Experimental efficiency analysis of a solar panel electricity generation system using planar reflection

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Abstract
Since energy consumption in all countries of the world is increasing day by day, the demand and interest on renewable energy resources are also increasing at the same rate. Using the current energy in the best way and searching for different energy sources have become an important field of study for countries. Studies on this area also continue in our country, which is lucky in terms of solar energy potential. In this experimental study, where the design and production stages were carried out interactively, the effect of reflected rays on the photovoltaic (PV) panel was observed and the comparison of reflected rays with direct rays was made. The system following the Sun and the system fixed at an appropriate angle was compared. Also, the theoretical and the experimental efficiency as a result of the experimental study of the movable and fixed system were calculated and compared for the direct and reflected radiation. The mechanism presented in this study allows more use of solar radiation by enhancing through reflection from surface-to-surface. With this experimental study more solar radiation will be provided with the panel placed on the back, in addition to the panel exposed to direct solar radiation. Thus, it will be possible to use double-faced panels for a solar tracking system.

1 | INTRODUCTION

Today, increasing energy needs have also caused the increasing demand for renewable energy sources. It is foreseen that the energy demand will increase day by day because of the development of technology and the growing population. For this reason, the highest efficiency must be obtained from renewable energy sources.

It is possible to examine energy sources in two classes as renewable and unrenewable. Energy sources, which run out when they are used and which take very long periods for renewal, such as oil, coal, and natural gas, are called unrenewable energy sources [1].

Renewable energy sources are defined as those that can regenerate themselves at an equal rate of the energy source or faster than the rate at which the resources run out. Today, solar and wind energy are the most frequently investigated and frequently preferred types of energy in renewable energy sources. In addition to these energy sources, geothermal, biomass, and hydroelectric power plants are also used as renewable energy sources [1].

1.1 | Prior art

Ceylan et al. [2] conducted a study and investigated different in vitro photovoltaic-thermal (PVT) systems to cool photovoltaic (PV) modules. In this study, a spiral pipe was placed behind the PV module, cooling water passed from the inside, and the system was cooled because it acted as a heat changer. Although the efficiency of a PV module that is not cooled and a cooled module were calculated as 10% and 13% by increasing at a rate of 3%.

Mishra and Tiwari [3] conducted a hybrid study and analysed the energy and exergy of PVT collectors. They analysed the thermal energy, electric energy, and exergy gain parameters of collectors with two different characteristics, which they called x and y. In this study, the collector called x...
and y were partially and fully coated with the PV module, respectively.

Chandrasekar et al. [4] conducted a study and emphasized that PV modules converted only 4% to 17% of the radiation coming from the Sun into electrical energy, and more than 50% was exposed as heat energy in the module. Therefore, the PV module was examined with passive cooling in their study to increase the efficiency of modules.

Bahaidarah et al. [5] conducted another study and reported that the study temperature greatly affected the efficiency of PV modules. They also examined the efficiency of the PV module, which had a water-cooled back for hot climate areas. They determined that the active cooling system increased the efficiency of the PV module at a rate of approximately 9%.

In their study, Agrawal et al. [6] examined the performance of a PVT air collector in indoor conditions. At the end of the study, they found that the average electric and thermal efficiency was 12.4% and 35.7%, respectively.

Teo et al. [7] conducted a study and designed and manufactured a hybrid PVT system by developing an active cooling system for PV modules. They also examined the system under in vitro conditions. They compared the temperature profiles with real temperature profiles by conducting thermal analysis and found that both designs were compatible with each other.

Gao et al. [8] conducted another study in vitro and examined PV modules connected parallel in different shade conditions. They tested the PV module under four different ambient conditions. These were (i) PV modules were positioned horizontally in an area that was shady with trees and were on the move; (ii) PV modules were positioned horizontally in an area that was shady with trees and had a 70 degrees angle with the horizontal plane and were on the move; (iii) PV modules were shaded with railings, and were fixed and horizontally positioned; (iv) under in vitro conditions, 300 W artificial radiation, and 53% shading area were created, and tests were performed.

In their study, Solanki et al. [9] performed the internal environment simulation and testing of a PVT air collector. They found the temperature of the PVT system that was examined under in vitro conditions as 42%, and electrical efficiency as 8.4%.

In his study, Kupeli [10] examined the methods used to determine the efficiency of solar cells and the parameters that affected efficiency. In the study, PV conversion systems, p-n joints in the structures of these systems, and working principles were explained and the methods used to determine the efficiency of solar cells were explained.

Batman [11] conducted a study and proposed an experimental and digital method to increase the efficiency of solar cells. The method was simple, and the basis was that it would be sufficient to direct solar cell modules to the Sun for all weather conditions. However, it is necessary to predict the direction, intensity and energy that would be produced by the PV module in cloudy weather. A measurement mechanism was established to collect the necessary data. An artificial neural network algorithm was used for prediction and to constantly update the system according to the retrieved data to direct a sample solar module. The data retrieved from the solar module was interpreted, and it was concluded that the efficiency of the panels driven by the algorithm was more.

1.2 Contribution of the study

In some previous studies [2, 8] with the purpose to increase efficiency, cooling using heat exchangers and different shade conditions have been tried.

Techniques for focusing from a spherical surface-to-a point and a cylindrical surface-to-a line are widely used in the literature to increase the intensity of sunlight [12, 13]. With the same perspective, in this study, a similar planar reflection mechanism is presented.

Geometric positioning between the collector and the mirrors provides planar reflection from the mirror surfaces to the backside of the collector and allows more use of solar radiation. Naturally, there is a need for double-faced panels, one exposed to direct solar radiation and the other to reflected radiation. The purpose of this experimental study is to examine the conditions of a collector exposed to reflected radiation from planar mirrors and the contribution of planar reflections. The lower panel in the shade will be less heated than the upper panel exposed to direct solar radiation. Due to this, in parallel with the previous studies, the relation between the temperature of the PV module and the efficiency will be observed experimentally. The efficiencies of the panels which receive direct radiation and receive the reflected will be compared. This research can also contribute to the development of double-faced panels and their cooling systems in a solar tracking system.

2 SOLAR ENERGY

Solar energy is the radiation energy that is exposed with fusion reactions in the Sun’s core. During the core reactions in the Sun, hydrogen is converted into helium, during which some energy is produced. Despite many factors that avoid solar energy, a small part of it arrives on the Earth. Even a small part of this is more than the total energy consumption of the Earth. Studies on benefiting from solar energy increased especially after the 1970s; solar energy systems were technologically advanced with these studies, decreased in terms of cost and solar energy made itself accepted as a clean energy source with its feature that does not affect the environment [14].

Approximately 30% of the radiation emitted from the Sun is reflected back from Earth, 20% is prevented by the atmosphere and clouds, and the remaining, which is 50%, reaches the Earth’s surface through the atmosphere [14].

In the astronomical unit, the solar constant, Gs, is the total solar radiation energy in unit time including all wavelengths of solar rays coming vertically onto a unit area outside the atmosphere. NASA reported that the solar constant was $G_s = 1353$
Total solar rays coming to any surface [15]

W/m² after many measurements in 1971. The World Radiation Center accepts and uses a solar constant value as $G_{sc} = 1367$ W/m² in calculations [15].

The solar radiation to Earth varies depending on its distance to the Sun and the incoming angle of the rays. The solar radiation of a point on Earth varies according to its geographical location, the change in the angle and distance between the Sun and the Earth during the Earth’s annual movement, and the daily atmospheric events [15].

Before they reach the Earth, the sunlight encounter several obstacles. Some of the sunlight change direction by being dispersed by the molecules in the atmosphere, and some of them lose their energy at a certain rate by being absorbed. The radiation that changes direction after being spread around is called diffused radiation [15].

Part of the diffused radiation is reflected back into space, and the other part reaches the Earth again. The radiation that reaches the Earth without deviating from the Sun through a direct path is called direct radiation. Some of the sunlight coming onto a surface are absorbed by the surface, some are reflected, and some pass through. The rays reflected from the Earth are called albedo in general and are indicated with $G_{ya}$, which is defined as the rate of the radiation reflected from a surface to the total radiation rate falling onto the same surface. Albedo is considered as an important factor for PV applications and receives different values between 0.2 and 0.8 depending on the type of the surface. The total of the solar radiation coming onto a sloped surface is the sum of the direct, dispersed, and reflected rays (see Figure 1) [15].

3 | PV SYSTEMS AND FORMULATION

3.1 | The angle in PV systems

The power produced by a PV system depends on the temperature and solar irradiance of the solar array [16]. Since PV system performance depends on the angle of the rays coming from the Sun, the system must be directed towards the Sun in the best condition to obtain maximum performance from the system. As a result of previous studies, it was observed that the panel has the highest efficiency in case the sunlight comes upright to the panel.

3.1.1 | Declination angle ($\delta$)

The angle of the rays coming from the Sun changes in the equatorial plane because of the Earth’s rotation axis changes by months. The declination angle varies between $-23.45^\circ \leq \delta \leq 23.45^\circ$ during a year. The value of the declination angle is calculated as in Equation (1) [17].

$$\delta = -23.45 \times \cos (0.986 \times (n + 10.5))$$ (1)

3.1.2 | Hour angle ($\omega$)

It is the angle where the solar longitude intersects the longitude of the place in question and is calculated in Equation (2) [17].

$$\omega = 15 \times (GS - 12)$$ (2)

3.1.3 | Surface azimuth angle ($\gamma$)

It is the angle between the projection of the rays from the Sun on a horizontal plane and the north-south direction, and is expressed in Equation (3) [17].

$$\gamma = \sin^{-1} \left( \cos (\delta) \times \sin (\omega) / \sin (\psi) \right)$$ (3)

3.1.4 | Zenith angle ($\psi$)

It is the angle between the rays of the Sun and the steepness of the horizontal plane, and is expressed in Equation (4) [17].

$$\cos (\psi) = \sin (\varphi) \times \sin (\delta) + \cos (\delta) \times \cos (\omega) \times \cos (\varphi)$$ (4)

3.1.5 | Elevation angle ($\alpha$)

It is the angle between the rays of the Sun and the horizontal plane. The relation between elevation and zenith angle may be expressed in Equation (5) [17].

$$\alpha = 90 - \psi$$ (5)

3.1.6 | Solar radiation amount

It is the monthly average of the daily total radiation coming to a horizontal plane ($I_{onz}$) and is calculated in Equation (6) [18]. Here $n$, $\varphi$, $\delta$ and $\omega$ refer to the average day representing each month, geographical latitude, the declination and the angle
between the rise-set hours of the Sun, respectively [18].

\[
I_{eq} = \frac{24 \times 3600}{\pi} \times 1353 \times \left[ 1 + 0.033 \cos \left( \frac{360 \pi}{365} \right) \right] \\
\times \left[ \sin (\delta) \sin (\varphi) \frac{2 \pi}{60} \omega + \cos (\delta) \cos (\omega) \cos (\varphi) \right]
\]  

(6)

3.2 | **PV system calculations**

There are two important criteria in PV system calculations, production capacity and panel efficiency. Production capacity depends on several parameters like panel area \(A\), panel efficiency, solar radiation amount \(G\), and ambient temperature.

System efficiency is obtained by determining the system area and calculating the solar radiation amount. The panel efficiency under temperature effect, the PV panel efficiency and instant production amount are calculated in Equations (7), (8), and (9) [18, 19].

\[
\eta_{c} = \eta_{0} \left[ 1 - \beta (T_{PV} - 25) \right] 
\]  

(7)

\[
\eta_{m} = \eta_{c} \times \tau_{g} \times \alpha_{c} \times \delta_{c}
\]  

(8)

\[
E_{PV} = A \times \eta_{m} \times G
\]  

(9)

Here, \(\eta_{0}\), \(\beta\), \(\tau_{g}\), \(\alpha_{c}\), and \(\delta_{c}\) refers to the panel efficiency in standard conditions, electric efficiency temperature coefficient, PV model permeability, PV model absorbance and package factor, respectively.

According to Lambert’s cosine theorem, the radiation amount reflected from a reflector is calculated in Equation (10) (see Figure 2) [20].

Here, \(G\), \(\rho\), \(\varphi_{1}\) and \(\varphi_{2}\) refer to the global radiation value, the rate of reflection by the mirror, the angle between the rays of the Sun and mirror normal and the angle between the rays reflected by the mirror and lower panel, respectively [20].

\[
G_{ru} = G \times \rho \times \cos (\varphi_{1}) \times \cos (\varphi_{2})
\]  

(10)

4 | **THE EXPERIMENTAL STUDY AND RESULTS**

The system was established in Elazig province, and the experiment was carried out under the conditions of this city. The solar energy potential, insolation time, and daily solar energy radiation of Elazig province are given (see Figures 3 and 4). The total solar radiation of Elazig is approximately 1550–1700 kW/m²-year [21].
The solar radiation values and insolation times are extremely high especially in summer months (see Figure 4). The total daily solar radiation within a month is 4.11% more than the average of Turkey with a 6.84 kW/m²-year value. Also, the time of insolation is 12.01 hours, which is 6.19% more than the average value of Turkey.

4.1 System design and characteristics of the equipment used

The system, which was designed and produced, follows the Sun on two axes. Two PV panels, two mirrors, two linear actuators, two wattmeters, radiation meters, sensors, digital thermostats and other elements were used in the system. The technical specifications of the panels and other equipment used are given (see Table 1 and Figure 5). Item 1 shows PV panels that were brought back to back to obtain double-faced panels (see Figure 5). The route of the rays reflected to lower panel from mirrors is given (see Figure 6). Since solar tracking system also covers the mirrors, the angle of the rays reflected from the mirrors with the lower panel is always constant.

The images of the system are given (see Figure 7). Panels are brought back to back and double-faced panels are obtained. The top panel receives direct solar radiation and this panel will be referred to as the upper panel (see Figure 7(a)). The bottom panel receives the rays reflected from the mirrors and this panel will be referred to as the lower panel (see Figure 7(b)).

The system follows the Sun in two axes by transferring the information retrieved from the sensors to the engines, which are driven by the battery fed by the upper panel. The technical specifications of the engines used in the study are given in Table 2.

4.2 Experimental study

The data were obtained in 6-day periods and at 30-min intervals in the established mechanism. In these measurements, the data were obtained from zenith angle (ψ), azimuth angle (γ), perimeter temperature (Tc), panel circumference temperature (TPc), panel surface temperature (TPV), the instant solar radiation coming perpendicularly to an upper panel (Gupper), the instant solar radiation coming perpendicularly to a lower panel (Glower), current (I), voltage (V), instant power (EPV) and produced energy (E).

The measurements were made for two different situations, and the efficiency analysis and total energy generated by the lower/upper panel amount were calculated. Upper and lower panels are used in both systems. While in the first case, the solar tracking system is active, in the second case the solar tracking system is passive. In the second case, it is stated that the system is fixed at a constant 49 degrees latitude value. With these two cases, it is aimed to compare the fixed and the movable system.

4.2.1 First observation status

Two mirrors active and solar monitoring system active. In this process (2–8 October), the upper panel is exposed to direct solar radiation, while the lower panel is exposed to solar radiation reflected from two mirrors. In the first six days, two mirrors were active in the system, and the solar monitoring system was active while the observation was made. Since the day-time values [22] read from the system are close to each other, only the data of 7 October are used.

The upper panel that followed the Sun in the system took direct sunlight in this process, and the radiation intensity on the lower panel, which received the rays reflected with two mirrors, was measured. Although two mirrors were active in the
system, it was determined measuring by solar radiation meter (solarimeter) that the radiation intensity coming to the lower panel was less than upper panel (see Figure 8(a)). Experimentally, the upper panel surface temperature was measured to be higher than the lower panel surface temperature (see Figure 8(b)). While the upper panel receives direct solar radiation, the lower panel only receives the reflected solar radiation. So, generally the upper panel temperature is higher. Only between the hours of 10:30 AM and 2:00 PM, the lower panel temperature was read higher due to double reflection when the radiation intensity was high. The angle of the rays reflected from the mirrors with the normal of the lower panel and the angle of the solar radiation with the normal of the mirror were 53 and 25.40 degrees, respectively (see Figure 13).

The instant power amount of the lower and upper panel are given (see Figure 8(c)). Due to the shading, the instant power amount in the lower panel dropped suddenly after 4:00 PM.

Although the surface temperature of the upper panel increased, the instant energy amount generated by it decreased (see Figure 8(d)). When the surface temperature decreased, the instant generated energy increased. It is an expected result that as the temperature increased, the distance and voltage values between energy bands decreased.

The effect of surface temperature on the energy amount is given (see Figure 9(a)). As the temperature increased, the instant energy decreased.

Although the radiation values increased initially, the decrease in the instant power amount occurred because of surface temperature (see Figure 9(b)). After 4:00 PM, there was a decrease in the instant power amount of lower panel; and at 5:00 PM, the lower panel completely cut production. This stemmed from the reduction in radiation amount coming to lower panel and partial shading on it.

It was found that although the instant radiation amount on the lower panel was low, the instant power produced by it was close to the instant power produced by the upper panel (see Figure 9(c)). It was determined that this result was due to the warmer upper panel.
FIGURE 8 For 1st status (a) amount of daily radiation coming direct to lower-upper panel, (b) change of lower-upper panel and circumference temperatures by time, (c) instant power amounts of lower-upper panel, (d) change of upper panel temperature and power value by time.

FIGURE 9 For 1st status (a) change of lower panel temperature and power values by time, (b) change of daily radiation and power values of lower-upper panel by time, (c) daily energy amount produced by lower-upper panel, (d) change of calculated and measured values of upper panel zenith and azimuth angles by time.
Because of the partial shading in the lower panel and the high-temperature values on the surface, the energy generated was less compared to the upper panel. Within six days, the lower panel produced 2015 Wh energy, while the upper panel generated 2382 Wh energy.

Values of zenith (ψ) and surface azimuth (γ) angle measured and calculated using Equations (3) and (4) were close to each other (see Figure 9(d)). The values are valid for the upper panel, which receives direct solar radiation. The surface azimuth angle of the PV panel was 0 degree because it was directed towards the south at 12:00 PM.

Efficiency values for upper and lower panels were calculated at 08:00 PM on 7 October. The efficiency values calculated theoretically according to Equations (7) and (8), and the efficiency values experimentally measured and calculated according to Equation (9) are given in Table 3.

As there were low module permeability, low module absorbance, and low package factor levels, experimental study efficiency was less than theoretical efficiency.

There was a decrease in lower and upper panel efficiency towards noon (see Figure 10). At this period, the radiation amount increased on the surface of the panel. At noon, it is expected that the panel efficiency is at the highest value. However, the most important parameter to consider is the temperature. Panel surface temperatures are at the highest values at noon. For this reason, it is observed that high-temperature values affected the PV panel negatively. Ozturk [23] conducted a study and examined the effect of temperature on the panel, and determined that it had a negative effect on the panel efficiency.

| Panel surface temperature (°C) | Instant panel output Power (W) | Instant radiation amount (W/m²) | Theoretical efficiency (ηₘ) | Experimental efficiency (ηₑ) |
|--------------------------------|-------------------------------|-------------------------------|-----------------------------|-----------------------------|
| Upper panel                    | 34.9                          | 40.6                          | 792                         | 0.110                       | 0.09767                     |
| Lower panel                    | 28.7                          | 41.8                          | 706                         | 0.113                       | 0.1117                      |

4.2.2 Second observation status

Two mirrors active and solar monitoring system passive: During the second observation process (10–15 October), the system with the upper panel directly facing the sun and the two mirrored bottom panel was directed to the south and the angle of the panel with the horizontal was determined as 49 degrees [24] to the latitude value of Elazig province in October, and the system is fixed at this angle. The movable system and the fixed system were compared. Since the daytime values read from the system [22] are close to each other, only the data of 14 October are used.

The change of radiation severity, which came with a steep angle to the upper and lower panel by time, was examined for the system in this condition (see Figure 11(a)). The radiation intensity to the upper panel took its highest level at around 12:00 PM. The lower panel received only the reflected rays between 10:30 AM and 1:30 PM because the system was constant.

As reflection occurred only in midday hours in the lower panel, the temperature levels increased during these hours (see Figure 11(b)).

The change in upper panel temperature and power values by time when the system was constant is given (see Figure 11(c)); and the change in lower-upper panel radiation and power values by time is given (see Figure 11(d)). As shown, temperature and radiation are two important parameters that affect the generated instant power amount. Although radiation amount increased at noon, there was a decrease in instant production as a result of high-temperature values that affected panel efficiency negatively (see Figure 11(d)).

After 12:00 PM, the radiation amount, which came with a steep angle onto the upper panel, decreased. However, there was no reduction in panel production as a result of the decrease in surface temperature values.

The daily energy amount produced by the lower and upper panel is given (see Figure 12(a)). As the lower panel receives reflection from the mirrors only at midday hours approximately in 3 hours, the fact that lower panel production values were lower than the upper panel was an expected result.

The data of the lower and upper panel on 14 October and the theoretical and experimental study efficiency values according to these data are given (see Table 4). Since theoretical efficiency is only based on surface temperature, calculations were made for two panels. The calculation could not be made because data could not be retrieved in the hour when there was no production.

There was a decrease in efficiency at noon, which was the hottest time (see Figure 12(b)). It was understood that this is
**FIGURE 11** For 2nd Status (a) amount of daily radiation coming directly to lower and upper panel, (b) change of lower-upper panel surface and circumferential temperatures by time, (c) change of upper panel temperature and power value by time, (d) change of lower-upper panel power and radiation values by time.

**FIGURE 12** For 2nd status (a) the energy amount generated by lower-upper panel, (b) change of lower-upper panel theoretical and experimental efficiency values by time.

**FIGURE 13** The reflection angles of the rays because of the warming on the panel. It was understood that the sudden rise, and after some time, the sudden decline in experimental study efficiency was because the rays that were reflected from the mirrors depending on the movement of the Sun first reduced the shadow on the panel and covered the panel completely, and then the reflected rays moved away from the panel (see Figure 12(b)).
### TABLE 4  Theoretical and experimental efficiency of lower-upper panel surface temperatures for 2nd observation status

| Hour | Panel surface temperature (°C) | Theoretical efficiency (%) | Experimental efficiency (%) |
|------|--------------------------------|----------------------------|-----------------------------|
|      | Upper panel | Lower panel | Upper panel | Lower panel | Upper panel | Lower panel | Upper panel | Lower panel |
| 08.00 | 258   | 182  | 115,009 | 118,957 | 149,171 | – |
| 08.30 | 272   | 194  | 114,282 | 118,333 | 129,504 | – |
| 09.00 | 287   | 221  | 113,503 | 116,931 | 109,316 | – |
| 09.30 | 296   | 216  | 113,035 | 117,191 | 98,270 | – |
| 10.00 | 352   | 227  | 110,127 | 116,619 | 91,607 | – |
| 10.30 | 364   | 385  | 109,503 | 108,412 | 87,275 | – |
| 11.00 | 455   | 472  | 104,777 | 103,894 | 82,292 | 25,458 |
| 11.30 | 450   | 482  | 105,036 | 103,374 | 79,611 | 82,070 |
| 12.00 | 456   | 516  | 104,725 | 101,608 | 79,757 | 82,367 |
| 13.00 | 523   | 283  | 101,245 | 113,710 | 86,725 | 20,842 |
| 13.30 | 517   | 322  | 101,556 | 111,685 | 85,032 | – |
| 14.00 | 478   | 316  | 103,582 | 111,996 | 106,323 | – |
| 14.30 | 447   | 309  | 105,192 | 112,360 | 114,046 | – |
| 15.00 | 412   | 283  | 107,010 | 113,710 | 136,177 | – |
| 15.30 | 351   | 279  | 110,178 | 113,918 | 151,175 | – |
| 16.00 | 285   | 255  | 113,607 | 115,165 | 155,158 | – |
| 16.30 | 234   | 224  | 116,256 | 116,775 | 57,575 | – |
| 17.00 | 212   | 20   | 117,398 | 117,554 | – | – |

### 5  CONCLUSION

The effect of reflected radiation on the PV panel was examined in the present study. The effects of once and twice intensified rays of the Sun were observed. The upper panel receives direct solar radiation. In the lower panel in the system, double intensity rays reflected from two mirrors were obtained due to mirrors. The comparison of the fixed and moving system was made. Detailed efficiency analysis was also made for the lower and upper panel. For both panels, theoretical and experimental efficiency values were calculated and compared. As a result of the data obtained, parameters that affected panel efficiency were determined. The negative effects of temperature on panels were indicated with graphics. It was determined that although the amount of radiation affecting panels was at the highest levels at noon, the panel efficiency was at its lowest levels at noon. The negative effects of double intensity on the panel were also determined.

For October, it was determined that the movable system was 12.3% more efficient than the fixed system. The effects of shading on the panel were also examined. Despite the weak radiation intensity in cloudy weather, the upper panel produced energy because the rays were dispersed, and there was no energy production in the lower panel.

Geometric positioning between the collector and the mirrors provides planar reflection from the mirror surfaces to the backside of the collector and allows more use of solar radiation. Naturally, there is a need for double-faced panels, one exposed to direct solar radiation and the other to reflected radiation. With this experimental study, the conditions of a collector exposed to reflected radiation from planar mirrors and the contribution of planar reflections were to examine. The lower panel in the shade was observed to be less hot than the upper panel exposed to direct solar radiation. Due to this, in parallel with the previous studies, the relation between the temperature of the PV module and the efficiency was observed experimentally. The efficiencies of the panels which receive direct radiation and receive the reflected have been compared. This research, has provided to the double-faced panels usage and also, has contributed to the development of the cooling systems in a solar tracking system.

Panel performance can be improved by improving the system design to ensure that the rays reflected from planar mirrors come to the panel at a more steeper angle and to minimise the shading on the panel.

Panel temperatures can be reduced and the upper and the lower panel efficiency can be increased by adding a suitable cooling system. Especially selecting the panel case frame from a material that is not affected by temperature can affect efficiency. Panel efficiency with one and two-fold intensity can be re-examined under these circumstances.

Wind speed can be added to the data received, and the effects of this parameter on the panel can be examined. Although high values are an unwanted parameter in terms of system security, it is an efficiency-improving parameter because of the system cooling. Optimum wind speed can be determined for the panel by considering both conditions.
Nomenclature

\( \alpha_c \) photovoltaic model absorbance
\( \delta, \omega, \gamma, \psi, \alpha \) declination, hour, surface azimuth, zenith and elevation angle, respectively
\( E \) produced energy (Wh)
\( E_{PV} \) instant panel output power (W)
\( G \) irradiation amount from the Sun (W/m²)
\( G_s \) solar hour
\( G_{s0} \) solar constant
\( G_{upper}, G_{lower} \) irradiation amount to upper and lower panel respectively (W/m²)
\( G_{rs} \) reflected ray
\( I_{avg} \) monthly average of daily total ray amount to horizontal plain (W/m²)
\( n \) average day representing each month
\( PV \) photovoltaic
\( PVT \) photovoltaic-thermal
\( T_C, T_{PC}, T_{PV} \) ambient, panel circumference and surface temperature (°C) respectively
\( \beta \) electric efficiency temperature coefficient
\( \delta_C \) package factor
\( \eta_0 \) panel efficiency in standard conditions
\( \eta_C \) panel efficiency under temperature effect
\( \eta_m \) general panel efficiency
\( \theta_1 \) angle between rays from the Sun and mirror normal
\( \theta_2 \) angle between rays reflected from mirror and lower panel normal
\( \rho \) reflection coefficient
\( \tau_s \) photovoltaic model permeability
\( \phi \) geographical latitude
\( A \) panel area (m²)

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