Performance Analysis of Solar Panels on Zinc Roofs

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Keywords: Solar Panel, Rooftop, Zinc Tile, Temperature, Efficiency.

Abstract: In general, the installation of PLTS Rooftop only considers the power capacity to be installed and the available roof area and does not consider the type of roofing material where it is installed. Meanwhile, the roof of the house has the absorption of sunlight and different thermal properties depending on the type of roofing material. This study aims to observe the temperature characteristics between the solar panels and the roof of the zinc tile material, where the effect of the height between the solar panels and the roof on the temperature and its effect on the efficiency of the solar panels. Based on the results of this study, the temperature characteristics between the solar panels and the roof (T3) various types of materials have an influence on the efficiency value of the solar panels, where the maximum efficiency value is obtained at a temperature (T3) of 34.14ºC of 4.67%.

1 INTRODUCTION

Utilization of solar energy as an alternative energy source for meeting electricity needs in Indonesia is very appropriate considering the geographical location in the tropics with solar heat available throughout the year. Indonesia's natural condition, which is relatively difficult to reach by a centralized electricity network, makes the choice of solar energy a must (Septiadi, Nanlohy, Souissa, & Rumlawang, 2009).

One of the photovoltaic solar energy technologies that is currently being developed is Rooftop Solar Power Generation technology or PLTS Rooftop. Rooftop PLTS is a reliable solution for energy supply (Peng & Lu, 2013). Some of the advantages of the PLTS Rooftop system are that it is easy and inexpensive to integrate with existing electrical systems and can reduce the burden on the existing system network. In addition, maintenance and operation are also easy, but the impact is significant for reducing pollution and the greenhouse effect (Castellanos, Sunter, & Kammen, 2017).

Seeing that the potential for solar energy in Indonesia is very large (NA, 2012), several studies regarding the use of PLTS Rooftop include (Tarigan, 2018) discussing the potential for implementing PLTS rooftops in campus buildings. (Hakim, 2017) examined the design of rooftop off grid solar panels in residential homes as an alternative source of electrical energy. (Mintorogo, 2000) investigated the strategy of applying photovoltaic cells in residential and commercial buildings. (Syafii, Novizon, Wati, & Juliandri, 2018) discusses the application of rooftop solar panels to reduce electricity consumption at peak load conditions. (Altan et al., 2019; Kotak, Gago, Mohanty, & Muneer, 2014; Salamanca, Georgescu, Mahalov, Moustaoui, & Martilli, 2016) discusses the implementation of rooftop solar panels in buildings.

In general, the installation of PLTS Rooftop only considers the power capacity to be installed (Alghamdi, 2019), and the available roof area and does not consider the type of roofing material where it is installed. Meanwhile, the roof of the house has the absorption of sunlight and different thermal properties depending on the type of roofing material. The research that has been carried out to determine the effect of temperature on the roof covering is by (Rahmat, Prianto, & Sasongko, 2017), (Selparia, Ginting, & Syech), and (Dominguez, Kleissl, & Luvall, 2011). (Rahmat et al., 2017) investigated the thermal conditions of the roof space produced from various types of roofing materials such as tile, asbestos and zinc. The results of this study indicate that the average temperature of the roof space on a tile roof is 1.91ºC to 2.31ºC lower than that of asbestos and zinc roofs. Tile roofs are also more resistant to solar radiation. The average tile roof surface

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temperature is 0.28ºC lower than the asbestos roof surface temperature and 1.55ºC lower than the zinc roof surface temperature. However, the lowest average roof surface temperature profile during the day on an asbestos roof is 38.71ºC. Research conducted by (Selparia et al.) discusses the manufacture and testing of tools to determine the conductivity of zinc plate, multiroof, and asbestos. From these results, it was found that the highest conductivity value was found on the zinc plate (0.482 W/m°C) and the lowest conductivity value was multiroof (0.132 W/m°C). (Dominguez et al., 2011) researched the Effects of Solar Photovoltaic Panels on Roof Heat Transfer discusses the roof temperature under PV is 2.5 times cooler than the roof exposed to sunlight.

Several related studies such as (Odeh, 2018), which discusses the thermal characteristics of rooftop PV installations. Several previous studies have discussed the effect of the type of roofing material used as a PLTS Rooftop installation on the temperature between the solar panels and the roof and have not examined the effect of the distance between the solar panels and the type of roofing material on the temperature of the solar panels and have not discussed its effect on the efficiency of the solar panels. In research (Firman, Said, & Djalal, 2022), discussing the performance characteristics of solar panels on clay and ceramic tile roofing materials, further research is needed on other types of materials. Based on this description, this study was made to observe the temperature characteristics between the solar panels and the roof of the zinc material. In this study, the effect of the distance between the solar panel and the roof on the temperature and its effect on the efficiency of the solar panel will be observed.

2 METHODS

2.1 Research Instrument Design

For the frame of the solar panel holder used hollow iron material measuring 4 x 4 cm and also angled iron measuring 3 x 3 cm, and for the material on the load panel used acrylic material. Figure 1 below shows the design of the solar panel framework and the roof.

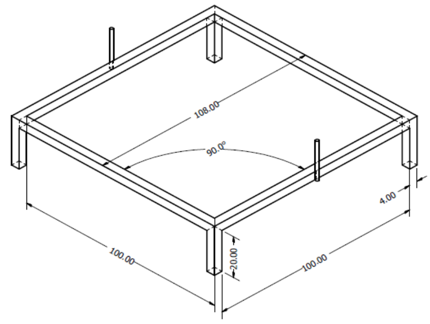

Figure 1: Solar panel mounting design.

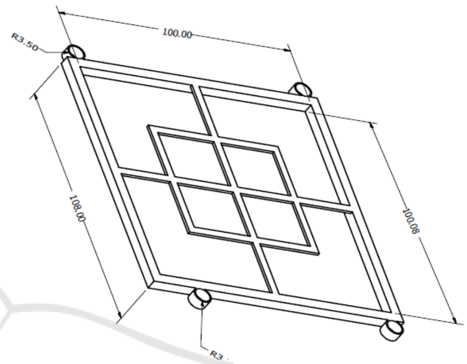

Figure 2: Tile mount design.

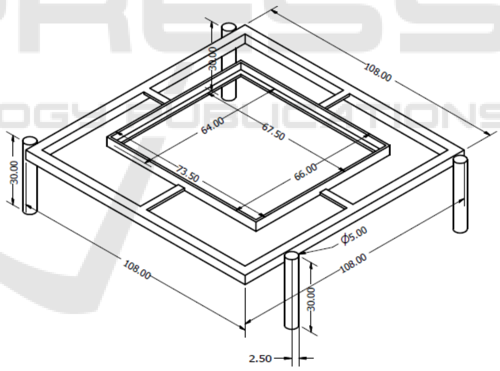

Figure 3: Dimensions of the solar panel framework and roof.

In designing the load panel as the output of the solar panel, acrylic material is used with a size of 75 x 60 cm. The following figure 2 shows the design of the research instrument placement.

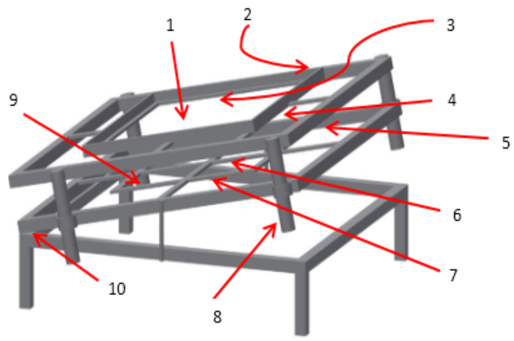

Figure 4: Research instrument placement design.

Information:

1. Solar Panel Mount
2. Solar Simulator Spot
3. Temperature above the solar panel, T1 (°C)
4. Temperature under the solar panel, T2 (°C)
5. Temperature between solar panel and roof, T3 (°C)
6. Temperature above the roof, T4 (°C)
7. Temperature under the roof, T5 (°C)
8. Distance Variation Adjuster (cm)
9. Roof Mount
10. Tilt Angle (°)

Figure 5: Data collection process.

2.2 Testing Procedure

After the process of making and installing the research components is complete, then proceed with the testing procedure. The steps in the testing procedure are as follows:

1. Testing will be carried out at 09.00 to 15.00 local time.
2. Adjust the angle of inclination of the solar panels based on the type of roof used.
3. Install solar panels on the roofing material with a distance of H1.
4. Measure the distance (cm) between the solar panels and the roof used.
5. Measure the temperature above the solar panel (°C) and the temperature between the solar panel and the roof (°C) using the TC-O8 Thermocouple Data Logger.
6. Measuring the amount of solar radiation (W/m2) on the solar panel using the Solar Power Meter SPM-1116SD measuring instrument.
7. Connect the solar panel output to the load panel and turn on the toggle switch.
8. Connecting the Voltmeter and Ammeter Datalogger with a laptop to observe the amount of current and voltage on the solar panel.
   - To ensure the datalogger and measurement instruments on the load panel are functioning properly, it can be determined by turning on the switch on the lamp, then increasing the voltage by turning the potentiometer in this case the dimmer to its maximum condition. The brightness of the lamp will be directly proportional to the amount of current and voltage as well as the intensity of the sun received by the solar panel. After all the measuring instruments are functioning properly, then the data collection can then be carried out.
9. Procedures 1 to 9 are repeated with a distance of H2 and H3.

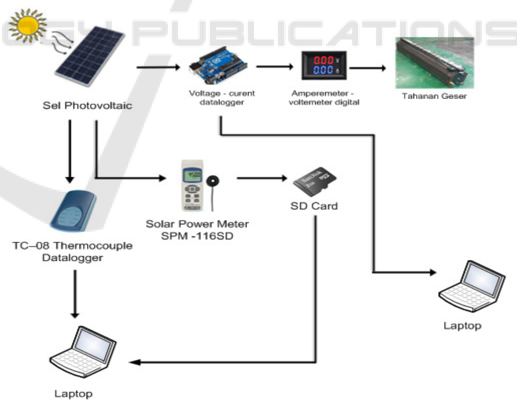

Figure 6: PLTS rooftop schematic.

3 RESULTS AND DISCUSSION

The research data contains solar panel parameters measured on the type of zinc roofing material, the distance between the solar panels and the roof varies, including the distances of 35 cm, 30 cm, 25 cm, and 20 cm. In the variation of distance, the research was conducted at 3 (three) observation times, namely at 09.30 WITA, 12.30 WITA, and 14.30 WITA.

The measurement data needed in this study include:

- Solar radiation, G_bt (W/m2)
- Temperature above the solar panel, T1 (°C)
- Temperature under the solar panel, T2 (°C)
- Temperature between solar panel and roof, T3 (°C)
- Temperature above the roof, T4 (°C)
- Temperature under the roof, T5 (°C)
- Solar panel current, I(A).
- Solar panel voltage, V(V)
- Time, (WITA)

The following is the research data from each of the above categories taken from the average value of the measurement results.

3.1 Characteristics I-V

Figure 5 shows the characteristics of the I-V curve with various variations in the distance of the solar panels on the zinc tile for the first experiment. The graph shows that the voltage generated by the solar panel is inversely proportional to the amount of current flowing, where the greater the voltage, the smaller the current. This is influenced by the resistive load used in this experiment which varies from the maximum value to the minimum value for each variation of the distance between the solar panel and the zinc tile. In the first experiment, the smallest voltage value was generated at a distance of 25 cm, which was 2.79 V with a current value of 2.08 A. While the largest voltage value was generated at a distance of 30 cm, which was 21.9 V with a current value of 0.27 A. In the second experiment, the smallest voltage value was generated at a distance of 35 cm, which was 0.95 V with a current value of 2.52 A. While the largest voltage value was generated at a distance of 30 cm, which was 23.93 V with a current value of 0.29. A. In the third experiment, the smallest voltage value was generated at a distance of 30 cm, which was 0.66 V with a current value of 1.74 A. While the largest voltage value was generated at a distance of 20 cm, which was 21.88 V with a current value of 0. 22 A.

Based on Figure 5-7, the battery charging work area is shown as an output on the solar panel which is controlled by the BCR (Baterry Control Regulator). BCR is a battery charging controller circuit in a solar cell system by regulating the voltage used to charge the battery in a voltage range of 11.4 V to 14.5 V as shown in the graph above for charging a 12 V battery. If the voltage drops to 11.4 V, the controller will charge the battery if the sun is shining at that time, but if it is at night, the controller will cut off the supply of electrical energy. If the voltage rises to 14.5 V, the controller will stop charging the battery. Overvoltage in the battery will result in a relatively short battery life.

From the graph trend of the first experiment, it can be seen that at a distance of 25 cm the current and voltage have a minimum value when compared to the current and voltage values produced at a distance of 20 cm, 30 cm and 35 cm. This is because the effect of convection heat transfer between the solar panel and the zinc tile at a distance of 25 cm is greater because this experiment was carried out when solar radiation was at its maximum value (daytime). While in the second experiment, it was seen that at a distance of 35 cm the current and voltage had a minimum value when compared to the current and voltage values produced at a distance of 20 cm, 25 cm and 30 cm. This is because the effect of convective heat transfer between the solar panel and the zinc tile at a distance of 35 cm is greater because this experiment was carried out when solar radiation was at its maximum value (during the day). Meanwhile, in the third experiment, it was seen that at a distance of 30 cm the current and voltage had a minimum value when compared to the current and voltage values produced at a distance of 20 cm, 25 cm and 35 cm. This is because the effect of convection heat transfer between the solar panel and the zinc tile at a distance of 30 cm is greater because this experiment was carried out when solar radiation was at its maximum value (daytime).

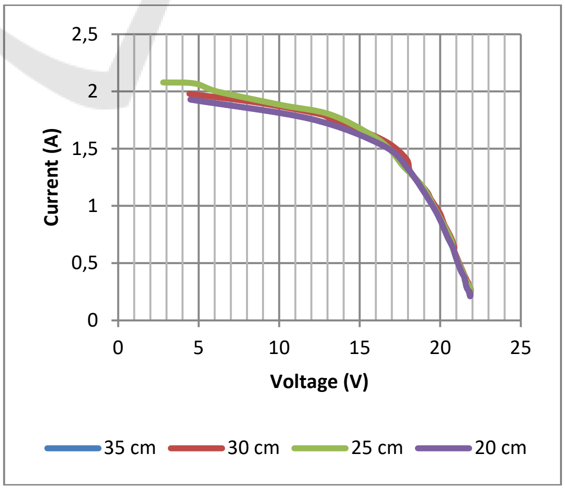

Figure 7: Characteristics of I-V curves with various distances of solar panels on zinc tile for the first experiment.

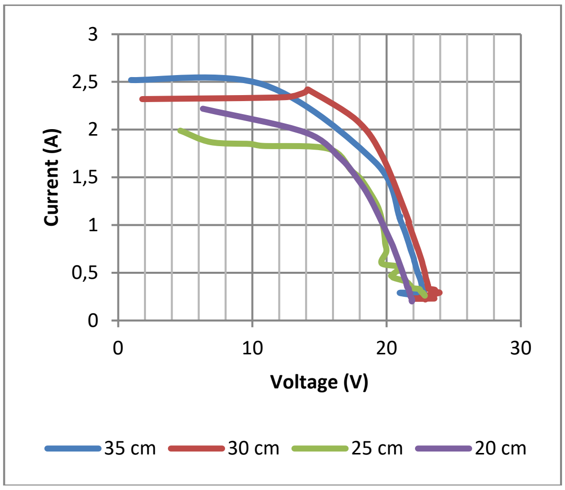

Figure 8: Characteristics of I-V curves with various distances of solar panels on zinc tile for the second experiment.

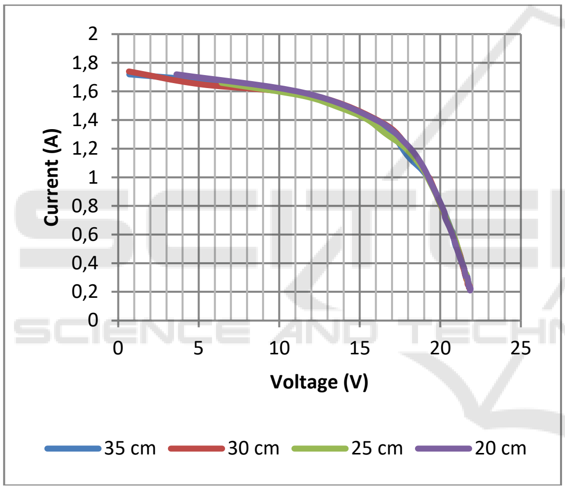

Figure 9: Characteristics of I-V curves with various distances of solar panels on zinc roof tiles for the third experiment.

3.2 Solar Panel Temperature Characteristics

Figure 7 shows a comparison of the temperature characteristics for several variations of the distance on the type of zinc tile material. In testing using the type of zinc tile material, it shows that at a distance of 35 cm, the highest T3 temperature in the test using zinc tile roofing material was obtained in tests conducted at 12.30 WITA which was 35.8oC. Next in the test with a distance of 30 cm, the highest T3 temperature was obtained in the test conducted at 14.30 WITA which was 36.82oC. Next in the test with a distance of 25 cm, the highest T3 temperature was obtained in the test conducted at 14.30 WITA which was 37.67oC. Next in the test with a distance of 20 cm, the highest T3 temperature was obtained in the test conducted at 14.30 WITA which was 35.62oC. Table 1 shows the results of testing the characteristics of solar panels on zinc roof tiles.

Table 1: Temperature characteristics of zinc tile material.

Range (cm)	Time (WITA)	G_{bt} (W/m^2)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
35	09.30	870.7	56.01	47.86	30.18	35.16	34.00
	12.30	1179	50.62	49.41	35.80	37.51	35.67
	14.30	732	57.42	54.35	34.14	38.29	35.63
30	09.30	887.2	57.30	51.04	31.51	35.67	33.76
	12.30	1032	56.59	43.85	35.44	38.95	37.74
	14.30	727.2	58.51	57.06	36.82	40.02	37.49
25	09.30	886.1	51.95	48.44	32.37	36.08	35.57
	12.30	974.2	56.36	55.65	35.51	39.20	37.48
	14.30	732	60.13	58.40	37.67	42.11	40.02
20	09.30	880.9	58.96	54.12	34.39	37.55	36.78
	12.30	1007	53.79	51.47	35.59	38.71	35.08
	14.30	720.1	58.96	56.72	35.62	41.32	39.84

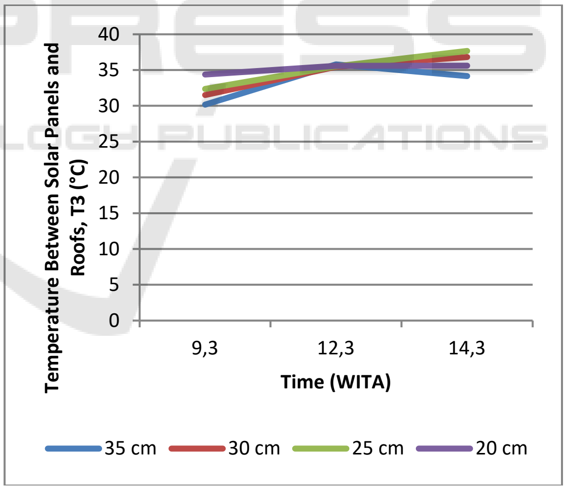

Figure 10: Comparison of temperature characteristics for zinc tile material.

Testing the characteristics of the temperature of the solar panels on the zinc tile shows an increasing trend in the temperature graph from 09.30 to 14.30. This is because zinc tile is a good conductor so the heat from the roofing material can move to the top of the solar panels.

3.3 Solar Panel Efficiency

For efficiency analysis, calculations were carried out by taking the sample data in Table 1 with a distance of 35 cm at 09.30 WITA. The parameters are as follows:

- Intensity of solar radiation, G_bt = 870.7 W/m2
- Voltage, V = 20.36 V
- Current, I = 0.51 A
- Cross-sectional area, A = 0.538x0.636 = 0.342 m2
- The temperature above the solar panel, T1 = 56.01
- The temperature under the solar panel, T2 = 47.86
- Temperature between solar panel and roof, T3 = 30.18
- Temperature above the roof, T4 = 35.16
- Temperature under the roof, T5 = 34.00
- Time = 9.30 WITA

Input Power Calculation, $P_{in}\ (W)$

$$P_{in} = G_{bt}\ x\ A$$
$$= 870{,}7\ W/m^2\ x\ 0{,}342\ m^2 \quad (1)$$
$$= 297{,}94\ Watt$$

Output Power Calculation, $P_{out}\ (W)$

$$P_{out} = V\ x\ I$$
$$= 20{,}36\ V\ x\ 0{,}51\ A \quad (2)$$
$$= 8{,}83\ Watt$$

Calculation of Solar Panel Efficiency, η (%)

$$\eta = \frac{P_{out}}{P_{in}}\ x\ 100\%$$
$$= \frac{8{,}83\ Watt}{297{,}94\ Watt}\ x\ 100\% \quad (3)$$
$$= 2{,}97\ \%$$

Table 2: Power and efficiency of solar panels on zinc tile.

Range (cm)	Time (WITA)	G_{bt} (W/m²)	V (V)	I (A)	P_{out} (W)	P_{in} (W)	η (%)
35	09.30	870.7	20.36	0.51	8.83	297.94	2.97
	12.30	1179	20.27	0.76	11.96	403.55	2.97
	14.30	732	18.10	0.78	11.72	250.62	4.67
30	09.30	887.2	19.01	0.85	13.99	303.57	4.61
	12.30	1032	20.67	0.84	14.13	353.13	4.01
	14.30	727.2	19.45	0.60	9.61	248.81	3.86
25	09.30	886.1	18.58	0.79	11.23	303.20	3.70
	12.30	974.2	19.15	0.79	12.63	333.33	3.81
	14.30	732	19.65	0.64	11.17	247.39	4.51
20	09.30	880.9	20.36	0.51	8.83	301.43	2.93
	12.30	1007	20.45	0.56	9.89	344.55	2.88
	14.30	720.1	20.14	0.53	9.23	246.41	3.75

The complete results of the calculation of input power, output power, and solar panel efficiency are shown in table 2 for the type of zinc tile material.

Table 3 shows the results of calculating the input power, output power, and efficiency of solar panels on zinc roof tiles. To see the comparison visually, the results of the efficiency calculations are displayed in a graphical form as shown in Figure 8. Figure 8 shows a comparison of the efficiency for several height variations of the types of zinc tile materials.

The highest efficiency value obtained for a height of 35 cm is 4.67% at the time of testing at 14.30 WITA. While the lowest efficiency value was obtained at the time of testing at 12.30 WITA which was 2.88%. The efficiency value in this experiment is influenced by the measured value of solar radiation and temperature based on variations in height between the roof and solar panels. Other factors that affect the efficiency of solar panels in this study such as wind speed and reflectance of sunlight from roofing materials to solar panels are assumed not to have much effect on this experiment because the test framework (solar panels and roofs) are not placed on tall buildings so that the -these factors are ignored. Figure 8 below shows the efficiency of each test on zinc tile material at various height distance variations.

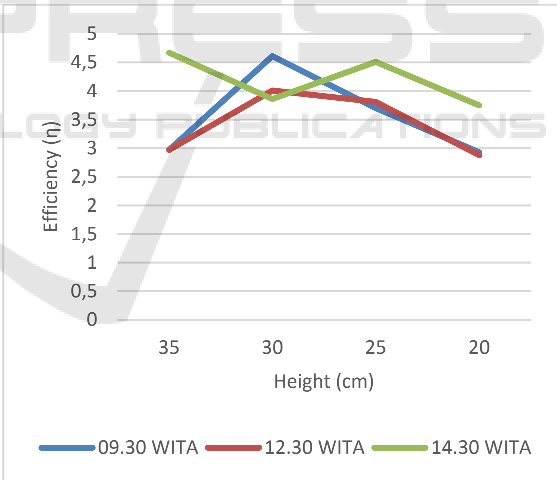

Figure 11: Comparison of efficiency of solar panels types of zinc tile materials.

4 CONCLUSIONS

Based on the research that has been done, it can be concluded that:

1. In the first experiment, the smallest voltage value was generated at a distance of 25 cm, which was 2.79 V with a current value of 2.08 A. While the

largest voltage value was generated at a distance of 30 cm, which was 21.9 V with a current value of 0, 27 A. In the second experiment, the smallest voltage value was generated at a distance of 35 cm, which was 0.95 V with a current value of 2.52 A. While the largest voltage value was generated at a distance of 30 cm, which was 23.93 V with a current value of 0. ,29 A. In the third experiment, the smallest voltage value was generated at a distance of 30 cm, which was 0.66 V with a current value of 1.74 A. While the largest voltage value was generated at a distance of 20 cm, which was 21.88 V with a current value of 0.22 A.

2. The highest efficiency value obtained for a height of 35 cm is 4.67% at the time of testing at 14.30 WITA. While the lowest efficiency value was obtained at the time of testing at 12.30 WITA which was 2.88%.

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