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Geometrical Solar Panel Reflectors Using Galvanized Iron Sheets

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Abstract

Solar panels are widely used in the Philippines to collect solar energy. To minimize deflection of sunrays on panels, reflectors are incorporated. The existing reflectors are the planar reflectors. Because of concerns in cost and availability, a need to find an alternative reflector arises. In this study, the galvanized iron (GI) sheets were used as reflectors attached in the four sides of the existing solar panels. The shapes of the reflectors as used in the experiments were rectangular, triangular, and parabolic. Experiment results have shown that for optimum performance, the tilt angle of the reflector with respect to the vertical axis of the panel must be 70° and the solar panel must be always perpendicular to the solar source. Any of the three reflector shapes can be used since there exists no significant difference on the output voltages at any time of the day. With the usage of the GI sheet as reflectors, the output voltage has increased up to 23.09% in average as compared to the set up with no reflector. The utilization of GI sheet as reflectors has advantages over the planar reflectors on costs and availability since GI sheets can be easily bought in any hardware store in the Philippines.

***Keywords**:* solar reflector, solar tracker, reflector shapes, GI sheet reflector, reflector tilt angle

1. Introduction

Solar energy is a useful form of energy in this present century (Aziz *et al.*, 2017). Solar panels are widely used in the Philippines because of high insolation. To maximize the presence of sunlight, panels are installed in solar trackers. However, the deflection of sunrays on solar panels reduces its output power (Yang *et al.*, 2017). Reflectors must be incorporated to address this problem. In principle, the reflector's shape and its tilt angle affect the efficiency of the solar panel (Kim *et al.*, 2012). The usual reflectors incorporated in solar panels were mirrors. Due to cost and accessibility issues of mirrors in the Philippines, there is a need to find alternative materials to be used as reflectors in solar panels. In this study, the GI sheets were used as reflectors.

Several related literatures and studies had been reviewed. The surface deflection of the sunrays in panels reduced its efficiency (Bentaher *et al.*, 2014). Solar panels must be perpendicular to the sun using solar trackers. However, diffuse reflection still existed because of the unevenness in the surface of the panels. To minimize losses of solar energy due to diffuse reflection, planar reflectors must be incorporated (Dang, 1985). According to Baccoli *et al.* (2015), the simplest and cheapest way of maximizing the solar energy flux incident on the collector surface was to integrate planar reflectors. It was also found out that when the reflector was added in solar panels, the optimum tilt angle has varied on a seasonal basis. The study conducted by Garg and Hrishikesan (1988) pinpointed that the optimum inclination of the reflectors was obtained in March, June, and December. This happened when the collector inclination was horizontal or equal to the latitude of its location. Kostic *et al.* (2010) reported that the optimum inclination of the reflectors was obtained when the collector inclination is fixed at 45°N. For a conventional system, the optimum tilt angle has varied depending on the season.

The reflectors are considered as vital elements in concentrating solar energy to the panels. An important characteristics of reflectors is the durability (Garcia *et al.*, 2016). However, one of the critical aspects in characterizing the behavior of the solar reflector is its capability to focus the incoming light rays to the solar panels (Alcañiz *et al.*, 2015). According to Breeze (2016), the reflection of solar energy from the reflector to the solar panel increased the efficiency of the panels. The study of Sharaf *et al.* (2016) emphasized that the gain of solar energy from tracking the sun was about 39% in cold cities and the gain in energy did not exceed 8% in hot cities due to overheating of the solar panels.

The studies as reviewed focused more on the effects of the planar reflectors as installed in solar trackers. The integration of these planar reflectors in the existing solar panels offered an improvement in the efficiency. The optimum tilt angles of the planar reflectors in seasonal basis were determined. However, no study as reviewed has been made on the evaluation of the reflectors made from galvanized iron sheets considering different geometrical shapes like rectangular, triangular, and parabolic. In the existing systems as investigated, mirrors were utilized as planar reflectors. But in this study, instead of mirrors, locally available GI sheets were used as reflectors. The main purpose of this is to evaluate if the utilization of GI sheets as reflectors offer significant increase in the output voltage of the solar panels. Also, this study aims to find out the best geometric shape of reflectors to be incorporated in solar panels.

2. Methodology

In this study, galvanized iron sheets were used as reflectors incorporated to the polycrystalline solar panel. Instead of using a mirror as a reflector, a galvanized iron sheet was used since it was cheaper and available in the Philippine hardware store. Galvanized iron sheets are highly reflective materials for solar energy. For the experiments, the three different geometrical shapes of the reflectors were evaluated as to the produced output voltages at the output of the solar panel. These were the rectangular, parabolic, and triangular shapes as shown in Figures 1, 2, and 3. A calibrated digital voltmeter was used to measure the output voltages of each of the reflector types.

The experiments were performed in the three different locations within Cebu, Philippines. The locations were the following: Cebu City (latitude of 10.2966° and longitude of 123.9061°), Mandaue City (latitude of 10.3334 and longitude of 123.9500), and Lapu-Lapu City (latitude of 10.2578 and longitude of 123.9443). These experiments were conducted during sunny days.

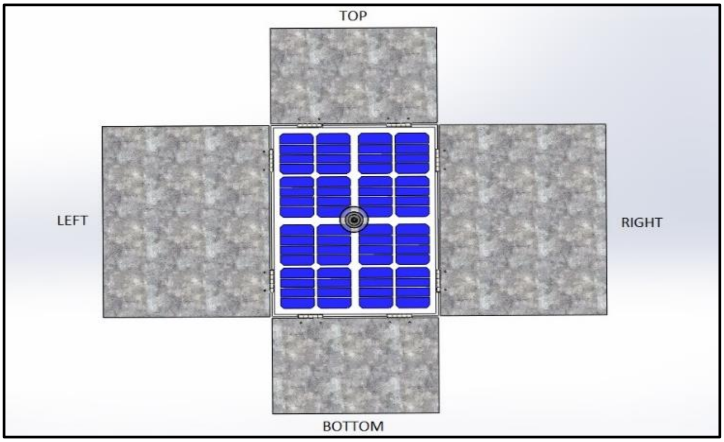

Figure 1. Top view of the solar panel with rectangular reflectors

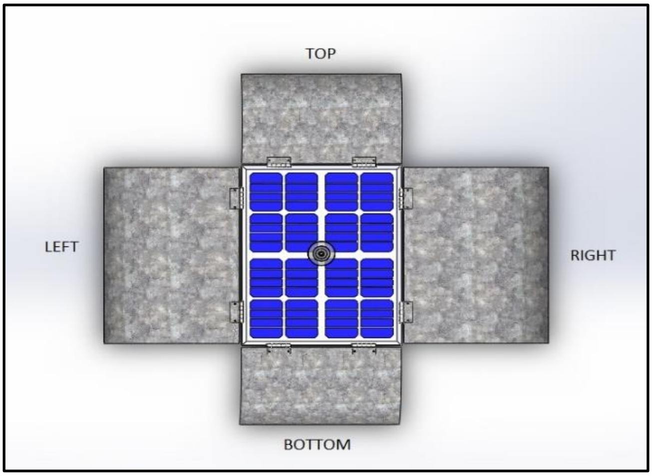

Figure 2. Top view of the solar panel with parabolic reflector

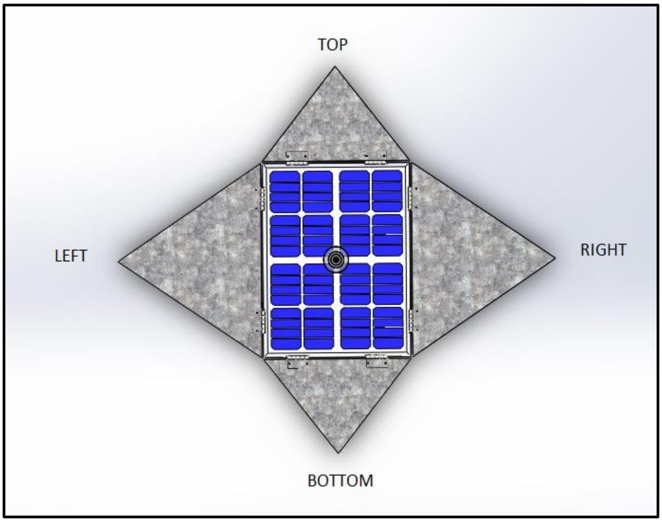

Figure 3. Top view of the solar panel with triangular reflector

2.1 Indoor Variable Reflector Tilt Angle Test

This test was conducted in an indoor environment with no other light source except the 500-W lamp which served as the solar simulator. It was placed above the solar panel at a distance of 1.5m. The tilt angle of the reflector was then made variable with respect to the lamp. For each of the reflector tilt angle, the corresponding output voltage of the solar panel was then recorded. This set up was done for the three types of reflectors. The purpose of this experiment was to determine the best tilt angle orientation of the reflector with respect to the solar simulator. The illustrations of the experiments were shown in Figures 4, 5, and 6. The sample picture taken during the experiments was shown in Figure 7.

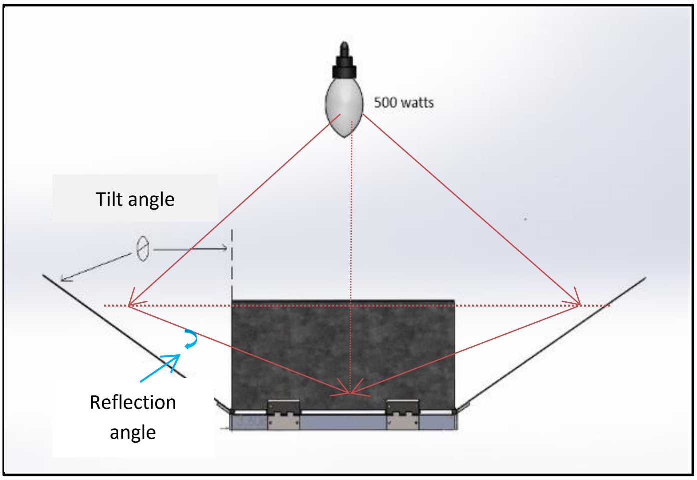

Figure 4. Setup for variable tilt angle test using rectangular reflector

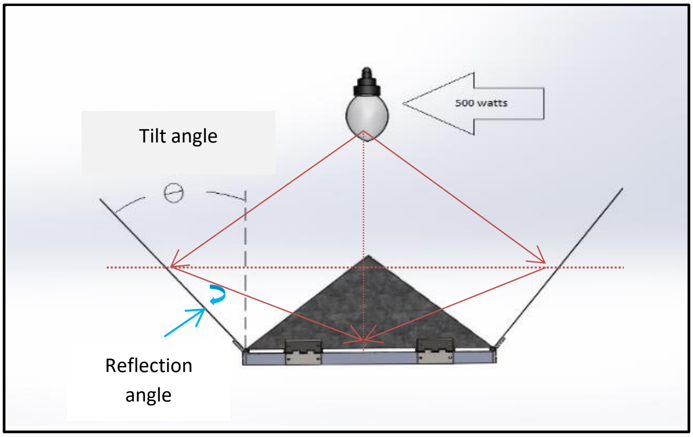

Figure 5. Setup for variable tilt angle using triangular reflector

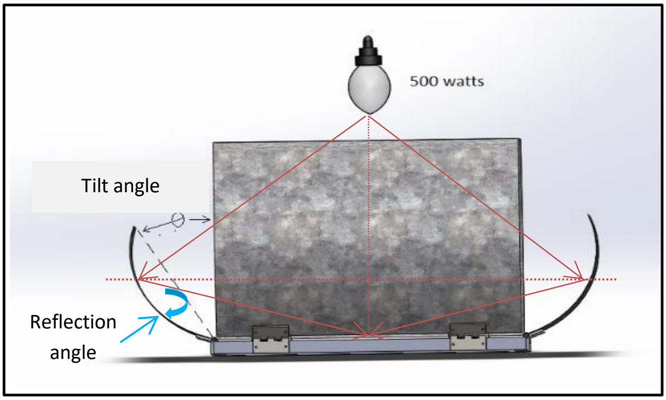

Figure 6. Setup for variable tilt angle using parabolic reflector

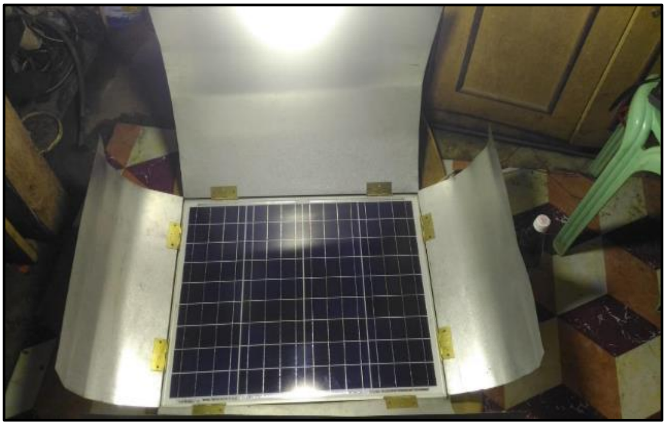

Figure 7. Sample picture taken during the actual experiment of indoor variable reflector tilt angle test inside a house in Mandaue City

2.2 Indoor Variable Lamp Angle Test

The reflector tilt angle was fixed at the best angle orientation as obtained in the indoor variable reflector tilt angle test. At this time, it was the lamp angle which was varied with respect to the vertical at 0°, 30°, and 60° respectively. This set-up was used for the 3 types of reflectors and with no reflector. The corresponding output voltages were measured and were recorded. The purpose of this experiment was to determine the best lamp angle orientation with respect to the solar panel in terms of obtaining the highest output voltage. The illustrations of the experiments were shown in Figures 8, 9, 10, and 11.

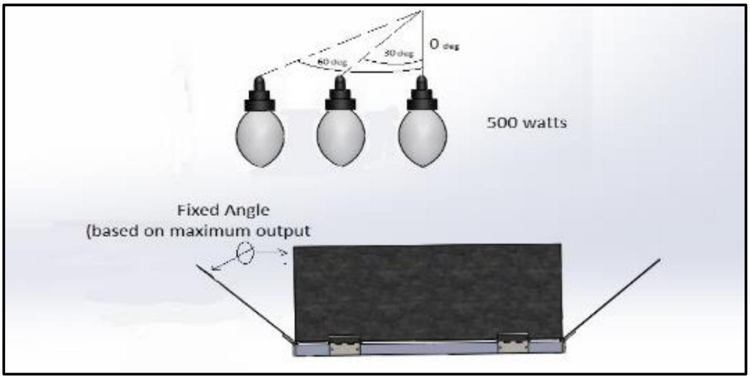

Figure 8. The setup for the variable lamp angle test using rectangular reflector

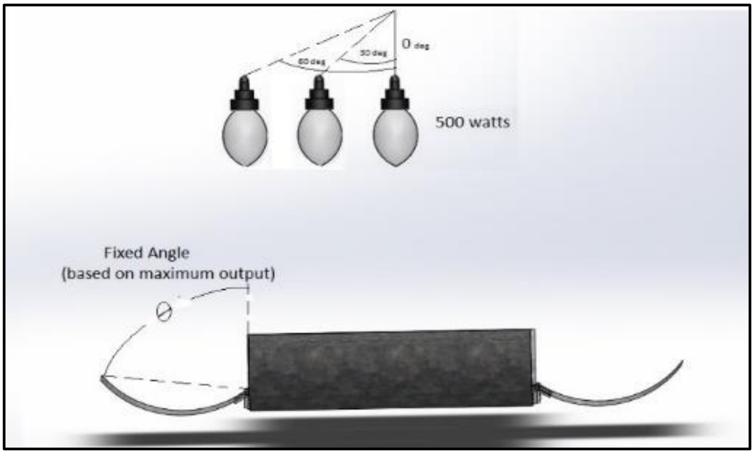

Figure 9. The setup for the variable lamp angle test using a parabolic reflector

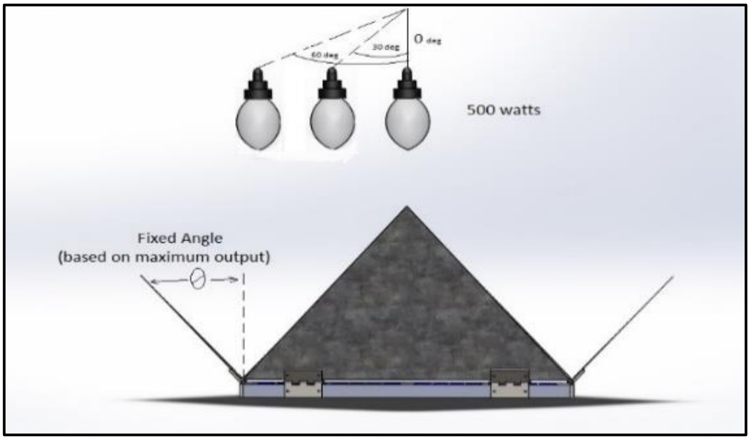

Figure 10. The set-up for the variable lamp angle test using a triangular reflector

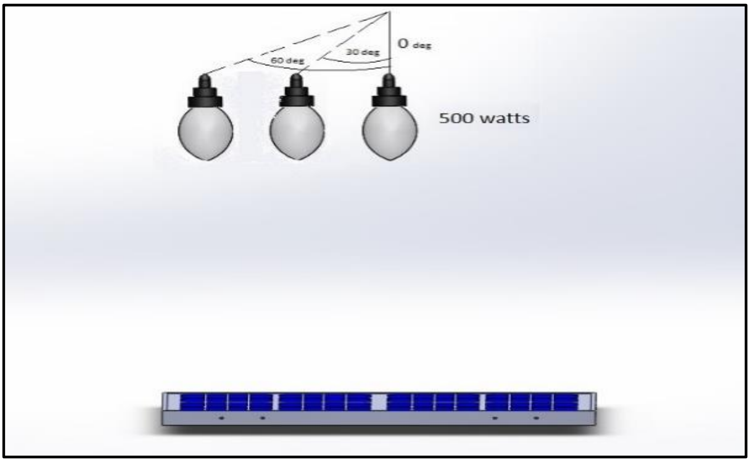

Figure 11. The setup for the variable lamp angle test with no reflector

2.3 Outdoor Solar Test

This test was conducted in the outdoors with no physical obstruction of sunlight and during sunny days. The reflector tilt angle was fixed at the optimum angle as obtained in the variable reflector tilt angle test. As based on the results of the variable lamp angle test, the solar panel was oriented in perpendicular with the sun in all reflector types. This was done by mounting the solar panel on the flat ground surface free from any sunlight obstruction using a try square to ensure flatness of the ground. A bevel protractor was then used to ensure that the mounted solar panel was always facing the sun at 90° angle with respect to the panel. In every hour interval, the tilt angle of the solar panel was adjusted using the bevel protractor such that it was perpendicular with the sun. The set-up was used for the three types of reflectors and with no incorporated reflector. The measurements and recordings were made in every 1-hour interval from 6:00AM to 6:00PM in the three different locations. The purpose of this test was to determine the best reflector type to be incorporated in solar panels in terms of obtaining the highest output voltages. Equation 1 was used in computing the percent increase in the output voltage for each of the reflector types with respect to solar panel with no reflector considering the values at 12NN. The experiments were shown in Figures 12, 13, and 14. The actual picture taken during the actual experiment was shown in Figure 15.

$$\% \ Vincrease = \frac{Vref\text{-}Vnoref}{Vnoref} \text{x } 100 \quad (1)$$

where:

Vref = output voltage with reflector, V
Vnoref = output voltage with no reflector, V

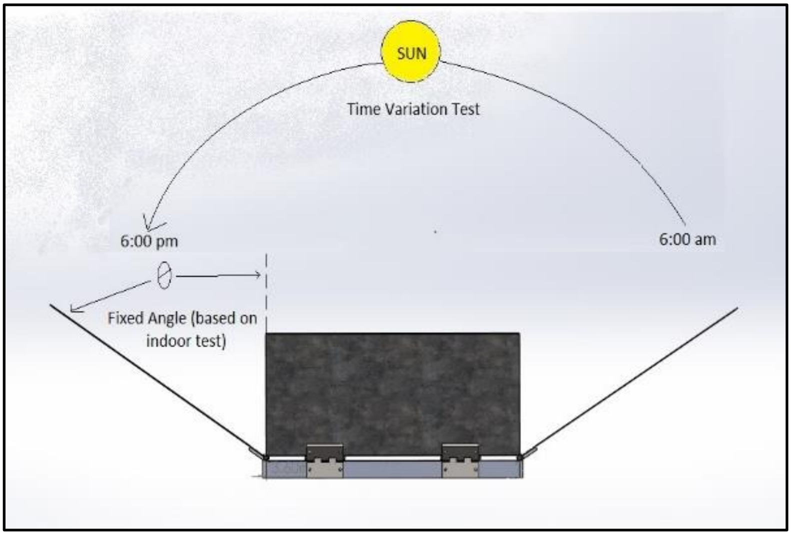

Figure 12. The setup of outdoor solar test using a rectangular reflector

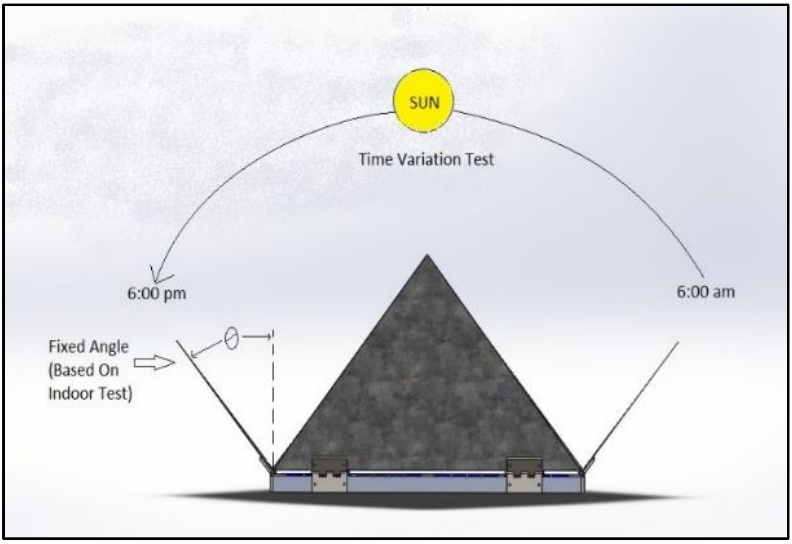

Figure 13. The setup of outdoor solar test using a triangular reflector

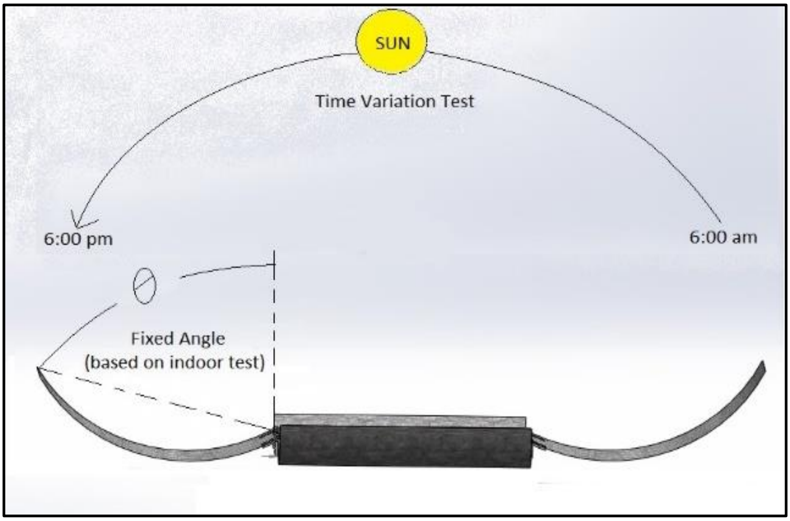

Figure 14. The setup of outdoor solar test using a parabolic reflector

Figure 15. Sample picture taken during the actual experiment of outdoor solar test as conducted in Cebu City

3. Results and Discussion

3.1 Indoor Variable Reflector Tilt Angle Test

The output voltages of the different reflector types for each of the tilt angles were tabulated in Table 1. The same output voltages were plotted in Figure

16. Though the rectangular reflector has the highest values of output voltages, the difference in readings between the lowest and highest values was 2.24V. This was 16.75% of the average value of 13.37V. However, using Analysis of Variance (ANOVA) for the values obtained of the different reflectors; the p-value was 0.305. This means that there exists a small significant difference of the output voltages for the different types of reflectors. Moreover, the tilt angle with the highest value of the output voltage for the three types of reflectors was 70º with respect to the vertical axis. This means that the reflector to be incorporated in the existing solar panel must be oriented at 70° with respect to the vertical in order to obtain the highest possible output voltage.

Table 1. Results of the variable reflector tilt angle test using the three reflectors

Tilt Angle	Rectangular	Triangular	Parabolic
0°	12.83V	12.60V	12.37V
5°	12.99V	12.63V	12.47V
10°	13.05V	12.78V	12.58V
15°	12.87V	12.79V	12.60Vs
20°	13.38V	12.78V	12.54V
25°	13.41V	12.81V	12.81V
30°	13.53V	12.91V	12.88V
35°	13.56V	12.97V	12.97V
40°	13.64V	13.05V	13.04V
45°	13.81V	13.06V	13.23V
50°	14.04V	13.02V	13.19V
55°	14.29V	13.67V	13.75V
60°	14.40V	13.64V	13.78V
65°	14.53V	13.85V	13.91V
70°	14.61V	14.14V	14.09V
75°	14.34V	13.63V	13.98V
80°	14.26V	13.38V	13.88V
85°	14.06V	13.27V	13.23V
90°	13.74V	13.16V	13.44V

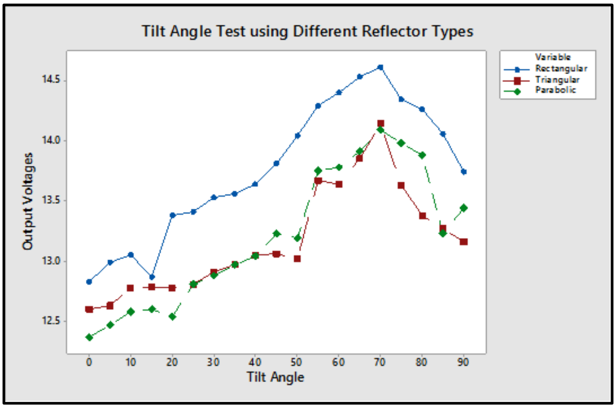

Figure 16. Scatterplot diagram of the variable reflector tilt angle test using the different reflectors

3.2 Indoor Variable Lamp Angle Test

Using the indoor condition for lamp angle test, the results were tabulated in Table 2. The three lamp angles were 0º, 30º, and 60º with respect to the vertical and the corresponding output voltages were shown in Figure 17. For the four reflector conditions, the highest output voltage was obtained when the lamp angle is 0º with respect to the vertical. This means that for optimum results, the solar panel must be always perpendicular with the solar source.

Table 2. Results of the indoor variable lamp angle test using the different reflector type and no reflector

Lamp Angle	No Reflector	Parabolic	Rectangular	Triangular
0°	11.23V	13.78V	13.79V	13.90V
30°	11.06V	13.55V	13.39V	13.61V
60°	10.78V	13.16V	12.44V	13.20V

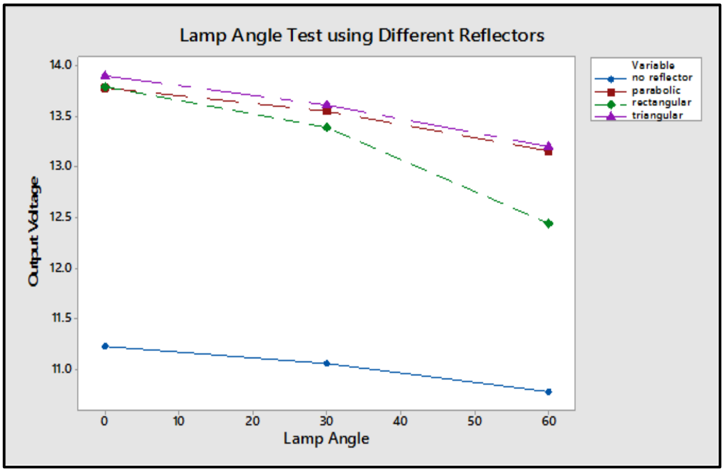

Figure 17. Scatterplot diagram of the results of the variable lamp angle test

3.3 Outdoor Solar Test

At the different times of the day in the three different locations within Cebu, the output voltages for the different reflector types were recorded in Table 3. The highest value of the output voltages was obtained at 12NN for all types of reflectors and the lowest was obtained at 6PM when the sun was out of sight. As noted, there exist significant differences in the readings as shown in Table 4. Moreover, an abrupt decrease in the output voltages was obtained between 4PM to 6PM as shown in Figure 18. Computing the percent increase in the output voltage for each of the reflector types with respect to solar panel with no reflector considering the values at 12NN, the results were shown in Table 5. By incorporating any reflector type to the existing solar panel, the output voltage increased by an average of 23.09% for reflectors positioned at 70º with respect to the vertical and the sun was perpendicular to the solar panel. Moreover, these output voltages using reflectors can be compared to the simulated photovoltaic (PV) module curve for a 10W polycrystalline crystal with no reflector by Giraldo *et al*. (2016) as shown in Figure 19. It was noted that the readings obtained using any of the reflector types were very close to the maximum expected output voltage of the solar panel which is the so-called open circuit voltage (Voc).

Table 3. Results of the solar outdoor test at different times of the day

Time of the Day	No Reflector, V	Parabolic Reflector, V	Triangular Reflector	Rectangular Reflector, V
6:00 AM	13.18V	18.79V	18.58V	18.73V
7:00 AM	13:59V	19.11V	18.93V	18.97V
8:00 AM	13.86V	19.15V	19.20V	19.18V
9:00 AM	14.39V	19.36V	19.11V	19.49V
10:00 AM	14.83V	19.59V	19.12V	19.49V
11:00 AM	15.24V	19.74V	19.16V	19.66V
12:00 PM	15.38V	19.93V	19.36V	19.53V
1:00 PM	15.24V	19.05V	18.92V	19.24V
2:00 PM	15.09V	19.05V	18.89V	19.03V
3:00 PM	14.51V	18.99V	15.52V	18.35V
4:00 PM	13.64V	16.20V	15.73V	17.75V
5:00 PM	8.79V	11.14V	11.75V	14.07V
6:00 PM	2.24V	4.32V	4.64V	4.16V

Table 4. Results of the solar outdoor test at different times of the day

Time of the Day	No Reflector, V	Voltage Difference (Parabolic)	Voltage Difference (Triangular)	Voltage Difference (Parabolic)
6:00 AM	13.18V	+5.61V	+5.40V	+5.55V
7:00 AM	13:59V	+5.52V	+5.34V	+5.38V
8:00 AM	13.86V	+5.29V	+5.34V	+5.32V
9:00 AM	14.39V	+4.97V	+4.72V	+5.10V
10:00 AM	14.83V	+4.76V	+4.29V	+4.66V
11:00 AM	15.24V	+4.50V	+3.92V	+4.42V
12:00 PM	15.38V	+4.55V	+3.98V	+4.15V
1:00 PM	15.24V	+3.81V	+3.68V	+4.00V
2:00 PM	15.09V	+3.96V	+3.80V	+3.94V
3:00 PM	14.51V	+4.48V	+1.01V	+3.84V
4:00 PM	13.64V	+2.56V	+2.09V	+4.11V
5:00 PM	8.79V	+2.35V	+2.96V	+5.28V
6:00 PM	2.24V	+2.08V	+2.40V	+1.92V
Average	13.07V	+4.19V	+3.76V	+4.44V

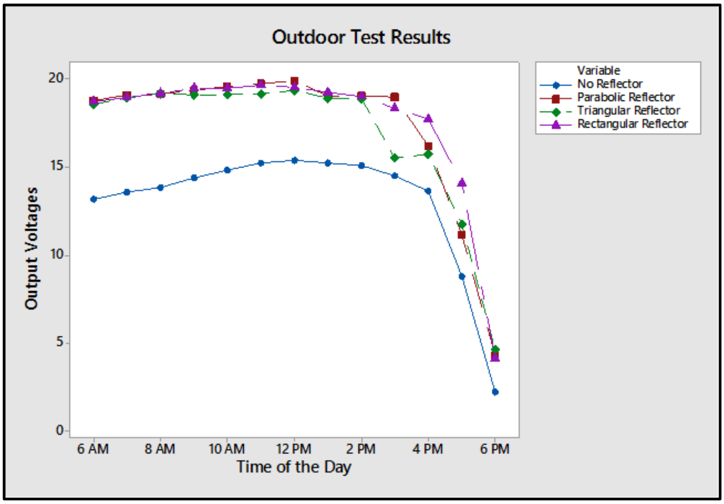

Figure 18. Scatterplot diagram of the outdoor test results recorded at different times of the day

Table 5. The percentage increase in the output voltages for the different reflector types

Reflector Type	% Vincrease
Rectangular	22.79%
Triangular	23.78%
Parabolic	22.71%

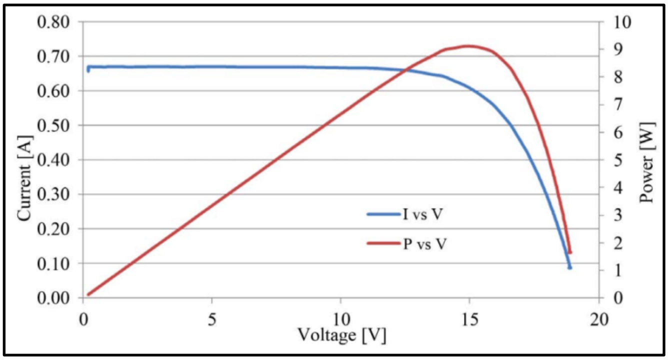

Figure 19. The PV model IV curve of 10W polycrystalline solar panel (Giraldo *et al*., 2016)

4. Conclusion and Recommendation

The integration of the galvanized iron sheets as reflectors to the existing solar panels increased the output voltage by an average of 23.09%. For the system to obtain the optimum results, the galvanized iron reflector must be fixed to the four corners of the solar panel at a tilt angle of roughly 70° with respect to the vertical axis of the panel. Also, the solar panel must be perpendicularly oriented to the solar source at all times to obtain maximum output voltages. Though the differences on the output voltages of the different reflector types are not considerably high, it is advisable to use the rectangular reflector type since it has the highest voltage increase as obtained. It is then highly recommended to use the galvanized iron sheets as reflectors to be incorporated in solar panels to have an increased output voltage at a cheaper cost as compared to conventional planar reflectors.

It is suggested that future works should utilize bigger size panels and utilize other materials like aluminum as reflectors. This is because GI sheets are quite vulnerable to corrosion as compared to aluminum. In the actual installations of the GI sheets to solar panels, designers should put into primary considerations the design parameters of the mechanisms as to fix the reflectors in these panels in order to maintain 90º angle with respect to the sun for maximum harnessing of solar energy. This can be best achieved if this solar panel with GI sheet reflectors be installed in a solar tracker. For optimum performance, such solar tracker can be mounted in the rooftop or in the ground level for as long as there is no sunlight obstruction throughout the daytime. It would be a challenge for future researchers to design solar trackers for ground or rooftop installations.

5. Acknowledgement

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