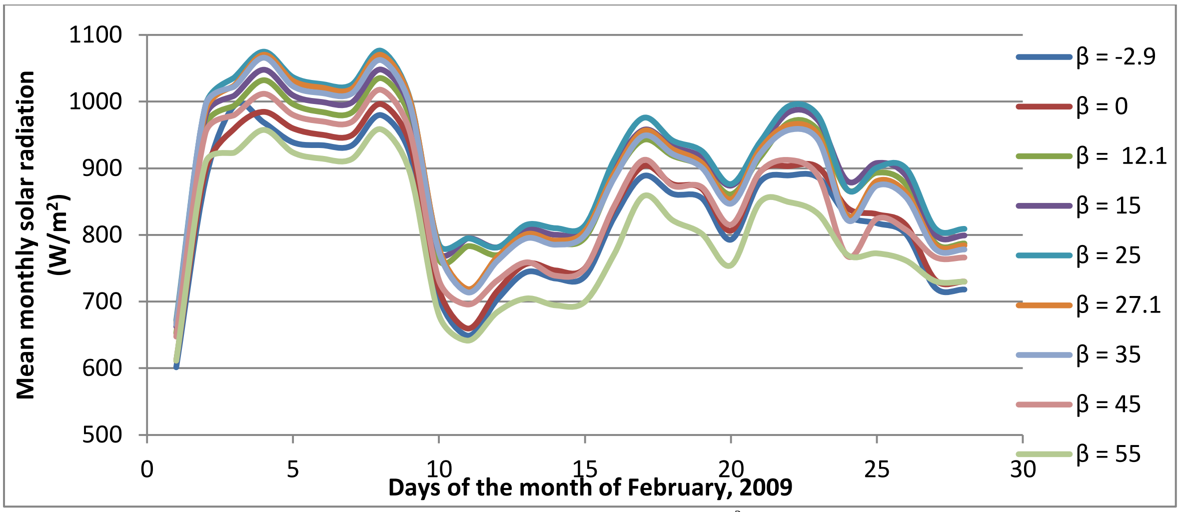

Figure 6: Variation of mean daily solar radiation (W/m^2) for February, 2009

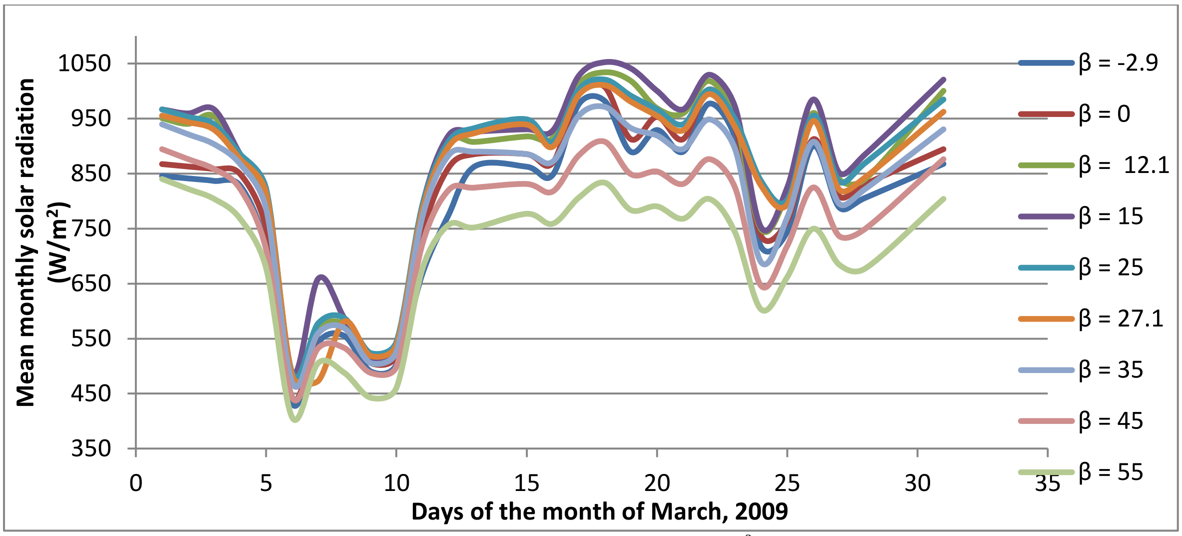

Figure 7: Variation of mean daily solar radiation (W/m^2) for March, 2009

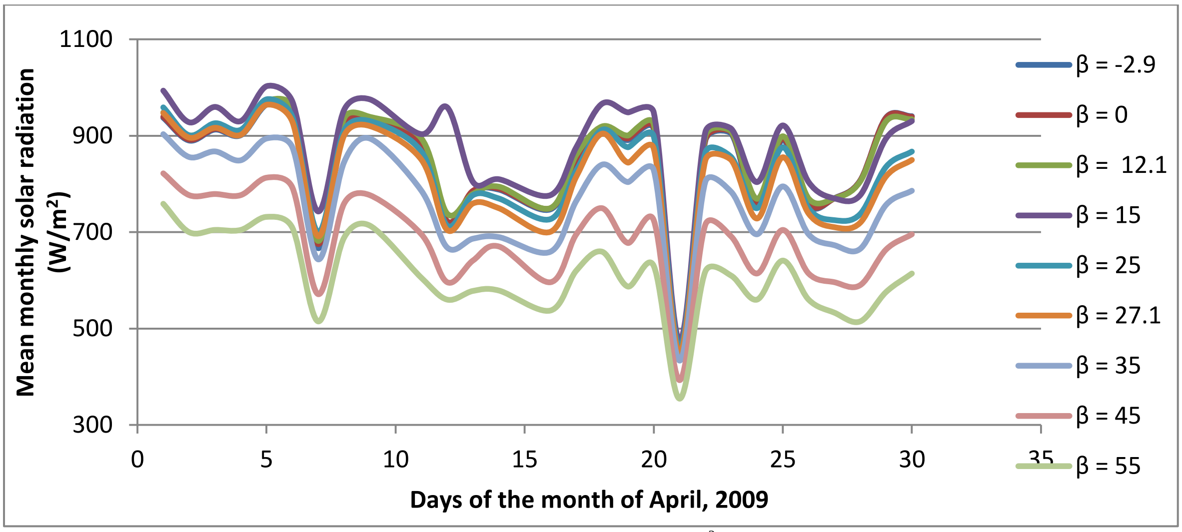

Figure 8: Mean daily solar radiation (W/m^2) for April, 09

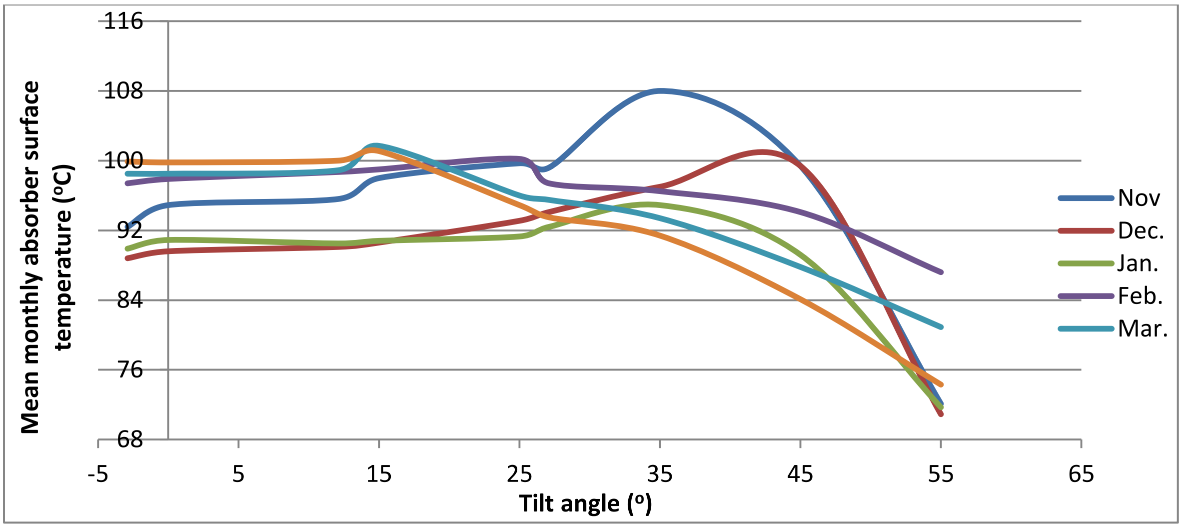

Figure 9: Variation of mean absorber surface temperature at different tilt angles for Nov, 08-Apr, 09.

V. CONCLUSSION

The following main conclusions were drawn from the results of the study;

1. A simple flat collector was constructed and experiments were performed to optimize its tilt angle and orientation in Kano and the experiments were performed for a period of six months (November, 2008 to April, 2009).
2. The optimum tilt angles for months of November to April were found to be 35°, 45°, 35°, 25°, 15° and 15° respectively. At these inclinations the mean monthly solar radiation collected were found to be 6% higher than that at latitude, 3% higher than at Φ +15° and 11% higher than at Φ -15°.
3. It could be simply stated that, for these months $(\Phi + 3^o) \leq \beta_{opt} \leq (\Phi + 33^o)$
4. The best orientation for solar collectors in Kano is due south.
5. In order to increase the utilization efficiency for solar collectors, it should be mounted at the monthly optimum tilt angle and the slope be adjusted once a month. At these adjustments, this study showed that the daily average solar radiation collected for the months was 779W/m^2.
6. Hence, the optimum tilt angle and orientation plays an important role in enhancing solar energy collection of solar collectors.

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RECOMMENDATION

From the result of the study the following recommendation were made:

1. Optimum collector tilt angles for other months (May to October) should be determined for Kano. This will enable the collector be tilted to track the sun for maximum energy collection for each month throughout the year.
2. Similar data be recorded for other cities of the country so as to determine the standard collector tilt angles for the country.
3. Further studies should be conducted to analyze the effects of the latitude and different climates on the optimum tilt angle. Also studies should be geared towards determining other solar parameters such as solar time, hour angle solar azimuth etc for all major cities of the country in order to simplify the design of solar systems and its optimization.

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