



## Solar Gain Augmentation Using Planar Reflectors on the West and East Sides of a Flat Plate Collector in Zaria, Nigeria

M. B. Abdullahi\*, I. Ajunwa, N. A. Ismail, I. U. Ibrahim and F. T. Faru

Department of Mechanical Engineering  
Ahmadu Bello University, Zaria, Nigeria.

### ABSTRACT

*With widespread calls for improved development of clean energy sources, solar thermal collectors are continuously receiving renewed attention being one of the easiest means of converting solar radiation to heat. Planar reflectors are often employed in flat plate collectors in order to boost solar radiation captured. Significant improvement in efficiency can be achieved if reflectors are positioned optimally. A model that predicts the additional solar gain using reflectors on the eastern and western side of a collector was developed using engineering equation solver (EES) and transient system simulation (TRNSYS) software. Simulations were carried out for various reflector angles using Zaria weather data and the monthly reflector tilts for optimum solar gain were obtained through parametric studies. The results show that solar radiation received by collector can be enhanced with the reflectors throughout the year except for the month of July for both reflectors and August for the eastern reflector. Also, the magnitude of contribution from reflector on the western side of the collector is higher.*

### ARTICLE INFO

#### Article History

Received: July, 2019

Received in revised form: Sept., 2019

Accepted: December, 2019

Published online: February, 2020

### KEYWORDS

Solar thermal collectors; TRNSYS;  
Reflector; Solar gains

### INTRODUCTION

Energy needs across the globe has increased drastically over the years due to population increase, technological advancement, and improvement in living conditions, among several other factors. Energy production is mostly in form of electricity or heat. The huge energy demand has raised concerns about the mode of generation and the corresponding effect on the climate. This has led to the development of clean or renewable alternatives which include utilization of the enormous solar radiation falling on the earth's surface.

One of the most popular forms of harnessing solar radiation is by converting to heat using flat plate collectors. Flat-plate

collectors are designed for applications requiring energy delivery at moderate temperatures, up to perhaps 100°C above ambient temperature. They use both beam and diffuse solar radiation, do not require tracking of the sun, and require little maintenance (Duffie and Beckman, 2013). Flat plate collectors have simple characteristics: they are easily assembled, and easily operated. Developments are being carried out continuously in the field of cover materials, absorber plate materials, absorber and glazing coating etc. along with the changes in the design, fluid used for heat transfer (Gajbhiye and Shelke, 2012). They find use in a variety of applications like solar water heaters, dryers, ovens, furnace etc. Flat plate collectors utilize both beam



and diffuse radiation. To maximise solar gain, the area from which heat losses occur is reduced as much as possible. It is also desired that the angle of incidence of the beam radiation is always minimized by optimizing the collector tilt angle. Finding the optimum tilt angle helps receive the maximum energy monthly, quarterly and yearly (Mansouri et al., 2016). The solar radiation incident on the collector surface can also be augmented using plane reflectors. Plane reflectors are found to be a convenient option for enhancing the solar radiation incident on the collector plane (Naik and Palatel, 2014). Plane reflectors can boost considerably, the solar radiation incident on a flat plate collector but can also present a major challenge in positioning because of the constant movement of the sun. As such, care has to be taken in determining the appropriate reflector – collector configuration, such that shading of the collector is minimised. One way of doing this is by tracking the movement of the sun. Tracking can be accomplished by manual periodic adjustment or by using trackers, both of which are either cumbersome or expensive. Therefore it is imperative to determine an optimum position of the plane reflectors with respect to the flat plate collector. The tilt angle depends mainly on the position of the sun and, therefore, is different from one location to another all over the world; in regard to the best orientation angle, it is advised to be directed towards the equator (Yasin et al., 2016).

A lot of investigation has been aimed at determining the optimum collector tilt angle and orientation of reflector-collector systems for maximum solar gain, but the validity of these findings depend on the location of the system. Kumar et al., (1994) developed a model for evaluating the exchange and shading factors of four plane reflectors fixed on the

edges of a flat plate collector. They obtained expressions for these factors using the various geometric angles describing the position of the sun with respect to the collector and reflector position. Baccoli et al., (2015) carried out a theoretical analysis of a collector augmented by a bottom booster reflector. The model was based on cases of possible variations in the geometrical angles of the setup. Simulations were carried out to find optimum angles of collector with respect to collector for weather conditions prevalent in south Sardinia (latitude 39° North). Handoyo, (2013) with the aid of Microsoft excel, used the second derivative of an expression relating the collector tilt angle to the angle of incident radiation to find the optimum tilt angle of a collector located in Surabaya (latitude 7.2°south). Nivas and Saravanan, (2013) used the TRACE PRO and PV sys software to simulate the net solar radiation incident on a photovoltaic panel. The result was used to estimate the cost of energy for various concentrator configurations. Kostic et al., (2010) carried out a comparative study on the influence of aluminium sheet and aluminium foil reflectors on the efficiency of a PV/thermal collector. It was found that aluminium foil in optimal position gave higher output. Skerlic et al., (2018) reviewed some criteria proposed by various researchers for determining the optimal position of a flat plate collector. It was also observed that 10 – 35 % of energy gain was lost as a result of inappropriate positioning of collectors. Yasin et al. (2016) developed a computer code in FOTRAN to optimize the tilt angle of a flat plate solar collector using a general polynomial equation. The results obtained were compared to that published by NASA and recommended for use in locations with mid and high latitudes in both hemispheres. Alsadi and Nassar (2017) carried out a theoretical analysis of a solar field

augmented by reflectors placed between the rows of collectors. Simulations were carried out and the design parameters were optimized for maximum augmentation of solar energy.

Most often, flat plate collectors are augmented with planar reflectors fixed at the edges of the collector. For collectors in the northern hemisphere, the collector is tilted towards the south, and a significant proportion of the reflected radiation is delivered by the plane reflectors on the upper and lower (the north and south) sides. But the physical structure of some solar devices might not allow for the free adjustment of reflectors attached on the upper and lower edges. An example of such is the case of a solar dryer with the drying chamber connected directly to the outlet of an air heating collector. In the present work, the additional solar gain as a result of planar reflectors placed at the sides (west and east) of a flat plate collector is investigated for a system located in Zaria. A model is written in EES to evaluate the total

solar radiation incident on a collector for different reflector angles. Simulations are also carried out using TRNSYS to determine the monthly reflector tilts required for optimum solar gain using Zaria (11.1°N, 7.7°E) weather data.

### SYSTEM DESCRIPTION

The system consists of a flat plate collector with two planar reflectors attached to the sides such that the length of each reflector coincides with the edges of the collector. The orientation of the whole setup is such that the surface azimuth angles of the collector, the east and west side reflectors are 0, 180 and -180 respectively. While the collector slope is fixed at an all year round optimum value ( $\beta_c$ ), the angle of inclination of the reflectors ( $\beta_{rw}$  and  $\beta_{re}$ ) can be varied to redirect the incident beam radiation on the collector surface. The whole assembly arrangement is shown in fig1. The collector and two reflectors are denoted by C,  $R_w$ , and  $R_e$  respectively.

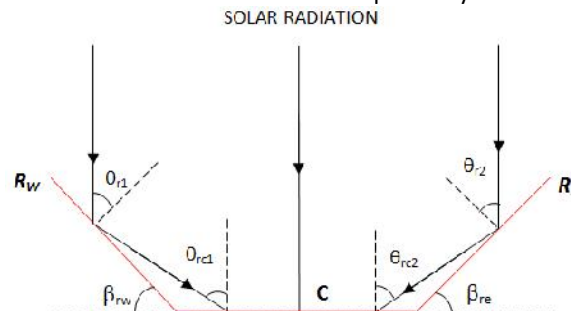


Figure1: A cross section of collector – reflector assembly.

### Analysis

When the system is exposed to solar radiation, the processes that lead to heat production can be summarized as: reflection, transmission and absorption. The reflectivity, solar transmittance and absorptance are all functions of the angle of incidence of solar radiation on the reflectors and collector surface. Heat produced is either transferred directly to

the heat transfer fluid by convection from absorber plate or by conduction through metallic pipes as in the case of solar water heater. There are also heat losses to the environment though the combined mechanisms of conduction, convection and radiation. The prediction of collector performance requires information on the solar energy absorbed by the collector absorber plate (Duffie and Beckman, 2013).



As such, only the absorbed solar radiation is considered in this work. The major assumptions employed in the analysis are as follows:

- i. The reflectors are specular
- ii. The collector surface is a blackened flat plate.
- iii. The absorptance is independent of direction.
- iv. Only shading of reflectors on collector is considered.

**Reflection**

Solar radiation incident on collector surface consist of the beam,

diffuse and reflected components. The planar reflectors either redirect the beam component of the solar radiation obstructs the collector, depending on the geometric orientation of the reflector with respect to the sun. The intensity of solar radiation redirected or obstructed by the reflectors is determined by the exchange and shading factors of reflectors on the collector. Tables 1 and 2 gives the expressions for the exchange and shading factors ( $f_{rc}$  and  $S_{rc}$ ) of each reflector for various boundary conditions (Kumar *et al.*, 1994).

**Table 1:** Expressions for exchange factors between  $R_w$  and the collector for six different regions

Region	Boundary conditions for reflection	Exchange factors ( $f_{rc1}$ )	Boundary conditions for shading	Shading factors ( $S_{rc1}$ )
1	$R_1 \geq 0, S_1 < -0.5$ $(R_1 + S_1 W_1) < 0.5 W_1$	$0.5 R_1 / W_1 (0.5 - S_1)$	$R'_1 \geq 0, S'_1 < -0.5$ $(R'_1 + S'_1 W_1) < 0.5 W_1$	$0.5 R'_1 / W_1 (0.5 - S'_1)$
2	$R_1 > W_1, S_1 \leq 0.5$ $(R_1 + S_1 W_1) \geq 0.5 W_1$	$0.5 [2 - (0.5 - S_1) W_1 / R_1]$	$R'_1 > W_1, S'_1 \leq 0.5$ $(R'_1 + S'_1 W_1) \geq 0.5 W_1$	$0.5 [2 - (0.5 - S'_1) W_1 / R'_1]$
3	$-0.5 \leq S_1 \leq 0.5$ $0 \leq R_1 \leq W_1$	$0.5 (1.5 + S_1) R_1 / W_1$	$-0.5 \leq S'_1 \leq 0.5$ $0 \leq R'_1 \leq W_1$	$0.5 (1.5 + S_1) R'_1 / W_1$
4	$S_1 > 0.5, R_1 \geq W_1$ $(R_1 - S_1 W_1) > 0.5 W_1$	$0.5 [2 - (S_1 - 0.5) W_1 / R_1]$	$S'_1 > 0.5, R'_1 \geq W_1$ $(R'_1 - S'_1 W_1) > 0.5 W_1$	$0.5 [2 - (S'_1 - 0.5) W_1 / R'_1]$
5	$0.5 < S_1 \leq 1.5$ $0 \leq R_1 < W_1$	$0.5 R_1 (2.5 - S_1) / W_1$	$0.5 < S'_1 \leq 1.5$ $0 \leq R'_1 < W_1$	$0.5 R'_1 (2.5 - S'_1) / W_1$
6	$S_1 > 0.5, R_1 \geq 0$ $(R_1 - S_1 W_1) < 0.5 W_1$	$0.5 R_1 / W_1 (S_1 - 0.5)$	$S'_1 > 0.5, R'_1 \geq 0$ $(R'_1 - S'_1 W_1) < 0.5 W_1$	$0.5 R'_1 / W_1 (S'_1 - 0.5)$

Where:

$$S_1 = -(e_{x1}/a) s_1 + (e_{y1}/a) c_1 \quad (1)$$

$$R_1 = (e_{x1}/a) c_1 + (e_{y1}/a) s_1 \quad (2)$$

$$W_1 = c_1 \beta_c \quad (3)$$

$$e_{x1} = -(a/2) s_1 \gamma_s - a \beta_r c_1 \gamma_s + C_{e1} u_1 \quad (4)$$

$$e_{y1} = -(a/2) s_1 \gamma_s - a c_1 \beta_r c_1 \gamma_s + C_{e1} v_1 \quad (5)$$

$$C_{e1} = a (\beta_r - \beta_c) / c_1 \theta_{r-1} \quad (6)$$

$$\hat{S}_1 = -(\hat{e}_{x1}/a) s_1 + (\hat{e}_{y1}/a) c_1 \quad (7)$$

$$\hat{R}_1 = (\hat{e}_{x1}/a) c_1 + (\hat{e}_{y1}/a) s_1 n_y \quad (8)$$

$$\hat{W}_1 = c_1 \beta_c \quad (9)$$

Corresponding author: Abdullahi, M. B. ✉ [babs2k4@gmail.com](mailto:babs2k4@gmail.com) ✉ Department of Mechanical Engineering, Ahmadu Bello University, Zaria. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



$$e_{x1} = -(a/2)s_1 \gamma_s - a c_1 \beta_r c_1 \gamma_s - \hat{C}_{e1} s_1 \theta_z c_1 \gamma_s \quad (10)$$

$$e_{y1} = -(a/2)s_1 \gamma_s - a c_1 \beta_r s_1 \gamma_s - \hat{C}_{e1} s_1 \theta_z c_1 \gamma_s \quad (11)$$

$$\hat{C}_{e1} = a \sin(S_{r1} - S_c) / c_1 \theta_c \quad (12)$$

**Table 2:** Expressions for exchange factors between Re and the collector for six different regions

Region	Boundary conditions for reflection	Exchange factors (f <sub>rc1</sub> )	Boundary conditions for shading	Shading factors (S <sub>rc1</sub> )
1	R <sub>2</sub> ≤ 0, S <sub>2</sub> < -0.5 (R <sub>2</sub> + S <sub>2</sub> W <sub>2</sub> ) > 0.5W <sub>1</sub>	0.5R <sub>2</sub> /W <sub>2</sub> (0.5 - S <sub>2</sub> )	R' <sub>2</sub> ≤ 0, S' <sub>2</sub> < -0.5 (R' <sub>2</sub> + S' <sub>2</sub> W <sub>2</sub> ) > 0.5W <sub>1</sub>	0.5R' <sub>2</sub> /W <sub>2</sub> (0.5 - S' <sub>2</sub> )
2	R <sub>2</sub> < W <sub>2</sub> , S <sub>2</sub> ≤ 0.5 (R <sub>2</sub> + S <sub>2</sub> W <sub>2</sub> ) < 0.5W <sub>2</sub>	0.5[2 - (0.5 - S <sub>2</sub> )W <sub>2</sub> /R <sub>2</sub> ]	R' <sub>2</sub> < W <sub>2</sub> , S' <sub>2</sub> ≤ 0.5 (R' <sub>2</sub> + S' <sub>2</sub> W <sub>2</sub> ) < 0.5W <sub>2</sub>	0.5[2 - (0.5 - S' <sub>2</sub> )W <sub>2</sub> /R' <sub>2</sub> ]
3	-0.5 ≤ S <sub>2</sub> ≤ 0.5 0 ≥ R <sub>2</sub> > W <sub>2</sub>	0.5(1.5 + S <sub>2</sub> )R <sub>2</sub> /W <sub>2</sub>	-0.5 ≤ S' <sub>2</sub> ≤ 0.5 0 ≥ R' <sub>2</sub> > W <sub>2</sub>	0.5(1.5 + S' <sub>2</sub> )R' <sub>2</sub> /W <sub>2</sub>
4	S <sub>2</sub> > 0.5, R <sub>2</sub> ≤ W <sub>2</sub> (R <sub>2</sub> - S <sub>2</sub> W <sub>2</sub> ) < -0.5W <sub>2</sub>	0.5[2 - (S <sub>2</sub> - 0.5)W <sub>2</sub> /R <sub>2</sub> ]	S' <sub>2</sub> > 0.5, R' <sub>2</sub> ≤ W <sub>2</sub> (R' <sub>2</sub> - S' <sub>2</sub> W <sub>2</sub> ) < -0.5W <sub>2</sub>	0.5[2 - (S' <sub>2</sub> - 0.5)W <sub>2</sub> /R' <sub>2</sub> ]
5	0.5 < S <sub>2</sub> ≤ 1.5 0 ≥ R <sub>2</sub> > W <sub>2</sub>	0.5R <sub>2</sub> (2.5 - S <sub>2</sub> )/W <sub>2</sub>	0.5 < S' <sub>2</sub> ≤ 1.5 0 ≥ R' <sub>2</sub> > W <sub>2</sub>	0.5R' <sub>2</sub> (2.5 - S' <sub>2</sub> )/W <sub>2</sub>
6	S <sub>2</sub> > 0.5, R <sub>2</sub> ≤ 0 (R <sub>2</sub> - S <sub>2</sub> W <sub>2</sub> ) > -0.5W <sub>1</sub>	0.5R <sub>2</sub> /W <sub>2</sub> (S <sub>2</sub> - 0.5)	S' <sub>2</sub> > 0.5, R' <sub>2</sub> ≤ 0 (R' <sub>2</sub> - S' <sub>2</sub> W <sub>2</sub> ) > -0.5W <sub>1</sub>	0.5R' <sub>2</sub> /W <sub>2</sub> (S' <sub>2</sub> - 0.5)

Where:

$$S_2 = -(e_{x2}/a)s_1 + (e_{y2}/a)c_1 \quad (13)$$

$$R_2 = (e_{x2}/a)c_1 - (e_{y2}/a)s_1 \quad (14)$$

$$W_2 = c_1 \beta_c \quad (15)$$

$$e_{x2} = -(a/2)s_1 \gamma_s - a \beta_r c_1 \gamma_s + C_{e2} u_2 \quad (16)$$

$$e_{y2} = -(a/2)s_1 \gamma_s - a \beta_r s_1 \gamma_s + C_{e2} v_2 \quad (17)$$

$$C_{e2} = a (\beta_r + \beta_c) / c_1 \theta_r \quad (18)$$

$$\hat{S}_2 = -(e_{x2}/a)s_1 + (e_{y2}/a)c_1 \quad (19)$$

$$\hat{R}_2 = (e_{x2}/a)c_1 - (e_{y2}/a)s_1 \quad (20)$$

$$W_2 = c_1 \beta_c \quad (21)$$

$$e_{x2} = -(a/2)s_1 \gamma_s - a c_1 \beta_{r2} c_1 \gamma_s - \hat{C}_{e2} s_1 \theta_z c_1 \gamma_s \quad (22)$$

$$e_{y2} = -(a/2)s_1 \gamma_s - a c_1 \beta_r c_1 \gamma_s - \hat{C}_{e2} s_1 \theta_z c_1 \gamma_s \quad (23)$$

$$\hat{C}_{e2} = a \sin(S_{r2} + S_c) / c_1 \theta_c \quad (24)$$

The angle cosines of the reflected rays from R1 and R2 on the collector surface are given by (Kumar *et al.*, 1994) as:

$$c_1 \theta_{r1} = -u_1 s_1 \beta_c c_1 \gamma_s - v_1 s_1 \beta_c c_1 \gamma_s - w_1 c_1 \beta_c \quad (25)$$

$$c_1 \theta_{r2} = -u_2 s_1 \beta_c c_1 \gamma_s - v_2 s_1 \beta_c c_1 \gamma_s - w_2 c_1 \beta_c \quad (26)$$

### Transmission

The total incident solar radiation comprising of the beam, diffuse and reflected components is transmitted

through the glazing of the collector. The transmittance for the beam and reflected radiation is a function of the angle of incidence, and refractive index of glass



cover. The transmittance of a single cover is given by (Duffie and Beckman, 2013):

$$\tau = \tau_a \tau_r \quad (27)$$

$$\tau_a = \exp\left(-\frac{KL}{\cos \theta_2}\right) \quad (28)$$

$$\tau_r = \frac{1}{2} \left( \frac{1-r_{||}}{1+r_{||}} + \frac{1-r_{\perp}}{1+r_{\perp}} \right) \quad (29)$$

Where  $r_{||}$  and  $r_{\perp}$  are the parallel and perpendicular components of unpolarized radiation:

### Absorption

The solar radiation transmitted through the transparent cover is absorbed at the surface of the blackened absorber plate. The extent of absorption is determined by the transmittance – absorptance product ( $\tau\alpha$ ) which is a combined property of the cover – absorber combination.

For most practical collectors, ( $\tau\alpha$ ) can be estimated as:

$$(\tau\alpha) \cong 1.01\tau\alpha \quad (30)$$

The total energy absorbed as a result of beam, diffuse and reflected solar radiation incident on collector surface is then given by equation (31) as (Kumar *et al.*, 1994);

$$Q_a = (1 - S_c)\{Q_C + Q_{R_w} + Q_{R_e}\} \quad (31)$$

$$Q_C = (\tau_b)_d I_b + (\tau_b)_a I_d \quad (32)$$

$$Q_{R_w} = \rho(\tau_r)_1 I_b \cos \theta_{r1} \quad (33)$$

$$Q_{R_e} = \rho(\tau_r)_2 I_b \cos \theta_{r2} \quad (34)$$

Where:

$Q_C$  is the absorbed energy due to solar radiation directly incident on the collector surface.

$Q_{R_w}$  is the absorbed energy due to solar radiation reflected from collector  $R_w$ .

$Q_{R_e}$  is the absorbed energy due to solar radiation reflected from collector  $R_e$ .

$S_c$  is the fraction of the collector surface shaded by the reflectors  $R_w$  and  $R_e$  and is given by:

$$S_c = S_{r1} + S_{r2} \quad (35)$$

Where:

$S_{r1}$  is the shading factor due to reflector  $R_w$

$S_{r2}$  is the shading factor due to reflector  $R_e$

The direction cosines of the reflected radiation from each reflector are expressed as (Kumar *et al.*, 1994):

$$c_1 \theta_{r1} = -u_3 s_1 \beta_c c_1 \gamma_s - v_3 s_1 \beta_c c_1 \gamma_s - w_3 c_1 \beta_c \quad (36)$$

$$c_1 \theta_{r2} = -u_4 s_1 \beta_c c_1 \gamma_s - v_4 s_1 \beta_c c_1 \gamma_s - w_4 c_1 \beta_c \quad (37)$$

$$u_1 = -s_1 \theta_z c_1 + 2c_1 \theta_{r1} s_1 \beta_r c_1 \gamma_s \quad (38)$$

$$u_2 = -s_1 \theta_z c_1 - 2c_1 \theta_{r2} s_1 \beta_r c_1 \gamma_s \quad (39)$$

$$v_1 = -s_1 \theta_z s_1 + 2c_1 \theta_{r1} s_1 \beta_r s_1 \gamma_s \quad (40)$$

$$v_2 = -s_1 \theta_z s_1 - 2c_1 \theta_{r2} s_1 \beta_r s_1 \gamma_s \quad (41)$$

$$w_1 = -c_1 \theta_z + 2c_1 \theta_{r1} c_1 \beta_r \quad (42)$$

$$w_2 = -c_1 \theta_z + 2c_1 \theta_{r2} c_1 \beta_r \quad (43)$$

### SYSTEM MODEL

TRNSYS (Transient System Simulation) and EES (engineering equation solver) were used to model the system. The various conditions for evaluating the exchange and shading factors shown in tables 1 to 4 were written in EES using the IF THEN ELSE logic statements. The

expressions for incidence angles of reflected radiation on collector and the transmittance – absorptance product were also written in EES. The TRNSYS studio model of the system is shown in figure 2. The EES file is linked to the TRNSYS studio through the Type66a component.

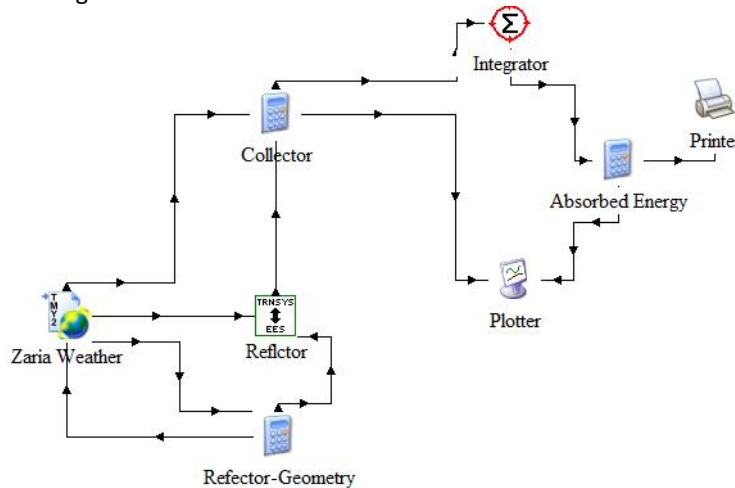


Figure 2. TRNSYS studio model of the collector – reflector setup

The type TMY-2 weather data component evaluates the beam and diffuse radiation, together with the geometric angles describing direction of beam radiation. The data is sent to the EES reflector model where the angle of incidence of reflected solar rays on the collector, exchange and shading factors of the reflectors and the transmittance absorptance products are evaluated and sent back to the TRNSYS environment. The total energy absorbed is evaluated using the equations component. The result is integrated by the Type24 quantity integrator which integrates the absorbed energy over a period of time specified in the control card. This is finally displayed in the Type 25c printer component. The result is also plotted as a function of time in the type 65d online plotter.

### SYSTEM SIMULATION

Methods for the evaluation of long-term solar system performance require that the average radiation absorbed by a collector be evaluated for monthly periods (Duffie and Beckman, 2013). To account for the fluctuating nature of weather components, simulations were carried out using the typical metrological year (TMY) data for Zaria in order to investigate the system output for a number of collector reflector orientations. The orientation of the collector is such that the surface azimuth is 0° while the slope is 22.5° (facing equator) which is the optimum tilt angle for Zaria (Eke, 2012). Parametric studies was conducted for a number of reflector tilt angles varying from 0° through 95° in steps of 5° and the outputs were obtained. The design parameters for the collector considered is shown in table 3. The model calculates the hourly absorbed

Corresponding author: Abdullahi, M. B. ✉ [babs2k4@gmail.com](mailto:babs2k4@gmail.com) ✉ Department of Mechanical Engineering, Ahmadu Bello University, Zaria. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



radiation for the representative days of each month of the year as given in Duffie

and Beckman, 2013.

Table 3: Collector design parameters

Parameter	Value
Collector area	1m <sup>2</sup>
Reflector area	1m <sup>2</sup>
Reflectivity of planar reflectors	0.88
Absorptance of flat plate	0.9
Extinction coefficient of glass	0.04

### RESULTS AND DISCUSSION

Hourly results of simulations carried out from 9am to 5pm for the representative days of each month of the year are presented. For the period when shading of collector surface is predominant, there is a reduction on the amount of energy which would have otherwise been absorbed by the collector without the reflector. As such,

the solar gain during this period is assumed to be zero. The additional energy absorbed with the aid of each of the reflectors ( $Q_{RE}$  and  $Q_{RW}$ ) was plotted as a function of the reflector tilt angle as shown in figures 3 and 4. The optimum reflector angle for maximum enhancement is the value at the highest point of the curve for each month.

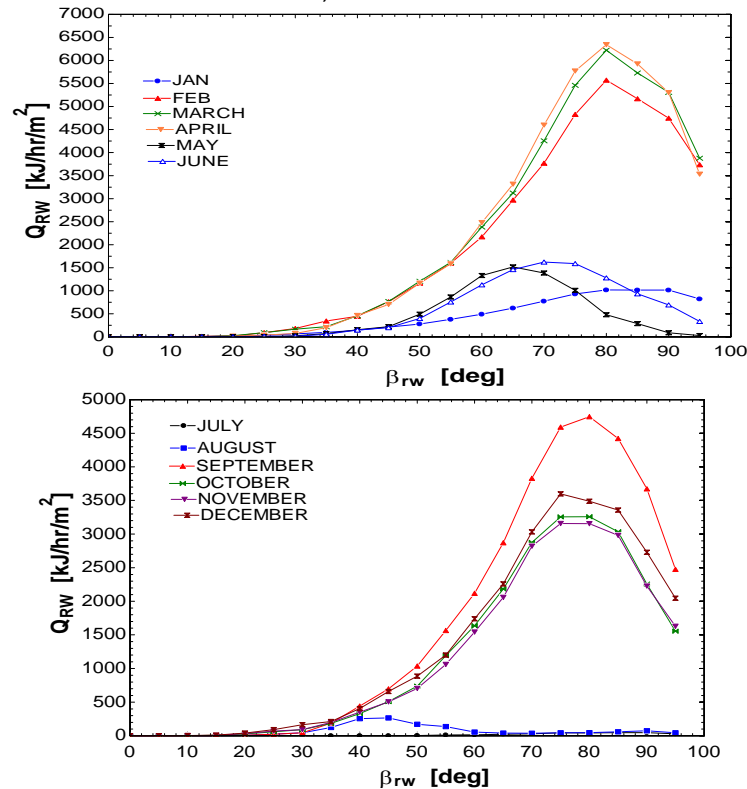


Figure 3: Additional solar gain with reflector  $R_w$  for the representative days of the months of January to December.

Corresponding author: Abdullahi, M. B. ✉ [babs2k4@gmail.com](mailto:babs2k4@gmail.com) ✉ Department of Mechanical Engineering, Ahmadu Bello University, Zaria. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



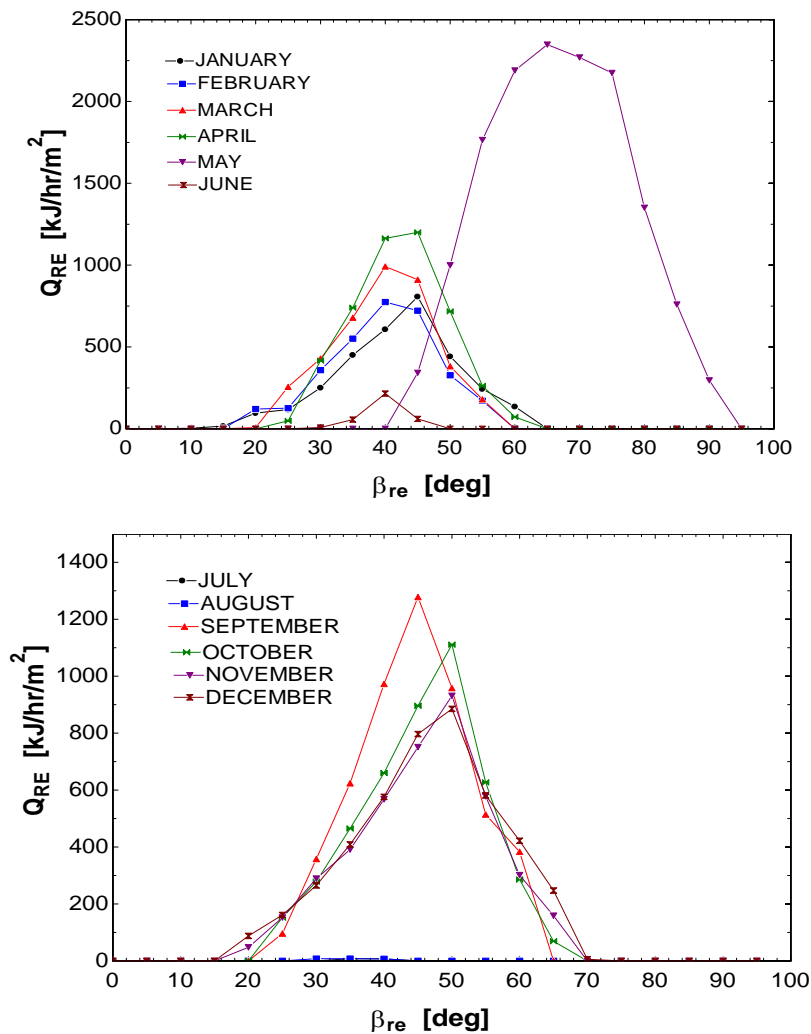


Figure 4: Additional solar gain with reflector  $R_E$  for the representative days of the months of January to December.

In order to ascertain the hours of the day for which the reflectors are effective, the profile of the hourly solar gain contributed by each reflector, at optimum tilt angles is simulated and results are displayed in figures 5 and 6. It can be observed that except for the months of January, September and October, reflector  $R_w$  is effective in other months from the

early hours of the day up to 3pm, after which shading of collector takes place during the later hours. The effect of reflector  $R_w$  in the month of August is almost insignificant when compared to other months. It can also be observed that more energy is absorbed due to reflector  $R_w$  than  $R_E$ . Also, reflector  $R_E$  has no effect in the month of July.

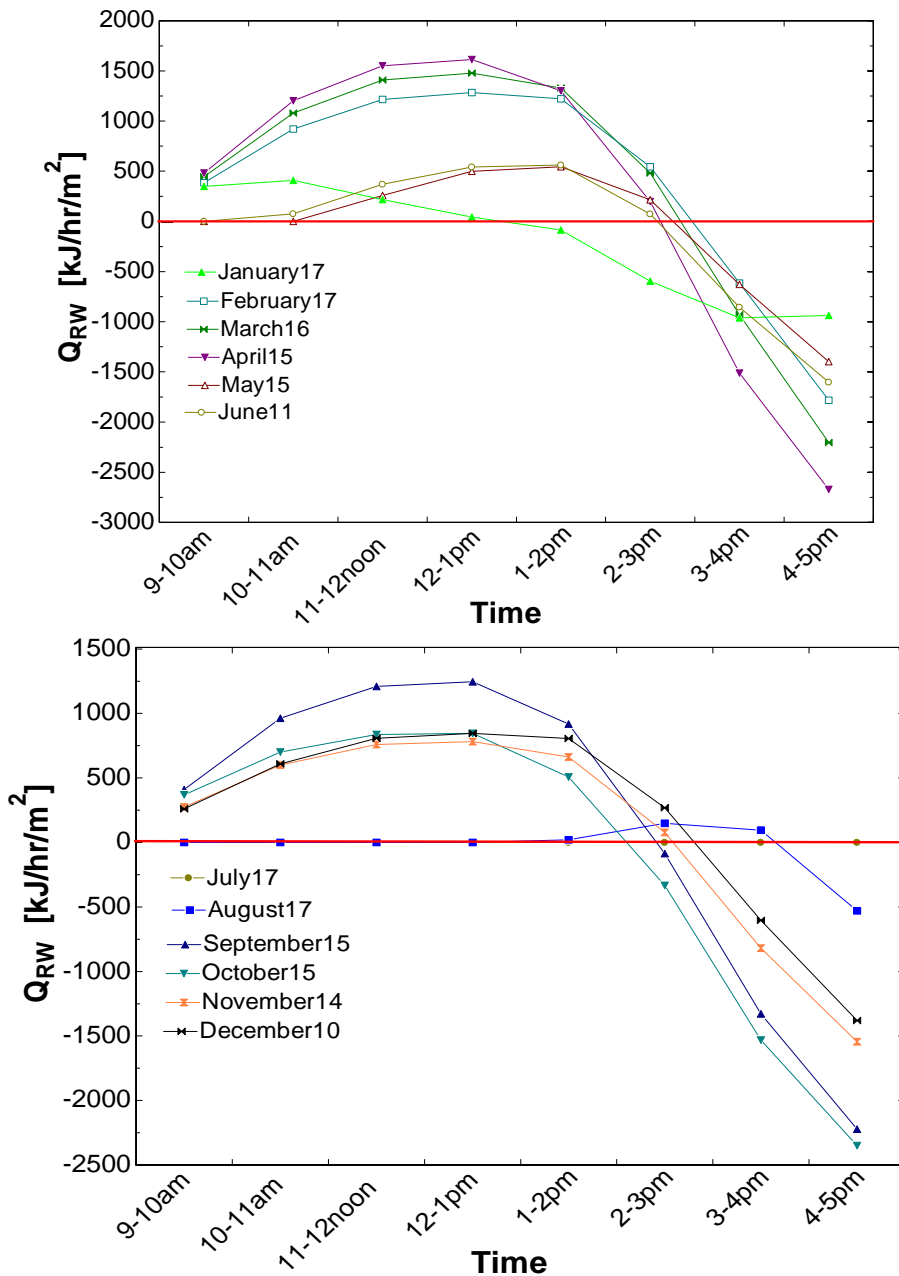


Figure 5: Hourly solar gain of reflector  $R_w$  for the representative days of January to December.

Table 4 gives a summary of the time of the day for which the reflectors are effective during the representative days of each month.

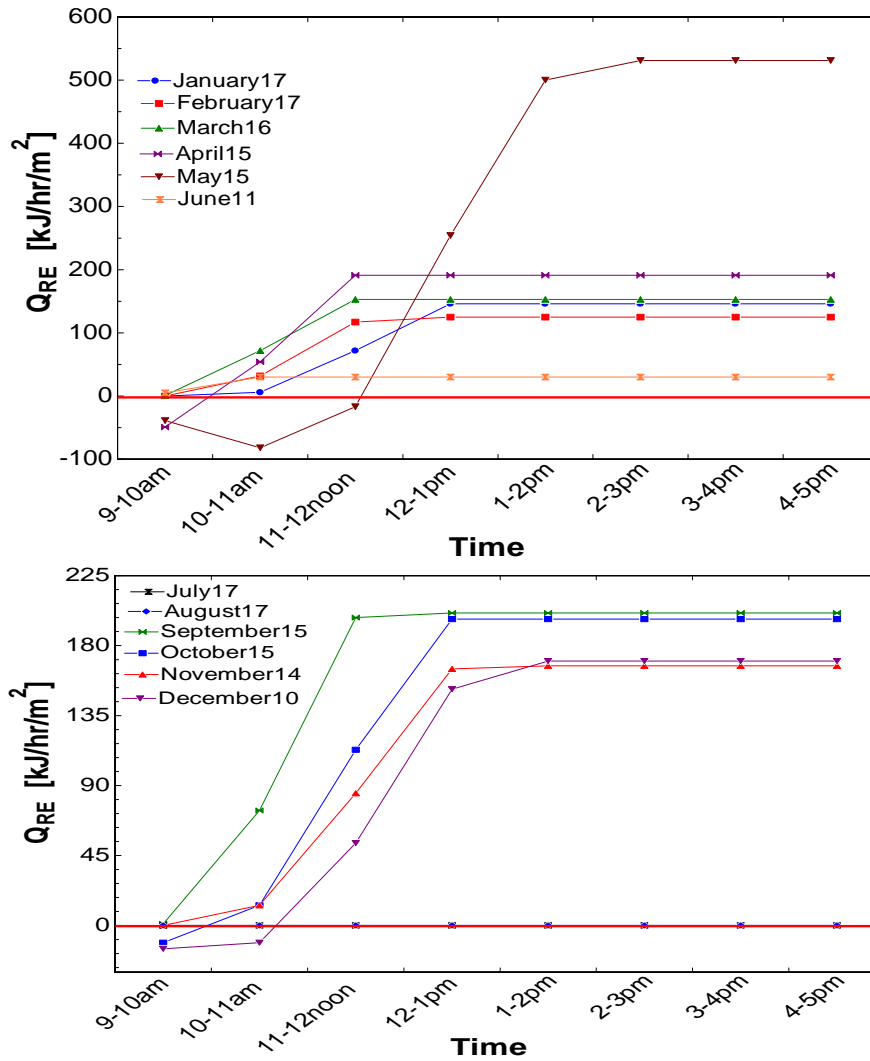


Figure 6: Hourly solar gain of reflector  $R_E$  for the representative days of January to December.

Table 4: Hours of effective concentration of solar radiation

Month	Time	
	$R_w$	$R_E$
January	9am-1pm	9am-5pm
February	9am-3pm	9am-5pm
March	9am-3pm	9am-5pm
April	9am-3pm	10am-5pm
May	9am-3pm	12noon-5pm
June	9am-3pm	9am-5pm
July	--	--
August	1pm-4pm	--

Corresponding author: Abdullahi, M. B. ✉ [babs2k4@gmail.com](mailto:babs2k4@gmail.com) ✉ Department of Mechanical Engineering, Ahmadu Bello University, Zaria. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



Month	Time	
	R <sub>w</sub>	R <sub>E</sub>
September	9am-2pm	9am-5pm
October	9am-2pm	10am-5pm
November	9am-3pm	9am-5pm
December	9am-3pm	11am-5pm

In order to compare the effectiveness of the reflectors, the percentage contribution of each reflector to

the total solar gain is plotted as shown in figure 7. It is obvious that the major concentration effect is due to reflector R<sub>w</sub>.

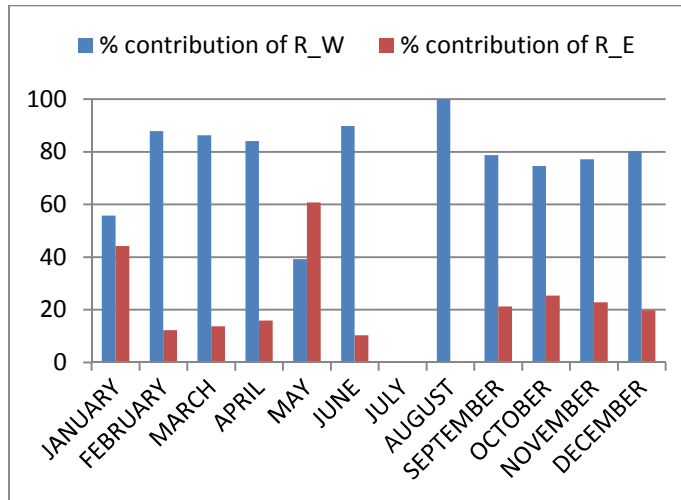


Figure 7: Comparison of the contribution of reflector R<sub>w</sub> and R<sub>E</sub> during the representative days of each month of the year.

### CONCLUSION

A model of a collector augmented by two plane reflectors was developed using TRNSYS and EES software. Simulations were carried out in order to determine the monthly optimum tilts of the two plane reflectors for weather conditions prevalent in Zaria. The results show that:

1. The solar radiation received by collector can be augmented throughout the year except for the month of July for both reflectors and August for the eastern reflector.
2. Concentration of solar radiation in certain months is effective for a specific period, after which significant shading of the collector takes place as shown in table 3.

3. The fraction of solar radiation contribution from reflector R<sub>w</sub> is higher than R<sub>E</sub>. Therefore, for situations where only one reflector is required, it should be placed at the western side of the collector.

### REFERENCES

Alsadi S. Y. and Nassar Y. F. "A Numerical Simulation of a Stationary Solar Field Augmented by Plane Reflectors: Optimum Design Parameters". *Smart Grid and Renewable Energy*, 2017, 8, 221-239. ISSN Online: 2151-4844.

Baccoli R., Mastino C.C., Innamorati R., Serra L., Curreli S., Ghiani E., Ricciu R. and Marini M. "A mathematical



- model of a solar collector augmented by a flat plate above reflector: Optimum inclination of collector and reflector". Energy Procedia 81 (2015) 205 – 214.
- Duffie J.A and Beckman W.A. "Solar Engineering of Thermal Processes" (Fourth Edition, 2013). John Wiley & Sons, Inc., Hoboken, New Jersey.
- Eke A.B. (2012) "Prediction of optimum angle of inclination for flat plate solar collector in Zaria, Nigeria". Department of Agricultural and Bioresources Engineering, College of Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike, Nigeria.
- Gajbhiye P.N. and Shelke R. S. "Solar Energy Concentration Techniques in Flat Plate Collector". International Journal of Mechanical Engineering and Technology. Volume 3, Issue 3, September -December (2012), pp. 450-458. ISSN 0976 – 6359.
- Handoyo E.A., Ichsania D. and Prabowoa. "The optimal tilt angle of a solar collector". Energy Procedia 32 (2013) 166 – 175.
- Kostic L.T., Pavlovic T.M. and Pavlovic Z.T. "Influence of reflectance from flat aluminum concentrators on energy efficiency of PV/Thermal collector". Applied Energy 87 (2010) 410–416.
- Kumar R., Kaushik S.C. and Garg H.P. "Analytical Study of Collector Solar-Gain Enhancement by Multiple Reflectors". Centre for Energy Studies, Indian Institute of Technology, Hauz Khas (1994), New Delhi-110 016, India.
- Mansouri E., Pirsalami M., Nasiri N., Farrizi M., Hashemizadeh M. and Alihosseini H. "Optimum Tilt Angle for Fixed-Array Solar Panels at a Constant Latitude of 29° to Receive the Maximum Sunlight". Bulletin of Environment, Pharmacology and Life Sciences [Spl. Issue 1] 2016: 26-30.
- Naik P.S and Palatel A. "Energy and Exergy Analysis of a Plane Reflector Integrated Photovoltaic-Thermal Water Heating System". International Scholarly Research Notices, Renewable Energy Volume 2014, Article ID 180618.
- Nivas.V and Saravanan.R. "Simulation analysis of Shadow Factor and unit cost in the booster mirror arrangement for a solar panel". International Journal of Engineering and Technology, Vol 5 No 5 Oct-Nov 2013. ISSN: 0975-4024.
- Skerlic J., Nikolic D., Cvetkovic D. and Miškovic A. "Optimal Position of Solar Collectors: A Review". Applied Engineering Letters Vol.3, No.4, 129-134 (2018) e-ISSN: 2466-4847.
- Yasin A. S., Fathi N. Y. and Ali A. K. "General Polynomial for Optimizing the Tilt Angle of Flat Solar Energy Harvesters Based on ASHRAE Clear Sky Model in Mid and High Latitudes". Energy and Power 2016, 6(2): 29-38.