International Journal of Engineering and Innovative Research

http://dergipark.gov.tr/ijeir

ANGULAR SOLAR RELATIONS ANALYSIS OF A FLAT PLATE SOLAR COLLECTOR IN BENIN CITY METROPOLIS

Eghosa Omo-Oghogho[1*], Ikpe Aniekan Essienubong[1]

[1] Department of Mechanical Engineering, University of Benin, P.M.B 1154, Benin City, Nigeria.

[*]Corresponding Author: eghosa.omo-oghogho@uniben.edu
(**Received:** 26.04.2020; **Revised**: 20.05.2020; **Accepted:** 15.06.2020)

ABSTRACT: The sun is one of the major sources of energy, the distance, position and rotation of the sun and the earth are obtained for proper collector design. The declination angles, zenith angles, solar azimuth angles and the incident angles of Benin City, Edo State where obtained considering the ambient conditions, longitude and latitudes of site under consideration. This was achieved through experimental investigation using a prototype designed flat plate solar collector system. Average declination angle of 14.6675, average zenith Angles of the sun of 22.1850, average incidence angle of 21.7650, average solar Azimuth angle of 77.0625 and average ratio of beam radiation of 1.0875 were obtained respectively. As a result of this, the average radiation on a tilted surface were obtained to be 1025.3258w/m^2 for enhanced flat plate solar collector design.

Keywords: Flat Plate Solar Collector, Tilt Angle, Declination Angle, Zenith Angles of The Sun, Solar Azimuth Angle, Incidence Angle, Ratio of Beam Radiation

1. INTRODUCTION

The annual amount of solar radiation received by the earth varies due to the changeable distance between the earth and the sun. The Earth- Sun distance has a minimum value of 1.471×10^{11}m which is called, perihelion, on December 21 and a maximum value of 1.512×10^{11}m which is called, aphelion, on June 21 [1]. The average distance between the earth and the sun that is called astronomical unit (AU) is 1.419×10^{11}m. The earth revolves around itself within an axis that has tilted angle of 23.45° with respect to its orbital plane axis [2]. This angle is the cause of the changeable solar radiation throughout the year.

Solar energy is a form of renewable energy that can be used in one form or another. This research work shows that a lot depends on the position and distance between the sun and the rotation of the earth.

Nielsen [3] gave an expression for determination of the global horizontal solar radiation intensity in nth hours of the day. Bena and Fuller [4], Sharma, Chen and Nguyen [5] and Iloeje [6] indicated that solar energy trapped by solar dryers is now commonly used globally in drying and preservation of agricultural products. The uses of helio-electrical devices, which trap solar radiation on horizontal plane, are increasing world-wide.

The total energy output of the sun is about 3.8 x10^{20} MW which is equal to 63 MW/m^2 of the sun's surface. Although the energy radiates in all directions relative to its location, only a small fraction of about 1.7 Kw of the total radiation emitted is intercepted by the earth [7]. Hanif et al. [8] analyzed the energy, exergy and efficiency of a flat plate solar air heater based on five different air mass flow rates of 0.5 (Natural), 1.31, 2.11, 2.72 and 3.03 kgs^{-1} under three different tilt angles of 25, 35 and 50^o. From the results obtained, the solar collector performance better at air mass flow rate of 3.03 kgs^{-1} under tilt of 35^o. At maximum air mass flow rate of 3.03 kgs-1and optimum tilt angle of 35^o, the maximum energetic efficiency of 51%, minimum exergetic efficiency of 24% as well as maximum overall efficiency of 71% were obtained.

Dare et al. [9] investigated the efficiency and insolation of flat plate solar collectors considering selected locations in the six geopolitical zones of Nigeria at different tilts. Performance of a flat plate collector in relation to heat transfer fluid in the absorber was examined using Standard Equation known as the Hottel -Whillier- Bliss Equation. The results obtained indicated that, as the incidence angle approaches 0^o, insolation become maximum and as incidence angle approaches 90^o, insolation becomes minimum.

To establish the dependence of first law efficiency, second law efficiency, orientation of flat plate collector, average temperature rise on the mass flow rate of water as well as the greenhouse effect, Swain et al. [10] experimentally investigated a solar water heater in technical collaboration with Welson Energy Systems which uses variable water flow rate ranging from 0.001-0.02 kgs^{-1}. The results revealed that the instantaneous efficiency increases with increase in mass flow rate while the second law efficiency decreased with increase in mass flow rate. The instantaneous efficiency and second law efficiency were observed to be more significant with greenhouse effect than it is without the greenhouse effect. Exergy loss was found to be more significant without greenhouse effect than it is with greenhouse effect. Skeiker [11] in an investigation of the optimum tilt angle for Syrian regions reported that the adjustment of solar collector tilt angle has the potential to increase the solar energy collection by 10%.

An empirical correlation of Erbs to determine the optimal tilt angle for Abu Dhabi was employed by Jafarkazemi and Saadabadi [12]. It was suggested that the tilt angle be adjusted for at least semi-annually. The difference between annual average optimum tilt angle and the latitude was obtained as $2\text{-}3^o$ and azimuth was suggested close to the due south. This correlates with the findings of Soulayman and Hammoud [13], where the general correlation for mid latitudes was derived to determine the optimum tilt angle of solar collectors. Optimum tilt angle was observed to not exactly depend on the latitude and should be adjusted for the collector at least semi-annually. Also in a study conducted by Khorasanizadeh et al. [14] using several diffused radiation models and long term solar radiation data availed to determine the optimum tilt angle for a site located in Iran, semi-annual adjustment of surface tilt was suggested.

Ucar et al. [15] employed five different geometries in solar air collector to improve the performance of the heater using passive heat transfer enhancement techniques. Among the solar collectors tested, collector with absorber surface at 2° angle was found to be optimum. On the other hand, Jamil et al. [16] suggested at least a seasonal or monthly adjustment of tilt angle for optimum output based on their findings obtained from optimum tilt for solar collectors at two sites in India using measured solar radiation data. The tilt angle for several cities in Saudi Arabia was optimized by Kaddoura et al. [17] using MATLAB model. Adjustment of tilt angle of the solar collector was suggested as six times annually. For optimum tilt angle, frequent adjustments was suggested in the months near equinox, due to rapid change in the direction of the sun compared to solstices. Bhowmik and Amin [18] developed a novel technology to improve the performance of the solar thermal collectors. To maximize the intensity of incident radiation, the reflector was allowed to change its angle with daytime. The radiations coming from the sun's energy were converted into heat which was transferred to a prototyped solar water heating system. Collector efficiency of around 10% was obtained using the reflector. A flat plate surface solar collector of dimension 0.5 m^2, hinged on a horizontal support at inclination from 0-90^o was fabricated in Zaria, Kaduna State, Nigeria by Akachukwu [19]. Solar radiation and varying degrees of inclination were taken for each month of the year. The result showed that optimum angle of inclination of a flat plate for maximum collection of solar radiation intensities were 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^o, in the months of January to December. An average annual increment of 4.23 % solar radiation intensity was achieved for flat surface located at the predicted optimum angle of inclination for each month when compared to the yearly average solar radiation intensity obtained from the same flat plate collector on horizontal position, and under the same condition.

The aim of this research is to effectively predict optimum angles of inclination and amount of solar energy gained, using Benin City, Edo State, Nigeria as the location of study.

2. MATERIALS AND METHOD

To carry out the experimentation using the designed flat plate solar collector, the amount of solar radiation, day, declination angle, zenith angle of the sun, azimuth angle and the angle of incidence on the inclined surface was determined. A particular day in each month was chosen (mid-month), this day has approximately the total solar radiation which is equal to the monthly mean value for that particular month [20]. To design a solar flat plate collector, the area was determined considering the temperature of fluid (water) expected and the expected solar radiation of the location. The heat requirement is a function of the mass flow rate and the time of heating. Figure 1 shows an isometric view of the flat plate solar collector experimental set-up tilted at 10^o and has a water supply tank and a water discharge tank. The materials used in the flat plate solar collector setup are as follows: Wood used for casing, fibre (Polyurethane) used for insulation, aluminium painted black used for absorber plate, copper used for flow tube, transparent glass used for glazing cover, plastic used for water supply and discharged tank, plastic hose used for connecting the water tanks. The following initial conditions were considered for the flat plate solar collector system.

i. Steady state system.
ii. 26.1^{o}C daily average water inlet temperature (Relates to ambient temperature obtained from the National Centre for Energy and Environment (NCEE), University of Benin, Edo State, Nigeria.
iii. Active heating time of the water is estimated to be about 6 hours, within which the sun is actively present. Though daily peak temperature may vary with time.
iv. 100^{o}C absorber plate temperature.
v. Average daily solar radiation I = 1017.695W/m^2 from NCEE, University of Benin.
vi. Specific heating capacity of water Cp = 4190J/kgK.
vii. Tilt angle of 10^o
viii. 300 litres capacity water tank was used to supply water to the solar collector. The tank was placed at 0.5m height from the collector inlet, thus creating the required pressure head for circulation of water in the system.

ix. The surface azimuth angle is 0^o (the collector is facing the south).
x. The solar parameters are calculated with the sun one hour after noon i.e. 15^o.

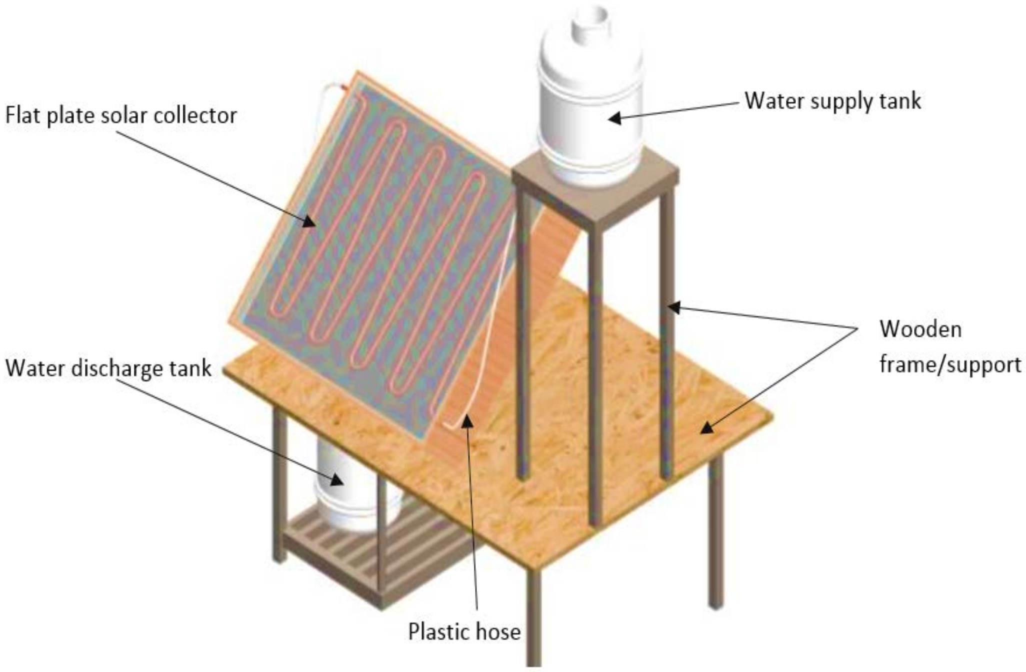

Figure 1. Flat plate solar collector setup.

2.1. Declination Angle

To effectively estimate the solar radiation of a tilted surface, there is need to know the angular position of the sun at solar noon, hence the determination of the declination angle considering the number of days. Declination angle varies and is calculated using the following relation:

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \quad (1)$$

where is the no of days. For n, the mean day in each month was used.

For January n=17, from Table 1.

Table 1. Recommended average days of various months and values of n by months [21].

Months	Days of the month	Mid-month	N
January	I	17	17
February	31 + i	16	47
March	59 + i	16	75
April	90 + i	15	105
May	120 + i	15	135
June	151 + i	11	162
July	181 + i	17	198
August	212 + i	16	228
September	243 + i	15	258
October	273 + i	15	288
November	304 + i	14	318
December	334 + i	10	344

2.2. Zenith Angles of The Sun

The Zenith angle was estimated considering the angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface has to be known in order to effectively estimate the amount of solar radiation on a solar collector.

The zenith angle is given by

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad (2)$$

Where, $\Phi = 6.5438^o$ $(lattitude\ of\ Benin\ City, Edo\ State, Nigeria)$

$\delta =$ declination angle.

$\omega = Hour\ angle.$ (15^0 was used because 1pm was considered as the time, during the system analysis)

2.3. Solar Azimuth Angle (γ_s)

The solar azimuth angle is estimated using the following relations:

$$\gamma_s = \text{sign}(\omega)\left|\cos^{-1}\left(\frac{\cos\theta_z\sin\phi - \sin\delta}{\sin\theta_z\cos\phi}\right)\right| \quad (3)$$

Where, Sign function is used to determine ω.

$\theta_z = Zenith\ angle.$

$\phi =$ lattitude of site.

$\delta =$ Declination angle.

2.4. Incidence Angle

The angle of incidence on the inclined surface is given by

$$\cos\theta = \cos\theta z\cos\beta + \sin\theta z\sin\beta\cos(\gamma s - \gamma) \quad \text{(Duffie and Beckman, [21]} \quad (4)$$

Where, $\theta =$ incidence angle.

β = tilted angle

$\gamma = 0, because\ it\ is\ facing\ south.$

$\theta z =$ Zenith angle.

$\gamma s =$ Solar azimuth angle.

2.5. Radiation on Tilted Surface

The data collected from the National Centre for Energy and Environment [22] are related to the horizontal surface, for purposes of solar process design and performance calculations, it is often necessary to calculate the radiation on a tilted surface of a collector from measurements or estimates of solar radiation on a horizontal surface. The geometric factor R_b, is the ratio of beam radiation on the tilted surface to that on a horizontal surface and this can be estimated using the following relations.

$$R_b = \frac{\cos\theta}{\cos\theta_z} = \frac{G_{b,t}}{G_h} \tag{5}$$

Where, θ = angle of incidence.

θ_z = zenith angle respectively.

$G_{b,t} = radiation\ on\ tilted\ surface.$

$G_h = radiation\ on\ horizonal\ surface.$

To utilize R_b the radiation on the horizontal surface was gotten from National Centre for Energy and Environment (NCEE), University of Benin, Edo State, Nigeria [22].

To determine the available energy in the solar collector, it is important to consider the equation for energy gained by the working fluid. This is given by Equation 6 [23],

$$Q_{use} = m_a C_p \Delta T \tag{6}$$

Equation for heat losses from the collector as the fluid flows from the solar collector to the atmosphere is expressed as [27]:

$$Q_{use} = A_{abs} Q_r [S_i - U_1\ (\Delta T)] \tag{7}$$

The energy leaked from the solar collector is given by Equation 8 [24].

$$E_1 = \left\{U_1 A_{abs}(T_{abs} - T_a)\ \left(1 - \frac{T_a}{T_{abs}}\right)\right\} \tag{8}$$

where S_i is the optical absorbed solar flux and U_l is the heat lost by emittance, reflection and optical efficiency of glazing given by Equation 9 [25].

$$Q_R = \frac{maC_P}{U_1 A_{abs}}\left[1 - exp\left\{\frac{-F\emptyset U_1 A_{abs}}{maC_P}\right\}\right] \tag{9}$$

The energy destroyed by the solar collector is given by Equation 10 [26].

$$E_d = -mC_P T_a \frac{T_{out}}{T_{in}} E_d = -mC_P T_a \left\{1n\left(\frac{T_{out}}{T_{in}}\right) - \left(\frac{T_{out} - T_{in}}{T_{abs}}\right)\right\} \tag{10}$$

where E_d is the heat lost energy due to absorber plate temperature difference with the fluids. It is the latent heat absorbed by the fluids in phase change. The exergy of the solar collector is given by Equation 11[27].

$$E_{out} = \left[\left\{\left(m_a C_P \left(T_{out} - T_a T_a l_n \frac{T_{out}}{T_a}\right) - \frac{m\Delta P_{out}}{\rho}\right) + mwC_P(T_w - T_a)\right\}\right] \quad (11)$$

The discharge flow rate of water expressed in m^3/sec is given by Equation 12

$$Q = \frac{\pi}{4} d^2 v \quad (12)$$

where d is the diameter of the collector pipe and v is the average velocity of fluid. In this case, the angle of incidence is given by Equation 13 [28].

$$Cos\theta = Sin\emptyset\ (Sin\delta\ Cos\beta + Cos\delta\ Cos\gamma\ Cos\omega\ Sin\beta) + Cos\emptyset\ (Cos\delta\ Cos\omega\ Cos\beta -$$

$$Sin\delta\ Cos\gamma\ Sin\beta) + Cos\delta\ Sin\gamma\ Sin\omega\ Sin\beta \quad (13)$$

where δ is the Declination angle, n is no of day in the yea, β is the slope angle ∅ is the latitude of the location γ is the surface azimuth angle and ω is the hour angle. Tilt factor for beam radiation is given by Equation 14.

$$rr_b = \frac{Cos\theta}{Cos\theta_z} \quad (14)$$

$$Cos\theta_z = (Sin\emptyset * Sin\delta) + (Cos\emptyset * Cos\delta * Cos\omega) \quad (15)$$

Radiation shape factor for the diffused radiation is given by Equation 16 while the tilt factor for reflected radiation is given by Equation 17.

$$R_d = \frac{(1+Cos\beta)}{2} \quad (16)$$

$$r_r = \frac{\rho(1-Cos\beta)}{2} \quad (17)$$

Instantaneous efficiency is given by Equation 18 while exergy (e) is given by Equation 19

$$\eta_i = \frac{\dot{m}C_P(T_2-T_1)}{I_t * A_p} \quad (18)$$

$$e = (h - h_o) - T_o(S - S_o) + \frac{V^2}{2} + gz \quad kJ/kg \quad (19)$$

3. RESULTS AND DISCUSSION

3.1. Angular Relations of Solar Radiation

The thermodynamic analysis was carried out considering some conditions, these conditions are ambient conditions, materials, the location of study and the mid-month in each month. The mid-months are recommended average days of various months and values of n by months. A particular day in each month was chosen (mid-month), this day has approximately the total solar radiation which is equal to the monthly mean value for that particular month.

3.1.1. Declination angle

Declination angle was estimated for a year considering the mid-month. Using Equation 1, the declination angle from January to December were gotten as follows.

Table 2. Declination angle from January to December for Benin City, Edo State.

Mid-Month	Latitude (ϕ)	No of Days(n)	Declination (d)
17 January 2018	6.5438	17	-20.91696257
16 February 2018		47	-12.95460809
16 March 2018		75	-2.417734805
15 April 2018		105	9.414893347
15 May 2018		135	18.79191752
11 June 2018		162	23.085911
17 July 2018		198	21.18369356
16 August 2018		228	13.45495968
15 September 2018		258	2.216886783
15 October 2018		288	-9.599397234
14 November 2018		318	-18.91195474
10 December 2018		344	-23.04962764

Table 2 shows the analysis of the declination angle from January to December for Benin City, Edo State, the mid-month, latitude and number of days were considered during the analysis. This analysis was carried out because the angle of declination is necessary to estimate for the angle of incidence which enables the radiation on a tiled surface to be known.

3.1.2. Zenith angle

The zenith angle was estimated for a period of one year and it was done using Equation 2 as follows.

Table 3. Zenith angle from January to December in Benin City, Edo State.

Mid-Month	Lattitude (θ)	No of Days(n)	Zenith Angle (ϑz)
17 January 2018	6.5438	17	31.16223057
16 February 2018	6.5438	47	24.54156547
16 March 2018	6.5438	75	17.45151134
15 April 2018	6.5438	105	15.12726132
15 May 2018	6.5438	135	19.05767107
11 June 2018	6.5438	16o2	21.95626908
17 July 2018	6.5438	198	20.61477906
16 August 2018	6.5438	228	16.29885949
15 September 2018	6.5438	258	15.56579039
15 October 2018	6.5438	288	21.99881101
14 November 2018	6.5438	318	29.43745646
10 December 2018	6.5438	344	33.02824726

Table 3 shows the analysis of the Zenith angle from January to December for Benin City, Edo State, the mid-month, latitude, number of days and the hour angle were considered during the analysis. This analysis enables us to known the angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface.

3.1.3. Solar azimuth angle

The solar azimuth angle was estimated using Equations 3 and this was done for a period of one year. It is shown on Table 4.

Table 4. Solar Azimuth angle from January to December in Benin City, Edo State.

Mid-Month	Latitude (θ)	No of Days(n)	Declination (d)	Solar Azimuth Angle(γs)
17 January 2018	6.5438	17	-20.91696257	-27.81909576
16 February 2018	6.5438	47	-12.95460809	-37.39236626
16 March 2018	6.5438	75	-2.417734805	-59.57057582
15 April 2018	6.5438	105	9.414893347	101.9242569
15 May 2018	6.5438	135	18.79191752	131.374367
11 June 2018	6.5438	162	23.085911	140.4476725
17 July 2018	6.5438	198	21.18369356	136.7302372
16 August 2018	6.5438	228	13.45495968	116.2453433
15 September 2018	6.5438	258	2.216886783	74.53216113
15 October 2018	6.5438	288	-9.599397234	-42.94294037
14 November 2018	6.5438	318	-18.91195474	-29.88037461
10 December 2018	6.5438	344	-23.04962764	-25.9089543

Table 4 shows the analysis of the solar Azimuth angle from January to December for Benin City, Edo State, the mid-month, latitude, number of days, hour angle and declination were considered during the analysis. This analysis helps to show the angular displacement from south of the projection of beam radiation on the horizontal plane.

3.1.4. Incidence angle

The angle of incidence on an inclined surface was determined using Equation 4 as shown in Table 5.

Table 5. Incident angles from January to December of Benin City, Edo State.

Mid-Month	Lattitude (θ)	No of Days(n)	Angle of Incidence
17 January 2018	6.5438	17	22.75053397
16 February 2018	6.5438	47	17.60890387
16 March 2018	6.5438	75	15.01592951
15 April 2018	6.5438	105	19.72562973
15 May 2018	6.5438	135	26.70224584
11 June 2018	6.5438	162	30.30883487
17 July 2018	6.5438	198	28.68973778
16 August 2018	6.5438	228	22.53011347
15 September 2018	6.5438	258	16.03038807
15 October 2018	6.5438	288	16.11188848
14 November 2018	6.5438	318	21.30486345
10 December 2018	6.5438	344	24.38399044

Table 5 shows the analysis of the incident angle from January to December for Benin City, Edo State, the mid-month, latitude and the number of days were considered during the analysis.

3.1.5. Ratio of beam radiation

The ratio of beam radiation is a geometric factor that deals with the ratio of beam radiation on the tilted surface to that on a horizontal surface. For the purposes of solar process design and performance calculations, it is often necessary to calculate the radiation on a tilted surface of a collector from measurements or estimates of solar radiation on a horizontal surface. The values on Table 6 were gotten using Equation 5.

Table 6. Ratio of beam radiation from January to December of Benin City, Edo State.

Rb	G_h (W/m^2)	$G_{b,t}$(W/m^2)
1.08	1017.695	1099.11
1.05	1017.695	1068.58
1.01	1017.695	1027.87
0.98	1017.695	997.34
0.95	1017.695	966.81
0.93	1017.695	946.46
0.94	1017.695	956.63
0.96	1017.695	976.98
0.99	1017.695	1007.52
1.04	1017.695	1058.40
1.07	1017.695	1088.93
1.09	1017.695	1109.28

Table 6 shows the analysis of the ratio of beam radiation from January to December for Benin City, Edo State, the Zenith angle and the angle of incidence were considered during the analysis. $G_{b,t}$ (W/m^2) was gotten by multiplying R_b by the horizontal solar radiation which was gotten from National Centre for Energy and Environment (NCEE), University of Benin, Edo State Nigeria).

4. CONCLUSION

The estimation of the various angles which are declination angles, zenith angles, solar azimuth angles and the incident angles was geared towards obtaining the radiation on a tilted surface. It is necessary to obtain the radiation on a tiled surface because the flat plate collector is tilted at some angle to get optimum solar energy. The available solar radiation of the locations shows a positive availability of renewable energy in the form of solar energy and the angular solar relations were estimated for the months of more solar radiation and the positions in which the solar thermal system (experimental setup) can be placed for more solar energy absorption.

REFERENCES

[1] Foster, Robert, Majed Ghassemi and Alma Cota. (2010): Solar energy: renewable energy and the enviroment. Boca Raton: CRC press.

[2] Goswami, D. Yogi, Frank Kreith and Jan F. Kreider. (1999): Principles of solar engineering. 2nd. Philadelphia: Taylor & Francis.

[3] Nielsen, R. 2005. Solar Radiation. http://home.iprimus.com.au/nielsens/.

[4] Bena, B. and R. J. Fuller. 2002. Natural convection solar dryer with biomass back up heater. Journal of Solar Energy, 72 (1): 75-83.

[5] Sharma, A., C. R. Chen, and V. Nguyen. 2009. Solar energy drying systems: a review. R*enewable and Sustainable Energy Review*, 13(6-7):1185-1210.

[6] Iloeje, O. C. 1993. Design, operation and performance of a solar rice dryer. In proc. 2nd Workshop on ‘‘SDTAI’’, Nsukka, Nigeria, 24-27 November.

[7] Kreith, F. and Kreider, J. F. (1978) Principle of solar engineering.
[8] Hanif, M., Khattak, M. K., Khan, M. and Ramzan, M. (2018) Energy, Exergy and Efficiency Analysis of a Flat Plate Solar Collector Used as Air Heater. Sains Malaysiana 47(5), 1061-1067.
[9] Dare, A. A., Odunfa, K. M., Ajuka, L. O., Oyedepo, S. O. and Adeaga, O. A. (2017) Estimation of insolation of flat plate solar collectors in selected cities in Nigeria. International Journal of Computational Engineering Research, 7(12), 14-28.
[10] Swain, B., Memon, S. A. and Achari, A. M. (2019) Parametric Analysis of Inclined Flat Plate Collector: A Review with Case Study. International Journal of Applied Engineering Research 14(7), 1658-1667.
[11] Skeiker, K. (2009) Optimum tilt angle and orientation for solar collectors in Syria. Energy Convers. Manag., 50(9), 2439–2448.
[12] Jafarkazemi, F. and Saadabadi, S. A. (2013) Optimum tilt angle and orientation of solar surfaces in Abu Dhabi, UAE. Renewable Energy, 56, 44–49.
[13] Soulayman, S. and Hammoud, M. (2016) Optimum tilt angle of solar collectors for building applications in mid-latitude zone. Energy Conversion Management, 124, 20–28.
[14] Khorasanizadeh, H., Mohammadi, K. and Mostafaeipour, A. (2014) Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in Tabass, Iran. Energy Convers. Manag., 78, 805–814.
[15] Ucar, A. and Inall, M. (2006) Thermal and exergy analysis of solar air collectors with passive augmentation techniques. Int. Commun. Heat Mass Transf., 33(10), 1281–1290.
[16] Jamil, B., Siddiqui, A. T. and Akhtar, N. (2016) Estimation of solar radiation and optimum tilt angles for south-facing surfaces in Humid Subtropical Climatic Region of India. Eng. Sci. Technol. an Int. J., 19(4), 1826–1835.
[17] Kaddoura, T. O., Ramli, M. A. M. and Al-Turki, Y. A. (2016) on the estimation of the optimum tilt angle of PV panel in Saudi Arabia. Renew. Sustain. Energy Rev., 65, 626–634.
[18] Bhowmik, H. and Amin, R. (2017) Efficiency improvement of flat plate solar collector using reflector. Energy Reports, 3, 119–123
[19] Akachukwu, B. E. (2011) Prediction of optimum angle of inclination for flat plate solar collector in Zaria, Nigeria. Agricultural Engineering International: CIGR Journal. 13(4), 1-11. 2011.
[20] Klein, S.A (1977): Calculation of monthly average insolation on tilted surfaces, solar energy laboratory, University of Wisconsin-Madison, Madison, WI 53706, USA.
[21] Duffie, J.A. and Beckman, W.A. (2013): Solar Engineering of Thermal Processes. John Wiley and Sons, inc., New York.
[22] National Centre for Energy and Environment (NCEE) (2017), University of Benin, Edo State Nigeria.
[23] Al-Sulaiman, F.A. 2014. Exergy analysis of parabolic trough solar collectors integrated with combined steam and organic Rankine cycles. Energy Conversion and Management 77: 441-449.
[24] Calise, F., d'Accadia, M.D., Macaluso, A., Piacentino, A. & Vanoli, L. 2016. Exergetic and exergoeconomic analysis of a novel hybrid solar–geothermal polygeneration system producing energy and water. Energy Conversion and Management 115(1): 200-220.
[25] Jafarkazemi, F. & Ahmadifard, E. 2013. Energetic and exergetic evaluation of flat plate solar collectors. Renewable Energy 56: 55-63.
[26] Farahat, S., Sarhaddi, F. & Ajam, H. 2009. Exergetic optimization of flat plate solar collectors. Renewable Energy 34(3): 1169-1174.
[27] Islam. S., Dincer. I. & Yalbas, B.S. 2015. Energetic and exergetic performamce analysis of a solar energy-based integrated system for multi generation including thermoelectric generators. Energy 93: 1246-1258.
[28] Kalogirou, S.A., Karellas, S., Badescu, V. & Braimakis, K. 2016. Exergy analysis on solar thermal systems: A better understanding of their sustainability. Renewable Energy 85: 1328-1333.