Solar photovoltaic/thermal air collector with mirrors for optimal tilts

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ABSTRACT

This work is the result of a study of a photovoltaic/thermal air collector that concentrates solar radiation using two mobile mirrors to enhance electrical and thermal energy. The study is made for the site of Tetouan (Morocco) (longitude=-5°, latitude=35.25°) for a daily variation during typical days in May, June, September, and December, days considered as clear sky. To prove the effectiveness of the mirrors on the production of both electrical and thermal energy by the collector, we compared their electrical and thermal efficiency in two cases, without and with mirrors at the optimal positions. We validate the obtained simulation results by comparing them to the results from experimental studies published in the literature, for which a strong agreement was obtained. The model estimates the solar energy received by the hybrid collector during the day, to optimize the performance of the fixed collector, we have searched for the values of the optimal daily tilt angles of the two mirrors which allowed us to enhance the quantity of incoming solar radiation on the collector. The tilt angles depend on the sun's elevation angle, the azimuth angle for typical days of the year.

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NOMENCLATURE

Nomenclature		
N	number of days in the year	-
TSV	local solar time in hour	-
A0	collector surface area	m^2
η_e	the electric efficiency	-
η_{cell}	the cell efficiency	-
η_{th}	the thermal efficiency	-
T_f	water input temperature	-
h	solar altitude angle	degre
T_{cell}	cell temperature	°C
NOCT	normal operating cell temperature	-
V_m	PV voltage at MPP	V
I_m	PV current at MPP	A
T_a	ambient temperature	°C
C_p	specific heat	J/kg K
m	Mass air flow rate	kg/s
M	Mass	kg
T°	Temperature of the slice	K

Greek letters	
τ_g	the glass transmissivity
δ	solar declination
φ	azimuth angle
Ø	the latitude of the location
P	absorber plate
F	fluid (air stream)
pb	back plate of absorber
f	fluid (air stream)
ω	sun hour angle
β	inclination
θz	solar zenith angle
η	efficiency

Subscript	
a	ambient air
Sk	sky
w	wind
g	cover
in	intial or intel
o	outlet
gr	ground
cell	photovoltaic cells

Nomenclature

P	Power consumed by the glass	w
h_c	Conduction heat transfer coefficient	w/m^2. k
h_r	coefficient of radiation heat transfer	w/m^2. k
Δs	Length of a slice (along the tube axis)	m
Δt	Time of a slice (along the tube axis)	s
Q_{elec}	The electrical power of the solar cell	w/
V_{oc}	open circuit voltage	V
I_{sc}	short circuit current	A

1. INTRODUCTION

In a world that suffers from a very high energy demands, the ideal solution for the production of electricity is solar energy with these two forms: photovoltaic and thermal, which is considered the safest, cleanest, and most economical source to overcome the energy deficit. The major part of the energy consumed by the photovoltaic panel is converted to thermal energy since they convert only 6-15% of the total incident energy [1], most of the radiation is converted into waste heat, which leads to a higher operating temperature and thus a decrease in photovoltaic efficiency and subsequent degradation of panel performance. To increase thermal as well as electrical energy of the collectors and to optimize the performance of the collector, various techniques have been adopted, however, their impact is not very significant. Moreover, the solar reflector is highly useful in concentrating the sun's rays on the solar panels. The radiation reflectors seem to be the ideal solution. These systems have been the subject of several types of research, experimental [2], [3] and analytical [4], [5].

This work is an analytical study of the performance of a photovoltaic/thermal (PV/T) air collector tilted at 35°, equipped with two reflectors in an adjustable optimal position during the day, compared to previous works, our work contributes the following novelties and additions: i) he inclination angle of the collector is identical to the latitude of the site following the researchers' recommendations for the best collecting of the radiation, ii) the collector is equipped with two reflectors type plane mirror which has a reflection coefficient the highest, iii) the inclination of the reflectors is optimized for each hour of the day, iv) the daily electrical energy production is raised by 52.64%, and v) the dissipated thermal energy is collected by the thermal air collector to reuse in other applications.

The aim is to show the impact of the reflectors on the electrical and thermal efficiency of the system and the influence of their optimal position on energy production. The obtained solutions have been compared to those of [6], [7] and a good agreement is concluded. Also, we compared our results with those of Siahaan and Siswono [2] who used several forms of the mirror with a photovoltaic panel and obtained a better output with the mirror of concave form in the optimal position, also Okasha *et al.* [8] who compared the incident radiation due to the use of the mirror for different angle of inclination and deduced the optimal angles for summer and winter. Our results are similar to those of these articles, which concluded that the use of mirrors in optimal position allows capturing the maximum irradiation.

This article is divided into six main parts: the introduction where we explained the background of the subject and make clear the problem we are going to deal with, subsequently expose the contribution of the manuscript and the innovative aspects of the work. We present related work in section 2, while section 3 discusses in detail the experimental methods and mathematical models used to estimate the incoming solar radiation on the surface of the collector using two reflectors, also the different electrical and thermal parameters of the system studied, section 4 reports the results of the theoretical study and the comparison with other similar research, as well as the general discussion and analysis of graphs and figure explaining what we found during the research. The two last sections are dedicated to the conclusion and perspectives.

2. RELATED WORK

Several solutions are suggested in published articles, to minimize the temperature increase and benefit from the waste heat, among these solutions are the hybrid PV/T collector, the hybrid conversion of solar radiation involves the simultaneous conversion of solar radiation into thermal energy and electrical energy in the PV/T collector. In the past few years, a PV/T hybrid air collector in which an innovative concept was proposed and tested by Haddad [9], the concept is designed to return the preheating air to a second heater. Touafek *et al.* [10] has tested practically the performance of a panel combining PV, thermoelectric generator (TEG) and water heating, experiments using four electrical loads indicated that the hybrid module's performance reaches, more than 80% of the overall efficiency. According to studies [11], [12], a very promising area of research is the development of PV/T air collectors, they are used for solar drying and solar air heating. Many researchers have been carried out PV/T air collectors, exploring aspects such as improving the efficiency by developing the design [13]. A review of the literature highlights that several studies have evaluated the ability of the nanofluid as a heat transfer fluid and optical filter in the PV/T system [14] as well as commenting on the advances in cooling techniques PV/T systems [15], [16]. The work of Tiwari *et al.* [17] found that the total thermal efficiency of the photovoltaic/thermal system is greatly boosted by using the thermal energy of the module. Both electrical and thermal efficiencies of a typical once-through PV/T hybrid air collector system are modeled, simulated and analyzed for two sampled case studies in Iraq bye [18]. A prototype experimental photovoltaic thermal collector using the special heat exchanger concept for a square PV module area was constructed and externally tested by [19], revealing that the electrical power increased by 6 W; also, the electrical power efficiency increased from 7.93-9.65%, and the thermal power efficiency of the PVT reached 74.3%. An extensive numerical model has been developed to evaluate the thermal and electrical parameters of a PV module at transient conditions by [20].

3. RESEARCH METHOD

3.1. Overview of the system under study

In Figure 1 we can see the different parts of hybrid collector PV/T, it composed with a glass cover, a monocrotaline's PV module with a length of 1.29 m and a width of 0.33 m, an absorber made of aluminium placed at the bottom of the module, the absorber is an enclosing chamber that contains the cooling liquid and the insulation to decrease the heat loss of the wool. As shown in Figure 2, the mirrors were placed on the panel to obtain a maximum concentration of solar radiation intensity and consequently increase the electrical energy. To achieve a higher intensity of solar radiation, the mirrors needed to be in the optimal position which we determined by numerical simulations, that is to say, In December, the mirror was at the lowest optimal position (5°), and in June at the highest (38°). To examine the effect of mirrors on the PV array's electrical performance, we compared the electrical performance in both cases, with and without mirrors in their optimal position [21].

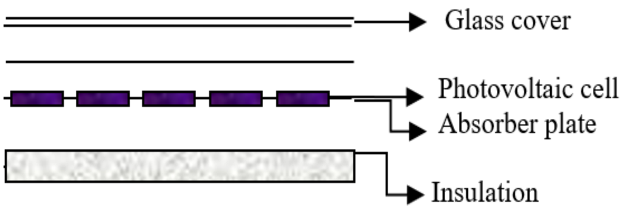

Figure 1. PV/T model diagram

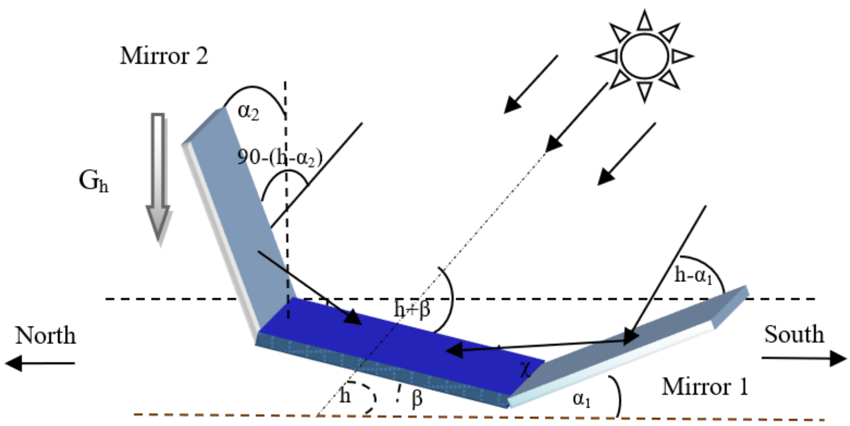

Figure 2. Reflectors on a photovoltaic panel

3.2. Methods of calculation

The laws of astronomical and geometrical components include the latitude of the localized area, the hour, and the number of days in the year controlling energy received from the sun onto a surface, therefore it is necessary to identify the sun's position by the parameters that characterize it: solar declination, is the angle defined as the angle from a plane perpendicular to the incoming solar radiation to the Earth's axis of rotation, calculated by (1). The local hour angle, is a zero angle at solar noon, and rises westward for every 15° of longitude by one hour, which can be calculated by (2). The solar time which is a function of longitude; this is given by (3), the azimuth angle is a function of time given in (4), the altitude angle of the sun is (5) Zenith angle expressed as (6) [22], [23].

3.2.1. Equatorial and horizontal coordinates

$$\delta = 23.54° \, sin \, [0.980°(N + 287)] \quad (1)$$

$$\omega = 15°(TSV - 12) \quad (2)$$

$$TSV = TL + ET + (L/15) \quad (3)$$

$$cos \, (\varphi) = (sin(h)sin(\emptyset) - sin(\delta))/(cos(h)cos(\emptyset)) \quad (4)$$

$$sin(h) = sin \, (\emptyset) \, sin(\delta) + cos(\emptyset)cos(\delta)cos(\omega) \quad (5)$$

$$cos(\theta z) = cos(\varphi - \beta) \, cos(\delta)cos(\omega) + sin(\emptyset - \beta) \, sin(\delta) \quad (6)$$

For estimating the radiation intensity over the ground at a specific area, we used the (7) [22] in which the intensity of extraterrestrial radiation over a horizontal surface is calculated by (8) and the intensity of extraterrestrial radiation over a surface positioned vertically to the sun on a specific day of the year is equal to (9):

$$\mathrm{I} = i_{oh} * 0.7^{(AM)*0.678} \quad (7)$$

$$i_{oh} = i_o * \cos(\theta_{z)} \quad (8)$$

$$i_o = (isc * [1 + 0.334 * cos(2\pi(N - 1)/365.25)] \quad (9)$$

The solar constant I_{sc}=1367 w/m²

3.2.2. The reflector's equations

The overall solar radiation G incident on the tilted PV collector with β, is determined by the model [24]:

$$G = G_{dir} + G_{dif} + G_{gr} + G_{r1} + G_{r2} \quad (10)$$

where

$$G_{r1} = G_{in} * sin(\beta + h) \quad (11)$$

$$G_{dif} = G_d * (1 + cos(\beta)/2) \quad (12)$$

$$G_{gr} = \rho g * G_h * (1 - cos(\beta)/2) \quad (13)$$

$$G_{r1} = \rho al * G_{in} * sin(\chi)sin(h - \alpha 1) \longrightarrow \chi = \beta + 2\alpha 1 - h \quad (14)$$

$$G_{r2} = \rho al * G_{in} * sin(\zeta)sin(h + \alpha 2) \longrightarrow \zeta = h + 2\alpha 2 - \beta \quad (15)$$

In the previous expression, G_{dif} represents the direct irradiation received by the collector, while G_{dif} is the radiation diffused over the sky, and G_{gr} is the reflected radiation by the ground, the radiation from the lower reflector that has arrived at the surface of the collector with an angle of inclination α1 has presented by G_{r1} and reflected radiation from the upper reflector that has arrived at the surface of the collector at an angle of inclination α2 is presented by G_{r2}. G_{in}, G_d, and G_h are the global incident solar radiation, diffuse solar radiation, and global solar radiation on the horizontal surface, respectively [25].

3.2.3. The electrical equations

It is essential to know the influence of the temperature in the natural weather conditions on the power output of the module and on cell efficiency. Using NOCT we studied the module temperature by (16) [26]:

$$T_{cell} = Ta + (NOCT - 20) * (G/800) \tag{16}$$

The solar irradiation received by the photovoltaic panel produces the input power of the system and the output power with the (17) and (18) [17], E (Wh) represents the amount of electrical energy produced by the PV system during the day, calculated by the (19):

$$P_{in} = G * A0 \tag{17}$$

$$P_{out} = I_{sc} * V_{oc} \tag{18}$$

$$E = \eta_{ref} * G * A0 \tag{19}$$

The panel's electrical efficiency ηe is determined by the following relation [24]:

$$\eta_e = (I_m * V_m / A_0 * G) \tag{20}$$

The efficiency of the cell is determined by the relation [25], [27]:

$$\eta_{cell} = \eta_{ref} * (1 - \beta_{ref} * (T_{cell} - T_m)) \tag{21}$$

3.2.4. Expressions of thermal energy for the solar PV/T collector

For each node in a lateral section, the heat balances can be written in the following general form [28]:

$$C_i/\Delta s\ (dT_i)/d_t = P_i + \sum_i ⟦(h_{ci} + h_{rij} + h_{ij})\ (T_j - T_i)⟧ \tag{22}$$

The following is the energy balance of all parts of the photovoltaic/thermal collector [29]:

- The glass covers

$$M_g\ C_g/\Delta s\Delta t(T_g - T_g) = P_g + h_w(T_a - T_g) + h_{(rg-sk)}(T_{sk} - T_g) + h_{(rg-cell)}(T_{cell} - T_g) + h_{(g-cell)}(T_{cell} - T_g) \tag{23}$$

- The photovoltaic cells

$$(M_{cell}\ C_{p_{cell}})/\Delta s\Delta t\ (T_{cell} - T_{cell}) = P_{cell} + h_{g-cell}(T_g - T_{cell}) + h_{(rg-cell)}(T_g - T_{cell}) + h_{(cell-p)}(T_p - T_{cell}) - Q_{elec} \tag{24}$$

where

$$Q_{elec} = \eta_e * P_{cell} * \beta_{cell} * \tau_g$$

- The absorber plate

$$M_p C_{pp}/\Delta s\Delta t(T_p - T_p) = P_p + h_{cell-P}(T_{cell} - T_p) + h_{p-f}(T_f - T_p) + h_{rbp-p}(T_{pb} - T_p) \tag{25}$$

- The fluid

$$M_f C_{pf}/\Delta s\Delta t\ (T_f - T_f) = h_{p-f}\ (T_p - T_f) + h_{pb-f}(T_{pb} - T_f)\ where\ T_f = (T_{f1} + T_{f0})/2 \tag{26}$$

- Back plate

$$M_{pb}C_{ppb}/\Delta s\Delta t(T_{pb} - T_{pb}) = P_{pb} + h_{pb} - f(T_f - T_{pb}) + h_{rp-pb}\ (T_p - T_{pb}) + h_{\text{rpb-in}} - (T_{in} - T_{pb}) + h_{rpb-in}(T_{in} - T_{pb}) \quad (27)$$

– The insulation

$$M_{in}C_{in}/\Delta s\Delta t(T_{in} - T_{in}) = h_{\text{rpb-in}}\ (T_{pb} - T_{in}) + h_{\text{cpb-in}}\ (T_{pb} - T_{in}) + h_{in-s}\ (T_a - T_{in}) + h_{rin-s}\ (T_a - T_{in}) \quad (28)$$

with a simulation using the Fortran software, based on the Gauss-Seidel numerical method [23] for the first-degree system of equations, we were in a position to identify the temperature of the parts of the collector and the temperature of the fluid at the outlet. The PV/T collector's thermal efficiency is calculated as the ratio between the heat extracted by the liquid used and the quantity of radiation applied on the glass. The thermal efficiency is defined by the (29):

$$\eta_{th} = (mC_p(T_f - T_m))/(A_0 * G) \quad (29)$$

4. RESULTS AND DISCUSSION

The variations in sunlight intensity (G) studied by the (10) over the PV collector surface, taken on May 4th at 12 noon considering the position of the mirrors, is illustrated in Figure 3, with α_1 and α_2 refer to the lower mirror angle with respect to the horizontal and the upper mirror angle with respect to the vertical planes, respectively. The sensor collects the highest possible radiation from the sun (1283 W/m²) in full sunlight when the upper mirror is set at an angle of 5° and the lower mirror at an angle of 37°, these two angles are taken as the optimal angles to collect the maximum energy. To validate our theoretical results, we have compared them with the experimental described in [16], [15]. While respecting the same climate conditions as well as the properties of the system as shown in Table 1 during May 4th and June 15th, the comparison is made for the following parameters: the cell temperature, the total irradiation, the electrical power of the output and the output temperature of the fluid.

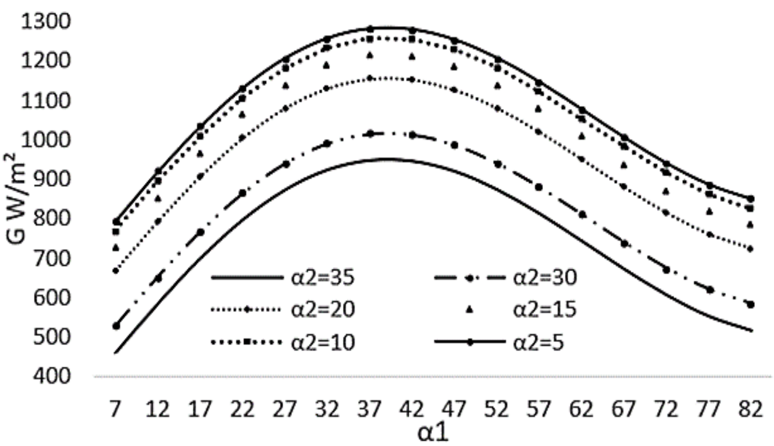

Figure 3. The sun's radiation G on the panel at several angles of reflector

Table 1. Photovoltaic module electrical data

Module type	PWX500 mono crystalline
Power (w)	50
V_{mpp} (V)	17.5 v_{dc}
I_{mpp} (A)	2.8
V_{oc} (V)	22.5 v_{dc}
I_{sc} (A)	3.23
η_{ref} (%)	12
L (m)	0.9
W (m)	0.43
PV module area (m²)	0.38

Figure 4 illustrates the difference between the theoretical and experimental temperature variation of the PV-cell during the day. We noted that the experimental values of the cell temperature (T_{cell} exp) approximately coincide with the values of the theoretical simulation calculated by (16) which validates our model, except for 12 pm, 1 pm, and 2 pm where the experimental values are greater due to uncertainties regarding the correlations applied in the mathematical analysis. The total irradiation values calculated by the mathematical model (10) for different mirror inclinations have been compared with experimentally measured values, which means there is a similarity between the two for the inclinations (α1) higher than 22° and lower than 50° and in optimal inclination of α2 as shown in Figure 5.

In Figure 6, we have plotted the experimental (p exp) and numerical (p out) results deduced by a MATLAB/Simulink simulation of the electrical power provided through the photovoltaic panel, the data collection is made from 8 am to 2 pm on May 4th. The average value measured equals 38.87 W, while the theoretical value equals 41.34 W. A comparison between the theoretically calculated fluid outlet temperature (T_f) and the experimental results (T_f experimental) from [14] for the fluid temperature at the absorber outlet for June 15 is shown in Figure 7, For a suitable comparison, we used the same properties of the system employed in the experimental study except for the fins that are not used, We observed a concordance with the experimental results, as the values of (T_f) are nearly equal to the experimental values (T_f experimental), as can be seen, the maximum calculated and measured values at noon are 319-318 k respectively, therefore, our model can be considered as an effective model and can be useful when predicting PV/T collector performance.

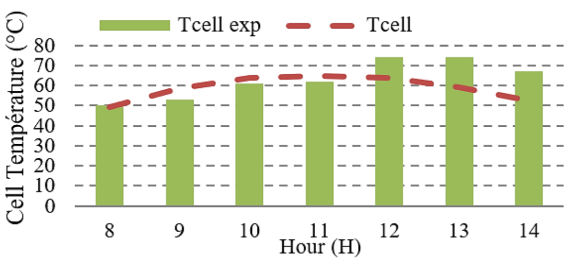

Figure 4. Experimental and theoretical temperature variation per hour of the PV cell on May 4th

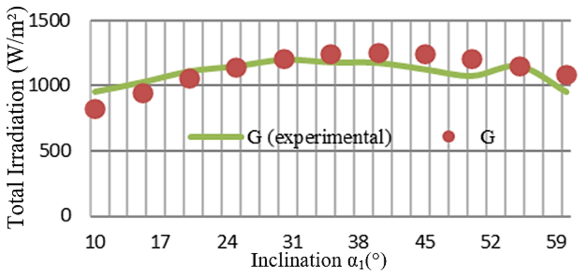

Figure 5. Variation of measured and theoretical solar irradiation for optimal reflector inclination on May 4th

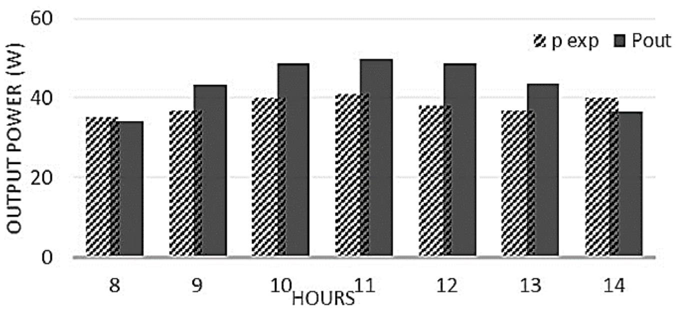

Figure 6. Hourly variation of the electrical output power, the measured and calculated values are as follows for May 4th

Weather conditions, incident energy, outdoor temperature, collector geometry, are all factors that influence collector performance, Thus, as Figure 8 clearly shows, the reflectors have little impact on the efficiency of the collector for this location, as this PV/T collector thermal efficiency without reflectors is near to the collector's thermal efficiency with reflectors. We must then ensure a large gap in temperature between the entry and exit of the fluid, besides increasing the material's thermal conductivity to improve the performance. Figure 9 [24] describes hourly fluctuation in the generation of electricity by the panel with and without application of reflecting devices for 4th May, the total electrical energy produced by the PV collector with mirrors in the ideal position is equal to 415.87 WH/day while the total electrical energy produced by the Photovoltaic collector without mirrors reaches 272.46 Wh/day, which shows the great influence of mirrors on the electrical energy produced. Figure 10 shows the electrical efficiency values of PV without and with mirrors during March 21st, the average efficiency value of PV without reflectors is (12.77%) and with reflectors in the best position equal (14.12%), it can be seen that the electrical efficiency of the PV (20) without mirrors is lower than that of the PV collector with mirrors and this is due to the increase in solar energy received. The hourly variation of the electrical efficiency of the PV panel cell as a function of temperature, calculated by (21), is shown in Figure 11. The increase of the solar intensity after usage of the mirrors leads to an increase in temperature, On the contrary, the electrical efficiency of the cell with mirrors is reduced from 11.25% to 10.67%, so we can assume that the absorption of sun's radiation led to a rise in cell temperature and the efficiency has decreased due to the negative influence of temperature on the cell's performance, it may come to the mind that the warmer it is, the more efficient it is for solar energy production, but it is not. Beyond a cell temperature of 30°, the efficiency of a solar panel decreases. Each degree above this limit reduces the efficiency of the installation by 0.37%. Which leads us to think about solutions for cooling the cells to lower their temperature.

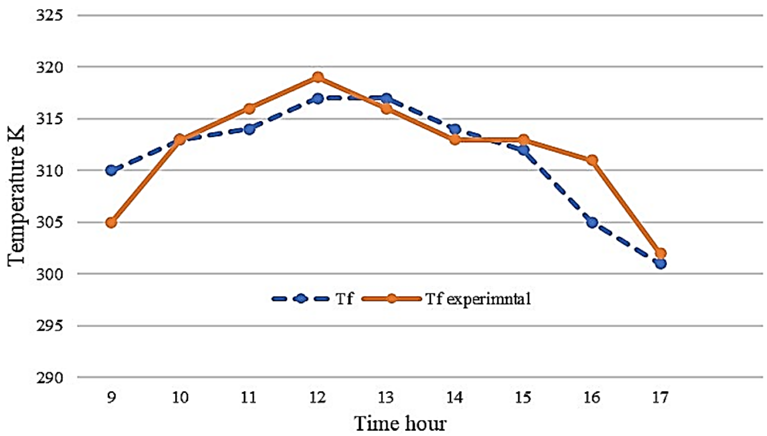

Figure 7. PV/T collector outlet air temperature hourly fluctuations. for June 15th

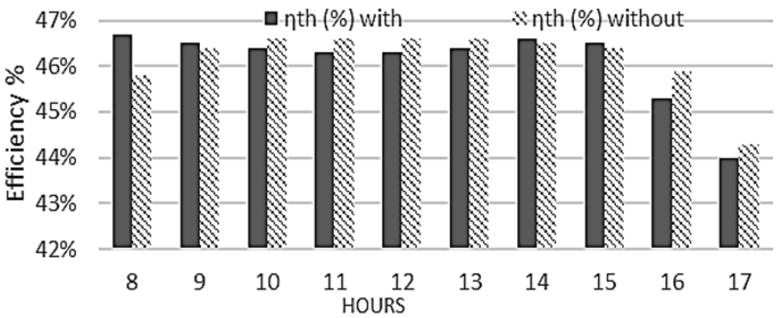

Figure 8. Hourly variations of thermal efficiency of the PV/T collector with and without reflectors

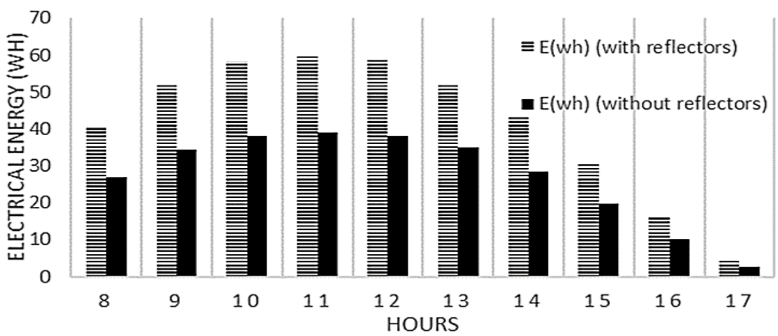

Figure 9. Hourly fluctuations in the PV/T collector's electrical energy with and without reflectors

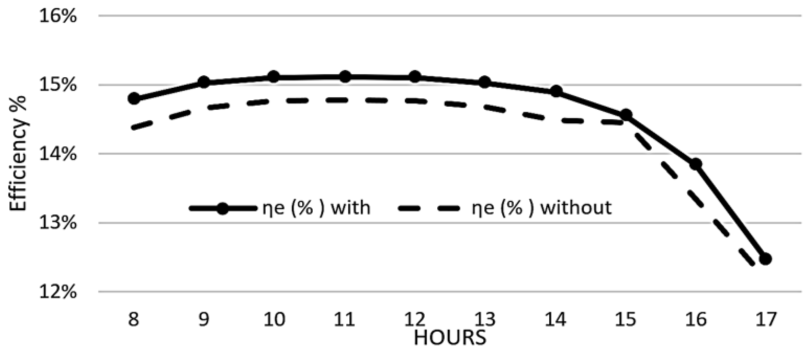

Figure 10. Impact of reflecting devices on the PV/T module's electrical efficiency

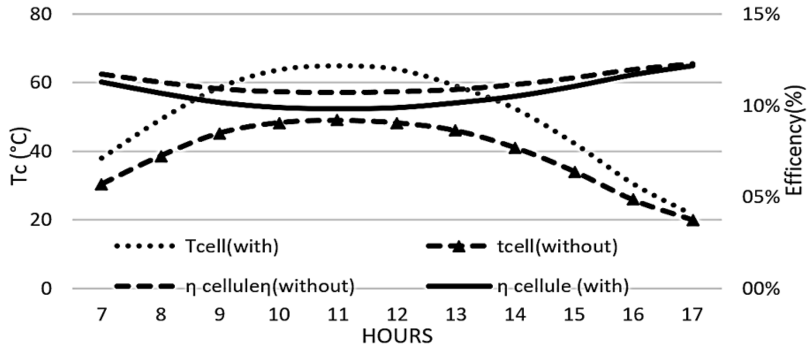

Figure 11. The Cell temperature impact on PV/T collector efficiency with/without reflectors

The results of the daily numerical calculations at several PV/T efficiency values, the total efficiency without and with mirrors in the optimal position on May 4th are shown in Table 2. The average values of thermal daily efficiency of the photovoltaic/thermal collector with reflectors and without reflectors in the optimized orientation during the period of summer are 46.17% and 46.10%, in each case. Meanwhile, the mean values of electrical daily efficiency of the collector PV/T in optimal position during the same period without and with reflectors are 13.75% and 14.09%, respectively. The total electrical generated energy of the PV/T collector without and with reflector in optimal position is 27.25 WH and 41.58 WH, respectively.

Table 2. The results of the daily measurements for a PV/T collector in optimal orientation, with and without reflectors

	With reflectors					Without reflectors				
Hour	ηe (%)	ηth (%)	ηtot (%)	ηcell (%)	E (wh)	ηe (%)	ηth (%)	ηtot (%)	E (wh)	ηcell (%)
8	14.29%	46.70%	60.99%	10.68%	40.76	13.88%	45.80%	59.68%	26.92	11.26%
9	14.52%	46.50%	61.02%	10.18%	51.66	14.16%	46.40%	60.56%	34.26	10.90%
10	14.60%	46.40%	61.00%	9.90%	58.32	14.27%	46.60%	60.87%	38.16	10.74%
11	14.61%	46.30%	60.91%	9.84%	59.82	14.28%	46.60%	60.88%	38.99	10.70%
12	14.60%	46.30%	60.90%	9.89%	58.5	14.27%	46.60%	60.87%	38.07	10.74%
13	14.52%	46.40%	60.92%	10.16%	52.16	14.18%	46.60%	60.78%	35.11	10.86%
14	14.39%	46.60%	60.99%	10.52%	43.5	13.99%	46.50%	60.49%	28.64	11.13%
15	14.05%	46.50%	60.55%	11.00%	30.36	13.95%	46.40%	60.35%	19.65	11.50%
16	13.33%	45.30%	58.63%	11.70%	16.23	12.84%	45.90%	58.74%	10.1	11.95%
17	11.97%	44.00%	55.97%	12.87%	4.56	11.68%	44.30%	55.98%	2.56	12.27%
η(moy)	14.09%	46.10%		10.67%	41.587	13.75%	46.17%		27.246	11.21%

Thermal and electrical efficiency and thus the daily total of electricity energy of the PV/T collector without the mirrors are lower than the thermal and electrical efficiency and the electrical energy with mirrors, but the electrical efficiency of the PV cell which is a feature of the cell temperature without mirrors in the optimal position is higher than the efficiency of the cell with mirrors. The system's performance is estimated for a representative day in September, December, and May. Simulation by numerical modeling was done to demonstrate how the mirrors at ideal angles would affect the collector's performance using a FORTRAN 90 program. Total radiation falling on the PV/T collector with and without mirrors is presented in Figure 12.

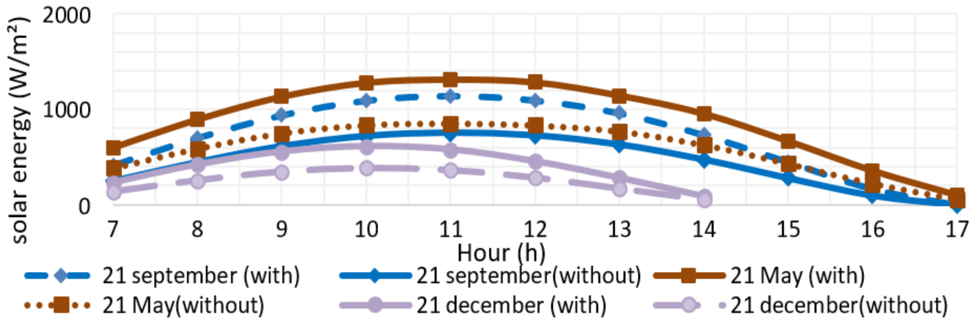

Figure 12. A change of solar radiation on PV/T during typical days, with and without mirrors in optimal position

Depending on the results obtained, it is advisable to boost the solar radiation capture surface by using mirrors or reflectors. This simple, inexpensive, and robust solution will improve the productivity of the solar collectors. Furthermore, mirrors permanently oriented to follow the path of the sun will increase the amount of energy converted by the panels, so it is necessary to orient the reflecting surface correctly. To recover the thermal energy lost around the panels, it is recommended to use a thermal collector that heats a heat transfer fluid to be used later. The cell temperature must be saved at a not too high to avoid degrading the efficiency of the PV cell. It is also recommended to think about the cooling of the panels because the temperature variations are more important if a greater amount of radiation is directed towards the panels, which can lower the performance of the system.

5. CONCLUSION

A PV/T collector, equipped with movable mirrors was the subject of this study. To ensure optimal operation of the collector and benefit from a large part of received radiation on the panel, also obtain a significant concentration of solar radiation intensity, we numerically determined the values of the best tilt angles of the mirrors in the daytime when the collector is set β=35°, This model is tested for validity when the simulation results are compared with the experimental model from the previous experiences, concordance of the numerical and experimental measurements over the year was obtained, allowing us to make reliable predictions for the ideal positions of the reflectors. The numerical calculation indicated that the optimal angular position of the lower reflector is the lowest (14°) in December and the highest (42°) in June, while the optimal position of the upper reflector is the lowest (5°) in June and the highest (30°) in December. Based on the results obtained from the PV/T module with and without mirrors in optimal positions, during typical days, it is concluded that: The solar mirrors raise the level of electrical efficiency of the panel, the average daily value of the electrical efficiency of the PV/T system without and with mirrors are 13.75% and 14.09% respectively. The entire electrical energy generated by the PV/T collector is enhanced using the mirrors, its value without and with mirrors is 27.25 WH and 41.58 WH, respectively. The electrical efficiency of the PV cell without mirrors is higher than the efficiency of the cell with mirrors because it depends on the cell temperature. The use of solar mirrors slightly reduces the thermal efficiency of the PV/T collector, its daily average value without and with mirrors is 46.17% and 46.10%, respectively. The inexpensive flat mirror is a perfect way to improve the performance of photovoltaic/thermal systems for a location with low temperature and good illumination.

6. FUTURE WORK

From the perspective of this work, we have planned to add cooling equipment or water spraying on the panel because of the temperature increase in the cells due to the use of reflectors Thus a study of automation of the mobility of the mirrors controlled by a microcontroller to change their optimal inclination each hour is required as future work to provide an optimal operation of the mirrors.

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