

THE EFFECTS OF ALUMINUM REFLECTOR SHAPES, ANGLES, AND THERMAL-LIGHT COVARIATION ON SOLAR PANEL PERFORMANCE

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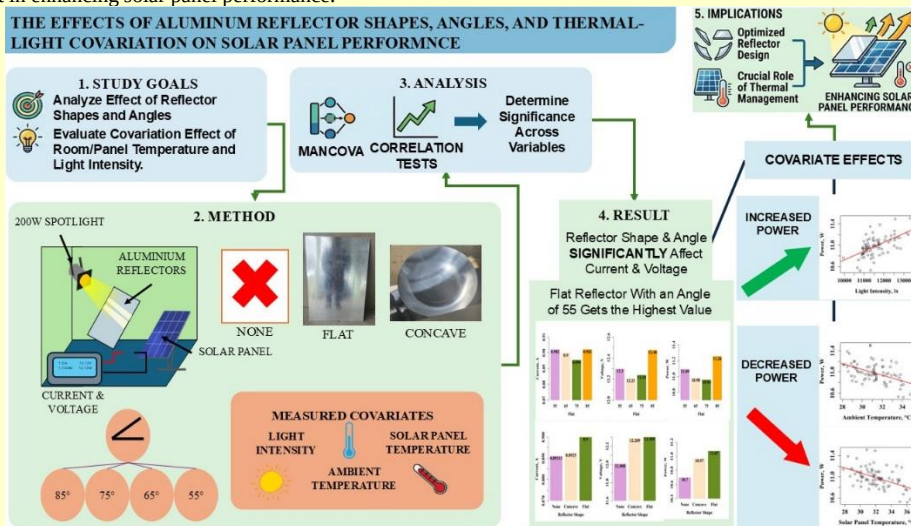
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Abstract

The performance of solar panels is strongly influenced by light intensity, panel temperature, and incident angle, indicating the need for reflector-based enhancements to improve power output. This study aims to analyze the effects of aluminum reflector shapes and angles on solar panel output while evaluating the covariation effects of room temperature, panel temperature, and light intensity. Experiments were conducted indoors using a 200 W spotlight with three reflector configurations (none, flat, concave) and angles of 55°, 65°, 75°, and 85°. Data were analyzed using MANCOVA and correlation tests to determine significance across variables. Results indicate that both reflector shape and angle significantly affect current and voltage, with the flat reflector delivering the highest power output, especially at a 55° angle. Light intensity was found to be the dominant covariate increasing power, whereas panel and room temperatures showed negative correlations. These findings highlight the crucial role of optimized reflector design and thermal management in enhancing solar panel performance.



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Keywords: aluminum reflector, reflector angle, light intensity, panel temperature, solar panel output

Introduction

As technology advances, the demand for electricity continues to rise, while fossil fuel resources are limited. The continued use of fossil fuels will lead to energy shortages and may cause environmental problems. Therefore, the development of new and alternative energy sources is necessary, one of which is solar energy. Solar energy is the most promising alternative energy source, particularly in countries with high solar radiation intensity throughout the year [1], [2]. The solar energy potential at the building scale indicates significant values for Global Horizontal Irradiance, direct radiation, and diffuse radiation, sufficient to support the design of solar panel systems [3]. Additionally, designing solar panel systems using software simulations can optimize the utilization of solar radiation on building roofs, capable of generating a significant supply of electrical energy [4]. But the panels need to create more power because the angle of the radiation, the amount of light, and the weather all affect how well they operate. More radiation hitting the panels doesn't always imply they make more power. This is because higher panel temperatures could make it tougher to turn energy into energy that can be used. Using reflectors is one way to improve the performance of solar panels, But having the light stronger can also make the panels hotter, which makes the system less efficient and less effective overall. The author needs to examine more closely how using reflectors and changing the temperature affect the performance of solar panels in order to find the best conditions for them to work.

One technology that uses solar energy as the primary energy source in electrical energy conversion is the solar panel (photovoltaic). The use of solar energy has expanded widely on both a residential and industrial scale, including as part of backup power systems and modern electrical systems based on the Internet of Things (IoT) [5]. However, solar panels can be monitored using a LabVIEW-based monitoring system designed to measure current, voltage, temperature, and light intensity in real time [6]. The performance of solar panels is not solely determined by the monitoring system but is influenced by environmental factors, particularly solar radiation intensity and temperature. Increased light intensity can boost current, voltage, and solar panel output

power due to the increased number of photons absorbed by the semiconductor [7], whereas temperature can reduce voltage as it rises, as energy conversion efficiency leads to increased carrier recombination and thermal energy accumulation within the photovoltaic cell [8]. Furthermore, environmental conditions can simultaneously affect both temperature and light intensity, thereby influencing the current, voltage, and power output of solar panels [9]. Consequently, a comprehensive understanding of the effects of environmental parameters and the physical configuration of the system is crucial for efforts to improve solar panel performance.

Several key factors can influence solar panel performance, including the intensity of light received by the solar panel, panel temperature, ambient temperature, and the addition of reflectors. High light intensity can improve solar panel performance, particularly in terms of current and power output [10]. However, increases in panel and ambient temperatures can reduce solar panel performance, particularly in terms of the panel's output voltage, thereby decreasing energy conversion efficiency [11]. As the solar panel temperature rises, it can lead to a decrease in the panel's output voltage, resulting in increased recombination of charge carriers within the cells, thus reducing the amount of energy converted. This condition causes light intensity to increase, but the solar panel's output power does not always increase to its maximum if the solar panel temperature is too high. Adding a reflector can improve solar panel performance, but the reflector's angle must be precise to ensure the solar panel receives greater light intensity [12]. The factors mentioned above determine the magnitude of the solar panel's output power.

Advances in solar panel performance have been achieved through the optimization of solar panel tilt angles. Previous research has provided solutions for increasing solar panel power output without adding more panels by adjusting the tilt angle to ensure that the intensity of light received by the panels is maximized [13], [14]. This approach offers significant economic and operational benefits, particularly for large-scale investments. However, an improper tilt angle results in minimal light intensity being received [15]. Maximizing the optimal performance of solar panels is one of the most widely applied solutions for solar energy development.

Not only does the angle of the panel matter, but the addition of reflectors can also affect the amount of light received by the solar panel. The use of reflectors can reflect light onto the surface of the solar panel, thereby increasing the energy received. The use of reflectors at specific angles has been demonstrated by previous research showing an increase in solar panel power output when using reflectors at specific angles compared to using no reflectors [10]. However, the effectiveness of reflectors can depend on the angle of the reflector relative to the solar panel [16]. An improperly angled reflector can result in suboptimal light reflection and less-than-optimal light intensity reception by the solar panel.

In addition to the angle of inclination of the reflectors relative to the solar panels, the shape of the reflectors is also a key factor in increasing the power output of solar panels. Previous studies have examined the shape and materials of reflectors. The use of configurations with two and four reflectors can increase the intensity of light received by the panels and make it more focused on the surface of the solar panels. Using four reflectors can increase the light intensity and power output of the solar panel compared to two reflectors, with the reflector tilt angle being a key factor in light reflection efficiency [17]. Not only the shape and number of reflectors, but the material used in the reflectors can also affect solar panel performance. Previous research indicates that concave puzzle-shaped glass reflectors and aluminum foil demonstrate that both materials can improve solar panel performance compared to no reflectors, but their light reflection characteristics result in different optimizations [18].

Prior studies suggest that enhancements in solar panel efficiency are generally attained by the optimization of the panel tilt angle or the implementation of reflectors, yet, these methodologies have predominantly been examined in isolation. Some earlier research has concentrated on refining the panel tilt angle to enhance light intensity, but other studies have highlighted the incorporation of reflectors to further amplify the light intensity received by the solar panel. Nonetheless, existing research concentrating on reflector shape is scarce and typically lack integration with concurrent optimization of the reflector angle, resulting in an incomplete understanding of the relationship between reflector parameters and solar panel performance. Other studies have only looked at how reflectors affect things in part, and they haven't looked at how changes in the shape of aluminum reflectors affect the amount of light and the power output of solar panels. Some studies that look at changes in light intensity don't take into account things like the temperature of the environment and the temperature of the panel. These things haven't been looked at in depth with covariates at the same time, even though the relationship between optical parameters and thermal factors could affect the solar panel's power output response. So, when the light gets brighter, the temperature of the panels and the air around them will rise, which will lower the power output of the solar panels, especially the output voltage. Additionally, there is a lack of research that examines the relationship between reflector shape, reflector angle, and thermal factors in controlled environments with controllable light sources. As a result, the mechanisms that connect these parameters are still not well understood. This study addresses a research gap by examining

the impacts of alterations in the shape and angle of aluminum reflectors, alongside assessing the influences of ambient temperature, panel temperature, and light intensity on solar panel output power. It employs an integrative methodology that simultaneously enhances light intensity and temperature through light reflection, a technique that has been underutilized in prior studies and represents the principal contribution of this research.

Research Methods

This study was conducted on Jalan Hikmah Banua, East Banjarmasin District, Banjarmasin City, South Kalimantan Province, Indonesia. The testing was conducted in a closed room to eliminate the influence of sunlight entering the room. This testing condition was implemented in a closed room so that the light source received by the solar panels originated from a spotlight, which could be consistently controlled and used to simulate sunlight intensity, thereby producing a measurable artificial light source that supported a more controlled observation of the effects of the treatments. The use of spotlights aimed to analyze the effects of variations in reflector shape and angle on solar panel performance, which could be observed objectively. The research was conducted over a period of 3 months, from preparation to data analysis. Observation data were collected three times (5 minutes, 10 minutes, and 15 minutes) during the morning, afternoon, and night.

The solar panel used in this study is a polycrystalline solar panel. A single 50-watt-peak (WP) solar panel was selected because it exhibits good response characteristics to variations in light intensity for laboratory-scale testing. This test was conducted using a spotlight as the light source, with a light intensity approximating that of sunlight under cloudy conditions, thereby enabling the simulation of radiation reception on the solar panel under controlled conditions. Therefore, the use of a spotlight was chosen because the light spectrum it produces is sufficiently representative to trigger the response of photovoltaic cells, thereby supporting the experimental evaluation of solar panel performance in the laboratory. The solar panel's tilt angle was aligned with the spotlight and fixed in position throughout the testing to ensure consistency. The specifications of the solar panel can be found in Table 1.

Table 1. Solar panel specifications

No	Specifications	Value
1.	Rated power (p _{max})	50 (W)
2.	Voltage at p _{max} (V _{mp})	18 (V)
3.	Current at p _{max} (I _{mp})	2,78 (A)
4.	Open-circuit Voltage (V _{oc})	21,6 (V)
5.	Short-circuit Current (I _{sc})	2,97 (A)
6.	Max System Operating Voltage	1000 DC (V)
7.	Maximum Series fuse rating	10 A
8.	Conversion rate	18,4 %
9.	Standard Test Condition	1000 W/m ² AM 1,5 25°C

The reflectors were made of highly polished aluminum. Two flat reflectors and two concave reflectors were positioned across the width of the solar panel at tilt angles of 55°, 65°, 75°, and 85°. The design and framework are shown in Fig. 1(a) for the flat reflector, Fig. 1(b) for the concave reflector, Fig. 2(a)–(d) for the flat reflector angles, and Fig. 3(a)–(d) for the concave reflector angles



Figure 1. Reflectors (a) flat and (b) concave

This study used a 200-watt floodlight as a stand-in for sunlight. The floodlight was employed to make sure that the light stayed at a steady level. The floodlight was put up above the solar panel. The solar panel and the floodlight were 54 cm apart. The floodlight placed in the middle of the solar panel so that the light would be spread out evenly throughout the panel's surface. To keep the therapy consistent, only one light source was employed during testing. So, it was possible to accurately adjust and monitor the amount of light on the solar panel.

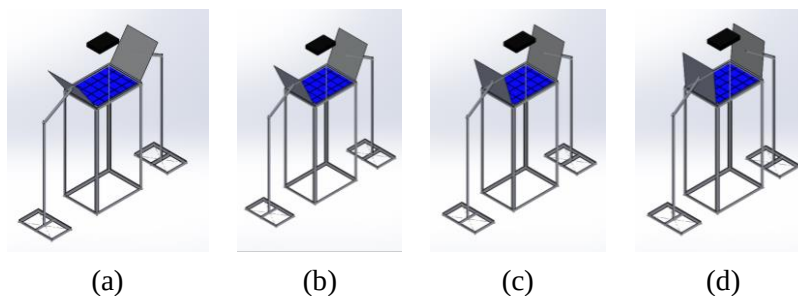


Figure 2. Angles of flat reflectors (a) 55°, (b) 65°, (c) 75°, and (d) 85°

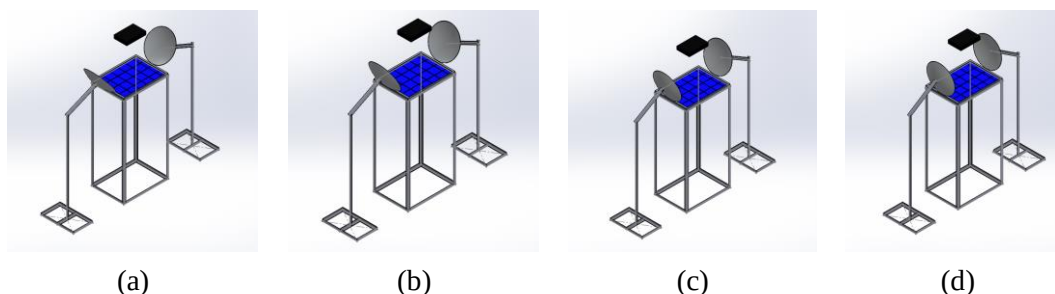


Figure 3. Angles of concave reflectors (a) 55°, (b) 65°, (c) 75°, and (d) 85°

This research measuring tool uses a digital wattmeter to find out how much current and voltage the solar panel was putting out. The solar panel had the solar charge controller on it. Data on current and voltage were collected after 5, 10, and 15 minutes. Light intensity measurement using a luxmeter to check the light level at three different places on the solar panel's surface as can be seen in Fig. 4 (a)-(d). Then, calculate the average light intensity data from the three places to get the final data. Temperature measurements were taken using an infrared thermometer to measure the temperature of the solar panel at three separate points on its surface. The results were then averaged to produce a final data set. Room temperature measurements are made using a special room thermometer to determine how hot the room is. Measurements are taken only once from a location near the solar panel installation site.



Figure 4. Measuring instruments: (a) digital wattmeter, (b) lux meter, (c) infrared thermometer, (d) thermometer

The experimental design in this study consists of main factors, nested factors, blocking factors, response variables, and auxiliary variables. The main factors are reflector shape (flat and concave, without a reflector as the control) and reflector angle (55°, 65°, 75°, 85°, without an angle as the control). The nested factor in this study is the reflector angle, which is nested within the reflector shape. The blocking factors consist of the time of data collection and the duration of light exposure in minutes (5 minutes, 10 minutes, and 15 minutes). The response variables are current and voltage. Finally, there are covariates in the form of room temperature, solar panel temperature, and light intensity.

The testing procedure was conducted under conditions without a reflector to serve as control data. Next, the reflector was installed according to a predetermined shape and angle. The spotlight was turned on, the room temperature was recorded, and the spotlight was left on for a specified duration. Next, record the values of current, voltage, solar panel temperature, and light intensity, then turn off the spotlight. Next, discharge the test results on the battery using a 5 W load. After that, repeat the process with different durations. This entire procedure is repeated for each combination of reflector shape and angle as well as different measurement times. The solar panel output power is calculated using Eq. (1), where P is the solar panel output power (W), V is the output voltage (V), and I is the output current (A). The power value is used as the primary response in the

statistical analysis. Power calculations are performed for each treatment combination and observation time. The power data is then analyzed together with the observed covariate variables.

$$P = V \times I \quad (1)$$

Multivariate analysis is essential in this study because there are two correlated response variables: the current and voltage output of the solar panel. These two variables are interrelated in determining the solar panel's output power and are simultaneously influenced by variations in the reflector's shape and angle. Additionally, this study examines the effects of covariates including solar panel temperature, ambient temperature, and light intensity which may influence the response variables.

Data with a multivariate design were analyzed using multivariate analysis of covariance (MANCOVA), specifically using parametric methods with the R software. If the analysis results did not meet the assumptions of MANCOVA, a non-parametric analysis was performed. The normality assumption for the multivariate results was tested using the MVN package. Subsequently, the assumption of homogeneity of covariance was tested using the covTestR package. Before conducting further analysis, a correlation test between panel output power and various covariates is required. If both the power and covariate data are normally distributed (based on a normality test, e.g., the Shapiro-Wilk test), the Pearson Correlation test is used. If one of the datasets is not normally distributed, the Kendall Rank Correlation test is used. Further analysis was performed univariately using the Generalized Additive Model (GAM) with the assistance of the mgcv package. Univariate tests for the GAM analysis results included the Shapiro-Wilk test for normality and Bartlett's test for homogeneity of variance.

Results and Discussion

1. The Effect of Shape on Solar Panel Output

The results of the tests conducted show that variations in the shape of the aluminum reflector affect the electrical output of the solar panel, as shown in Fig. 5. The solar panel without a reflector produced a current of 0.89111 A, a voltage of 12.008 V, and a power of 10.7 W, while the solar panel with a flat reflector showed an increase in current, voltage, and power to 0.9 A, 12.305 V, and 11.07 W, and the one with a concave reflector showed an increase in current, voltage, and power to 0.8925 A, 12.289 V, and 10.97 W. These increases are caused by the reflectors, which reflect light that does not directly hit the solar panel surface, thereby increasing the light intensity received by the solar panel and simultaneously boosting the panel's output power [19]. This finding corroborates previous research indicating that the incorporation of reflectors onto a solar panel enhances its light absorption, thereby augmenting its output power relative to the absence of reflectors [12]. Flat and concave reflectors help solar panels make more power because they let more light hit the panels. These results show that having a reflector can make solar panels work better without adding more panels or using more energy. This is important for getting the most out of solar panel systems, even though the increase isn't very big.

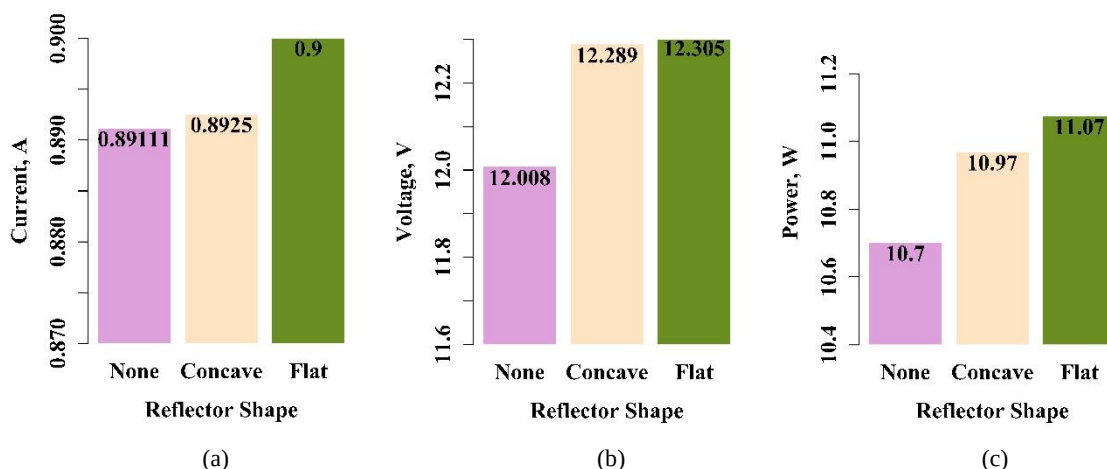


Figure 5. Average test results for variations in (a) current, (b) voltage, and (c) power

2. The Effect of the Angle of a Flat Reflector on Solar Panel Output

Fig. 6 shows that variations in the angle of the flat reflector can affect the output of the solar panel. The largest increase in current occurred at angles of 85° and 55°, while the lowest occurred at an angle of 75°. The highest voltage occurred at an angle of 85° with a value of 12.48 V, and the lowest occurred at an angle of 65° with a value of 12.21 V. Regarding the solar panel's output power, a significant change occurred at an angle of 85°, while the smallest change occurred at an angle of 75°. These findings indicate that the use of a reflector

to increase light intensity can reflect a greater amount of light onto the solar panel surface, thereby effectively increasing the voltage and power output of the solar panel, however, there is no significant change in current. Physically, the increase in solar panel output due to additional reflection from the reflector's surface aligns with the reflector's operating principle of maximizing the number of photons reaching the panel, thereby increasing the voltage and output power of the solar panel [20]. These findings demonstrate that the use of reflectors at specific angles plays a crucial role in enhancing solar panel output power, as the reflector's orientation determines the effectiveness of light concentration received by the solar panel. The 85° angle demonstrates a higher solar panel output, making it a key design parameter in the development of reflector-based solar panel systems.

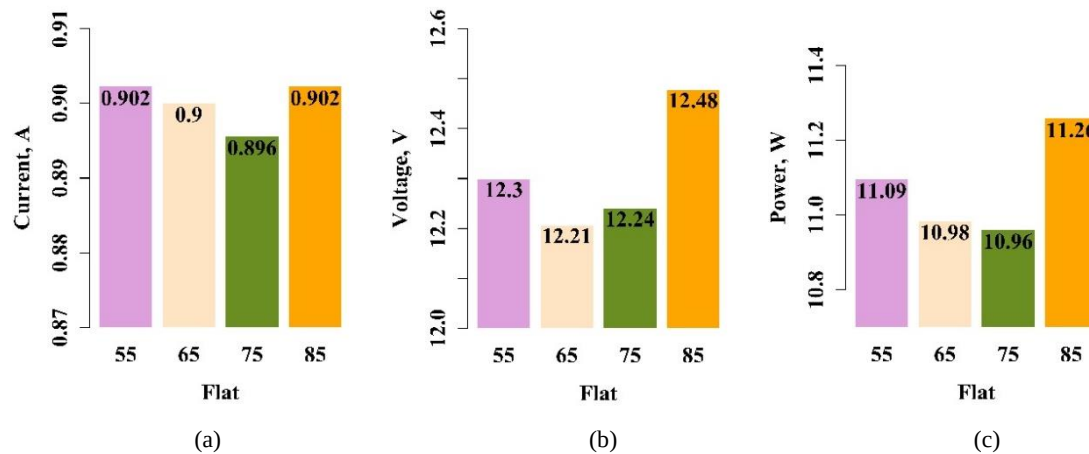


Figure 6. Average test results for different angles on a flat surface: (a) current, (b) voltage, and (c) power

3. The Effect of the Concave Reflector Angle on Solar Panel Output

The test for concave reflectors at different angles is shown in Fig. 7. The current values are not very different from 0.89 A, no matter how you look at it. The other tests show that the voltage and power levels have changed. At 75°, the voltage was 12.4 V, which was the highest, and at 55°, it was 12.22 V, which was the lowest. At 75°, the most power was 11.03 W, and at 55°, it was 10.91 W. This phenomenon the variation in voltage and power values is caused by the reflection of light intensity by the concave reflector, resulting in varying numbers of photons received by the solar panel and consequently affecting the output. These results demonstrate that the use of a concave reflector can produce more focused light concentration on specific areas, thereby potentially increasing solar panel output. This finding indicates that the relationship between the reflector's shape and angle is a critical factor in enhancing solar panel output.

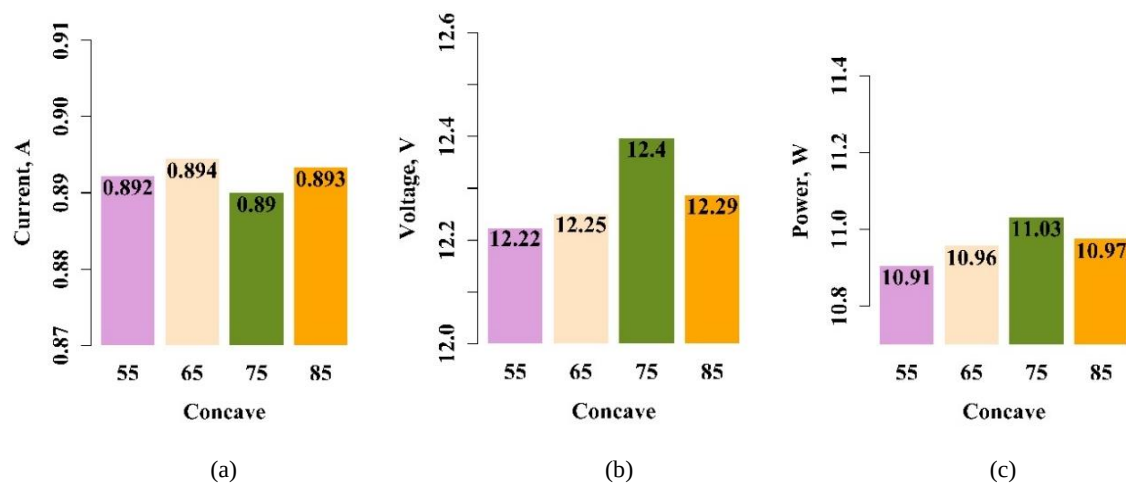


Figure 7. Average test results for different angles on the concave shape: (a) current, (b) voltage, and (c) power

4. MANCOVA Results

The results of the test using Multivariate Analysis of Covariance indicate that the independent variables and covariates simultaneously have a significant effect on solar panel output, as shown in Fig. 8. The reflector shape, reflector angle, test duration, solar panel temperature, and light intensity have a very significant influence on solar panel output, with the reflector shape exhibiting the most dominant influence based on the

trace value of 0.90198, which is greater than the other influences, this proves that the addition of a reflector has a stronger contribution to increasing solar panel output. The test duration value of 0.64547 and the interaction between reflector shape and angle of 0.64124 have significant effects, indicating that improvements in solar panel performance are not solely determined by thermal factors or light intensity but are also strongly influenced by the reflector's geometric configuration. Other factors also have an influence but are not as significant, such as ambient temperature, which indicates that thermal conditions play a crucial role in solar panel performance and the duration of illumination, while panel temperature and light intensity continue to have a significant influence on solar panel output as covariates. The results obtained regarding the interaction between the reflector's shape and angle show a significant effect on solar panel output, indicating that reflector effectiveness is determined by the combination of these two parameters in increasing the light intensity received by the solar panel. Overall, these results indicate that reflector optimization must consider operational environmental factors to achieve optimal solar panel output and demonstrate that the design of reflector-based solar panel systems needs to prioritize reflector geometry as a primary design parameter alongside thermal factors to achieve a more efficient and optimal configuration.

Df	Pillai approx	F num	Df den	Df	Pr(>F)
Shape	2	0.90198	26.6975	4	130 3.584e-16 ***
Minute	2	0.17692	3.1540	4	130 0.016394 *
Time	2	0.64547	15.4871	4	130 2.194e-10 ***
T.Panel	1	0.31677	14.8364	2	64 5.083e-06 ***
T.Room	1	0.13549	5.0151	2	64 0.009477 **
Intensity	1	0.25709	11.0740	2	64 7.412e-05 ***
Shape:Angle	6	0.64124	5.1126	12	130 5.930e-07 ***
Residuals	65				

Signif. codes:	0	****	0.001	***	0.01 ** 0.05 . 0.1 ' '

Figure 8. MANCOVA Results

4.1. The Effect of Solar Panel Temperature on Solar Panel Output Power

The test results, which looked at the relationship between solar panel output power and solar panel temperature, show a negative relationship. This is clear from the data distribution and the linear regression line that goes down in Fig. 9. The output power of a solar panel goes down as the temperature of the panel goes up. This shows that the temperature of the panel has an effect on how well it works. In these conditions, a big rise in panel temperature causes the output voltage to drop because the carriers recombine more and the semiconductor material's internal resistance rises. This lowers the maximum power the panel can produce. This finding is in line with earlier studies that found that higher operating temperatures lower energy conversion efficiency and slowly lower output power [21]. Other research has also shown that temperature affects the voltage drop of solar panels the most, which directly lowers the maximum power of the solar panel system [22]. So, the results of this test back up what has been said before: controlling the temperature of the panels is very important for keeping solar power systems running at their best.

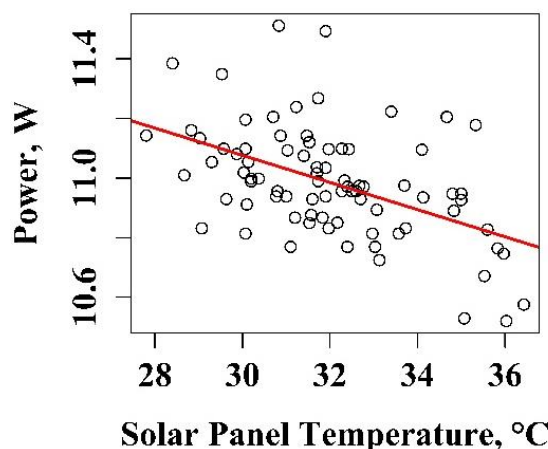


Figure 9. Correlation graph between solar panel output power and panel temperature

Based on the results of the correlation test between solar panel power output and solar panel temperature using Pearson's Product-Moment Correlation method, as shown in Fig. 10. Given that the data on solar panel power output and solar panel temperature are normally distributed. The results obtained were a t-value of -5.0002, df of 79, p of 3.38×10^{-6} , and a correlation coefficient of -0.4903026. Since the p-value obtained is less than 0.05, the test results indicate that there is a significant relationship between solar panel output power and solar panel temperature.

```
Pearson's product-moment correlation

data: Power and T.Panel
t = -5.0002, df = 79, p-value = 3.38e-06
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
-0.6401223 -0.3045584
sample estimates:
cor
-0.4903026
```

Figure 10. Results of the correlation test between solar panel output power and panel temperature

4.2. The Effect of Ambient Temperature on Solar Panel Output Power

Test results obtained using a correlation analysis between solar panel output power and ambient temperature indicate that ambient temperature has a negative effect on solar panel output power, as evidenced by the data distribution and the downward-sloping linear regression line in Fig. 11. As ambient temperature increases from the lowest value of 28 °C to the highest of 34 °C, power output decreases, indicating that environmental conditions can affect solar panel performance. The effect of ambient temperature on power output is indirect; however, it can influence the temperature of the solar panel itself, thereby accelerating the decline in the panel's output voltage and power output. This leads to increased carrier recombination and internal resistance within the semiconductor material. This phenomenon suggests that an increase in ambient temperature worsens the thermal conditions of the solar panel, leading to a decrease in system efficiency and power output [21]. Other findings also indicate that the effect of ambient temperature on panel performance is primarily manifested through an increase in solar panel temperature, which subsequently reduces the system's maximum voltage and power [22]. Therefore, these findings indicate that controlling ambient thermal conditions is a critical factor in maintaining the stability of solar panel output.

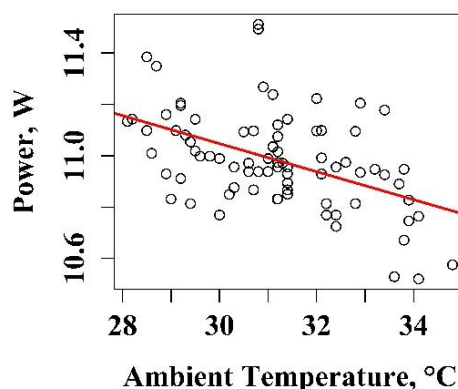


Figure 11. Correlation graph between solar panel output power and room temperature

Based on the results of the correlation test between solar panel output power and room temperature using Pearson's Product-Moment Correlation method, as shown in Fig. 12. Given that the data on solar panel output power and room temperature are normally distributed. The results obtained were a t-value of -4.867, df of 79, p of 5.681×10^{-6} , and a correlation coefficient of -0.4803234. Since the p-value obtained is less than 0.05, the test results indicate that there is a significant relationship between solar panel output power and room temperature.

```
Pearson's product-moment correlation

data: Power and T.Room
t = -4.8675, df = 79, p-value = 5.681e-06
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
-0.6323527 -0.2926686
sample estimates:
cor
-0.4803234
```

Figure 12. Results of the correlation test between solar panel output power and room temperature

4.3. The Effect of Light Intensity on Solar Panel Output Power

The results obtained from a correlation test between solar panel output power and light intensity indicate a positive relationship, as evidenced by the data distribution following an upward-sloping linear regression line, as shown in Fig. 13. An increase in light intensity also increases solar panel output power, indicating that the amount of light radiation received by the solar panel surface directly affects the panel's output power. Physically, an increase in light intensity increases the number of photons absorbed by the semiconductor material of the solar panel, thereby increasing electron excitation and the resulting photocurrent, which

ultimately increases the solar panel's output power. This finding aligns with previous research stating that an increase in light intensity can boost the power output of solar panels in both field tests and simulations [23]. Other studies have also shown that light intensity is a critical environmental parameter affecting solar panel performance, where variations in light intensity positively correlate with power output due to the increased number of photons available for energy conversion [24].

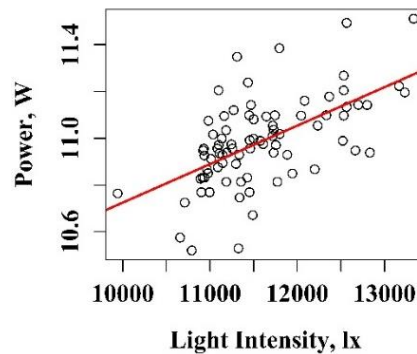


Figure 13. Correlation graph between solar panel output power and light intensity

Based on the results of the correlation test between solar panel output power and light intensity using Kendall's rank correlation tau method, as shown in Fig. 14, the solar panel output power data is normally distributed, but the light intensity data is not normally distributed. The results obtained were a z-value of 5.6302, a p-value of 1.8×10^{-8} , and a correlation coefficient of -0.4803234. Since the p-value obtained was less than 0.05, the test results indicate that there is a significant relationship between solar panel output power and light intensity.

```
Kendall's rank correlation tau

data: Power and Intensity
z = 5.6302, p-value = 1.8e-08
alternative hypothesis: true tau is not equal to 0
sample estimates:
tau
0.4283094
```

Figure 14. Results of the GAM test for various shapes

4.4. Test of Shape Variation Based on the Generalized Additive Model

Fig. 15 shows the results of The GAM test for various shapes, indicating that the shape of the reflector has a significant effect on the output power of the solar panel. The concave reflector has a positive coefficient of 0.1656 ($p = 0.00141$), and the flat reflectors have a higher effect with a coefficient of 0.2891 ($p < 0.001$). This means that both types of reflectors increase output power compared to the condition without a reflector, with flat reflectors having a very strong effect on solar panel output power. The test time and duration variables also do not have a significant effect ($p > 0.05$). These results show that changing the shape of the reflector is a major factor in increasing the power output of solar panels. The test time and duration in this study did not have a big effect.

```
Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  10.789876  0.068472  157.580 < 2e-16 ***
ShapeConcave  0.165618  0.049678   3.334  0.00141 **
ShapeFlat     0.289110  0.051155   5.652  3.63e-07 ***
MinuteM10     0.009137  0.044680   0.204  0.83860
MinuteM15     0.014742  0.052179   0.283  0.77842
TimeMorning   -0.040903  0.071201  -0.574  0.56759
TimeAfternoon -0.003882  0.065467  -0.059  0.95290
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 15. Results of the GAM test for various shapes

4.5. Testing Variations in the Angle of a Flat Reflector Based on the Generalized Additive Model

Fig. 16 shows the results of the GAM test at various angles with a reflector, indicating that changing the angle of the flat reflector does not affect the amount of power generated by the solar panel. At 75° , the effect is very bad, with a coefficient of -0.2980 ($p = 0.0138$). This means that the 75° angle gives off less power than the other angles. At 65° , the power output is the second lowest, with a coefficient of -0.092172 ($p =$

0.0996). The 85° angle doesn't make a difference. The time and duration variables of the test are not very different. These results show that changing the angle of the reflector doesn't change the output power much in a straight line. The solar panel only works well at certain angles.

Parametric coefficients:					
	Estimate	Std. Error	t value	Pr(> t)	
(Intercept)	11.11845	0.10374	107.174	<2e-16	***
Angle65	-0.09272	0.05421	-1.710	0.0996	.
Angle75	-0.29804	0.11248	-2.650	0.0138	*
Angle85	-0.03144	0.17113	-0.184	0.8557	
MinuteM10	0.06791	0.07949	0.854	0.4011	
MinuteM15	0.10589	0.09859	1.074	0.2930	
TimeMorning	-0.16436	0.07993	-2.056	0.0503	.
TimeAfternoon	0.17352	0.10436	1.663	0.1089	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Figure 16. Results of the GAM test at various angles on a flat surface

4.6. Testing Variations in the Angle of a Concave Reflector Based on the Generalized Additive Model

Fig. 17 shows the results of GAM tests at various angles using a concave reflector, indicating that changing the angle of the concave reflector has a similar effect on the solar panel's output power. The 75° angle has a very strong positive effect, with a coefficient of 0.11507 ($p = 0.00631$). This means that the 75° angle has the most power of all the angles. With a coefficient of 0.03814 ($p = 0.04277$), the second highest power output is at an angle of 65°. The 85° angle, on the other hand, doesn't make much of a difference. The time and length of the test variables were not very different. In general, these results show that certain angles of reflectors, especially 65° and 75°, can statistically boost the output power of solar panels. Changes in the time and length of the test do not seem to matter.

Parametric coefficients:					
	Estimate	Std. Error	t value	Pr(> t)	
(Intercept)	10.92959	0.05663	192.998	< 2e-16	***
Angle65	0.08168	0.03814	2.142	0.04277	*
Angle75	0.11507	0.05173	2.998	0.00631	**
Angle85	0.12334	0.10215	1.207	0.23925	
MinuteM10	-0.06814	0.04605	-1.480	0.15220	
MinuteM15	-0.09783	0.05686	-1.721	0.09841	.
TimeMorning	0.01966	0.06180	0.318	0.75320	
TimeAfternoon	-0.01034	0.05571	-0.186	0.85440	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Figure 17. Results of the GAM test at various angles on a concave shape

Conclusion

Based on the results obtained, the use of aluminum reflectors increases the power output of solar panels compared to systems without reflectors, and the use of flat reflectors yields the most optimal results compared to concave reflectors. Various angles analyzed yielded better output responses, particularly 85° for flat reflectors and 75° for concave reflectors, indicating that solar panel output optimization is influenced by the combination of reflector shape and angle. MANCOVA results demonstrate that reflector shape is a highly significant factor influencing solar panel power output, accompanied by interaction effects between reflector shape and angle, as well as covariates such as panel temperature, ambient temperature, and light intensity. Correlation analysis confirms that the relationship between panel temperature and room temperature is negative with respect to solar panel output power, while light intensity is positive, underscoring the importance of thermal and radiative factors on solar panel performance. The GAM test results confirm that the use of reflectors, particularly flat reflectors, is a key parameter in increasing solar panel power output. Overall, the analysis indicates that the use of reflectors can increase solar panel power output, while controlling thermal factors has the potential to reduce solar panel power output.

CrediT authorship

Nur Zaini Khafid: Conceptualization, Methodology, Investigation, Writing — Original Draft, dan Result Analysis. **Aqli Mursadin:** Formal Analysis, Data Curation, Visualization, Statistics, Supervision, dan Validation. **Sopyan Ali Rohman:** Methodology, Investigation, Writing — Review and Editing, Supervision, dan Validation.

Declaration of Competing Interest

The authors declare no competing interests.

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