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Comparative analysis of solar panel output power with variations of Heatsink type cooling systems

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Abstract

The heatsink is installed on the back sheet of the solar panel in the form of a fin so that the air under the solar module helps the heatsink perform cooling. Temperature testing uses a thermocouple temperature sensor at several calibrated points, taking volt and current data using a multimeter. The results of this test obtained a deviation comparison value between solar panels without a heat sink and using a heat sink of ±1%. So, the similarity of deviation values from the research is used as a control variable. From all the data that has been taken, using heat sinks on solar panels can reduce excess heat in the solar panel modules. The heat transfer that occurs in this experiment is by conduction and convection. The heatsink's good performance in releasing heat with high power output can be seen at 12.25 because the resulting thermal efficiency is related to the power released at the same time. The thermal efficiency value is 20.88%, and the power increase is 19.31%.

***Keywords**: Solar panel; Heatsink; Temperature; Power*

1. INTRODUCTION

With the increasing depletion of non-renewable energy resources such as petroleum and other fossil energy, developing new renewable energy is necessary. Solar energy is currently one of the most widely developed examples of new renewable energy (1). Through the photovoltaic process, solar energy can produce the needed electrical energy. The biggest obstacle in generating electricity from solar panels is the increase in temperature on the surface of the solar cells, which is influenced by the temperature in the surrounding environment and operating temperature. This results in a decrease in the efficiency and performance of the photovoltaic process of the solar panels (2). High temperatures in the solar panel working process will reduce the maximum output power value because the sun's radiation is at its maximum (3). There are many ways to reduce these high temperatures, one of which is with a cooling system. Cooling systems are divided into passive cooling and active cooling, and heatsink are included in the passive cooling type because they operate on the principle of natural convection. Many types of cooling systems are generally used on solar panels, including heat sink. Heatsink are recommended because, in some conditions, the wind performance and heatsink design can reduce the maximum temperature sustainably (4).

Several researchers have studied quite a lot of research on the use of heatsink. The use of heat ink has been proven to reduce high temperatures in solar panels so that they can maintain circuit resistance. In the photovoltaic process, temperature is the most important thing to pay attention to because it can affect the efficiency and performance of solar panels. Experiments carried out using 10WP polycrystalline type solar panels with a cooling system on the solar panel with a heatsink type that has a finned design can reduce the temperature by 3-5℃ and can increase the output power by around 15% (5). This test was carried out with 36 types of heat sink with different designs and sizes. The experiment was carried out between 11:00-12:30. The simulations carried out in this experiment used ANSYS FLUENT 2022 of 36 types of heat sink only three types of heat sink were analyzed (6). The experiment was carried out using a 50WP polycrystalline solar panel, testing varying the number of fins on the heatsink and analyzing the wind speed vector using simulation (7).

Some of the research above carried out many CFD simulations. In this research, there is little discussion about heat transfer. Therefore, the research that will be carried out focuses on testing heat transfer that occurs through experiments. In this research, the heat transfer that occurs in solar panels involves natural conduction and convection. Through the natural convection process, the heatsink is expected to release heat to the environment, and the conduction heat transfer that occurs between materials flows well. The discussion in this experiment will be to test the characteristics of the two solar panels to test the performance of the cooling system from the power on the solar panels. Data collection was carried out using an Arduino-based thermocouple sensor.

2. METHODS

2.1 Solar panel

The working principle of solar panels triggers positive and negative layers, which combine to produce an electric field. When photons encounter semiconductor silicon atoms, heat from the sun releases the electrons. Electrons flow through semiconductor materials to produce an electric charge (8). There are various types of solar panels, depending on needs and function. Solar panels are generally divided into two types: polycrystalline and monocrystalline. Polycrystalline panels are made from many different tiny crystals, have slightly lower conversion efficiency than monocrystalline panels, and are more economical regarding production costs. Monocrystalline is made from a single crystal, has high conversion efficiency, and generally has a higher cost.

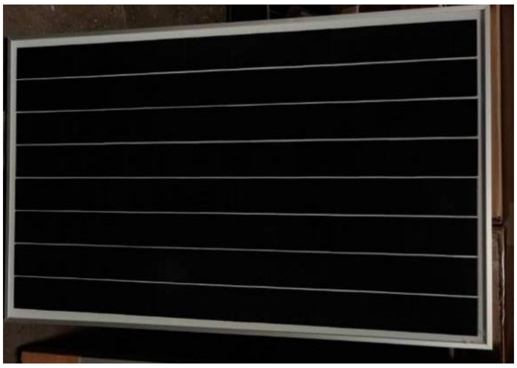

Figure. 1. Solar panel

The type of solar panel used in the research is mono-shingled panels. This type has a larger cross-section than other solar panels. The advantage of mono-shingled panels is that, in terms of design, the trim panels are combined without gaps between cells. This shape reduces losses caused by shading between cells and improves the performance of solar panels (9). This type also has a glass layer that protects the solar cells, maintaining weather resistance and humidity and increasing the lifespan of the solar panels against physical damage. Specifications relating to the solar panels in the experiment are shown in Table 1.

Table 1. Solar Panel Specifications

Properties	Specifications
Rated maximum power (Pm)	50W
Tolerance	0-5W
Voltage at Pmax (Vmp)	18V
Current at Pmax (Imp)	2,78A
Open-Circuit Voltage (Voc)	22,11V

Short-circuit current (Isc)	2,94A
Thermal conductivity (Alumunium)	237Wm^{-1}K^{-1}
Thermal conductivity (thermal paste)	1.2 Wm^{-1}K^{-1}
Total heatsink	5 unit
Total thermocouple sensor	10 unit per module
Load Resistance	8.8 Ω
Rated maximum power (Pm)	50W

2.2 Heat Transfer by Conduction

Conduction heat transfer is the transfer of heat transmitted through particles at rest. Even though they are stationary, these particles can transfer heat from one particle to another using direct contact between the particles (10). Conduction heat transfer can be illustrated in Fig. 2, where it moves from surface 1 to surface 2. Conduction heat transfer is very dependent on the conductivity of the material through which the heat passes (k), the heat transfer surface area (A), A is the product of H, the distance between the surfaces (L), and the heat transfer temperature difference (ΔT). Mathematically the equation.

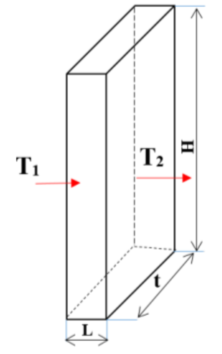

Figure. 2. Heat transfer by conduction

$$\dot{q} = \frac{-kA(T_2 - T_1)}{L} \tag{1}$$

Information:
$\dot{q}$ = The amount of heat delivered (Watt)
K = Thermal conductivity of materials (Watt/m.K)
A = Material surface area (m^2)
ΔT = Temperature difference between two sides of the material (K)
L = Material thickness (m)

2.3 Heat Transfer by Natural Convection

Convection heat transfer is a heat transfer that involves the transfer of a moving mass as a whole (11). In general, convection heat transfer involves fluid flow as the medium. The fluid flow moves and carries heat; as long as the fluid moves, the particles between the fluids are in direct contact, as in conduction heat transfer. However, in convection transfer, there is mass transfer by advection. Therefore, convection results from a combination of conduction and convection. In this study, convection heat transfer is considered natural convection. Natural convection occurs naturally without any additional energy to move the fluid. In general, convection heat transfer is given in Fig. 3. The convection heat transfer rate per unit of time results from the product of the thermal convection coefficient, the heat resistance surface area, and the temperature difference. The temperature difference here is the difference in temperature at the end of the heatsink compared to the ambient temperature.

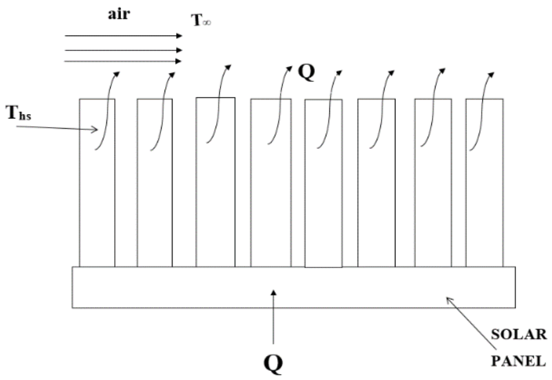

Figure. 2. Heat transfer by convection

$$Q_p = h_p \cdot A_p \left(\bar{T}_{p,o} - T_{\infty,2}\right) \tag{2}$$

Information:
Q_p= The amount of heat removed or through convection (Watt)
h_p = Convection heat transfer coefficient (W/m^2.K)
A_p= Surface area of solar panel (m^2)
$\bar{T}_{p,o}$= Surface temperature of solar (K)
$T_{\infty,2}$ = Ambient Temperature (K)

$$h_p = \frac{Nu_p \cdot k}{L_p} \tag{3}$$

Information:
Nu_p = Nusselt number

$$Nu_p = \left[0.825 + \frac{0.387 Ra_p^{\frac{1}{6}}}{\left\{1 + \left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right\}^{\frac{8}{27}}}\right]^2 \tag{4}$$

Information:
Pr = Prandtl number
Ra = Rayleigh number

$$Ra = Gr \cdot Pr = \frac{g\beta\left(\bar{T}_{p,o} - T_{\infty,2}\right)L^3}{v\alpha} \tag{5}$$

Information:
Gr = Grashof number
v = fluid kinematic viscosity (m^2/s)
α = Thermal diffusivity (m^2/s)
L = Length characteristic (m)
K= thermal conductivity of fluid (watt/m$\cdot K$)

2.4 Heatsink

A heatsink is a component that can absorb heat from its surroundings (12). Heat sink on solar panels are used to minimize heat to increase efficiency. Adding a heatsink can extend the lifespan of solar panels. The heatsink model is made from aluminum with dimensions of 300×79×38 mm, a heatsink thickness of 3mm, and a fin thickness of 2 mm. The heat sink is installed on the module for better cooling. Thermal paste with a thermal conductivity of 1.2 W/m.K increases the heat transfer coefficient between the module and the heatsink.

Figure. 4. Heatsink

2.5 Thermocouple

The function of the thermocouple in the solar panel device is as a temperature measuring tool on the back sheet and top sheet of the solar panel (13). Install thermocouples at several points to determine the heat distribution in the solar panels. The thermocouple sensor resists low to high temperatures and can respond quickly to changing temperature readings. This research uses a calibrated thermocouple; the microcontroller is an Arduino Mega 2560 connected directly to the thermocouple. Calibration is carried out on the sensor to compare it with trusted measuring instrument standards. The average uncertainty value of the calibrated thermocouple is 25.31 ± 0.66.

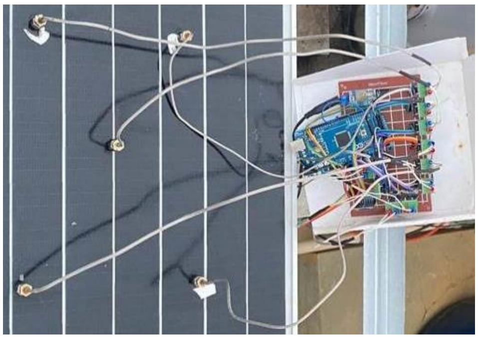

Figure 5. Thermocouple

2.6 Setup Apparatus

Temperature measurement uses a thermocouple sensor attached to the side of the top sheet and back sheet. The position of the thermocouple is made diagonally, plus one right in the middle, to get the temperature distribution on both the top sheet and back sheet sides. The thermocouple on the back sheet side is made the same as the top sheet side to determine the temperature difference on both sides. Experimental voltage measurements are divided into open and closed-circuit measurements using measured resistance. Voltage measurements with an open circuit are measured with a multimeter applied in parallel. Voltage measurements with a closed circuit are made by applying a multimeter in parallel along with the resistance value. Current measurements are divided into short-circuit and current measurements with measured resistance values. Short circuit current measurements are carried out to obtain the maximum current produced by the solar panel module. Current measurements with resistance are carried out by applying a measured load to obtain current with power based on the measured voltage. Current measurement using a multimeter connected in series.

The research was carried out by comparing two solar panel modules using heat sink and without heat sink. Then, thermal paste is applied between the back sheet of the solar panel module and the heatsink to increase heat transfer energy by conduction. The solar panel module is installed facing north. Fig. 7 shows the solar panel module's dimensions and the thermocouple's position during the experimental process.

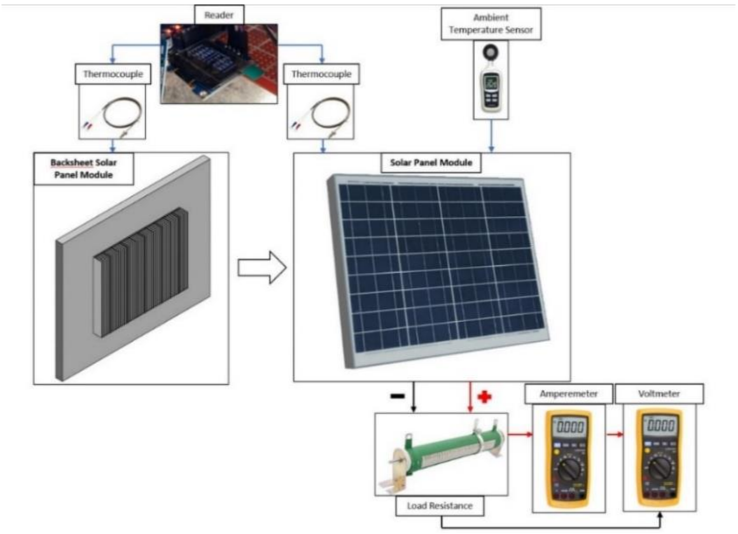

Figure. 6. Setup Apparatus

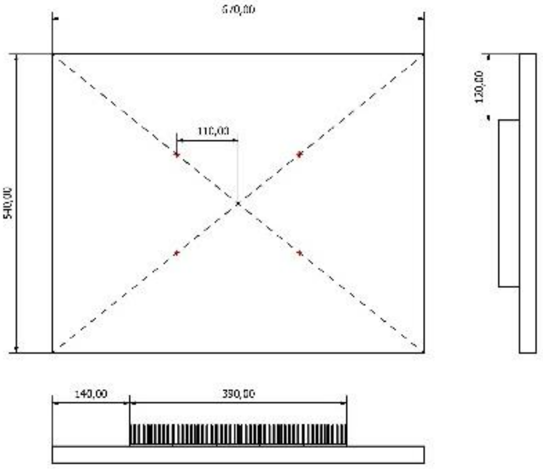

Figure 7. Thermocouple position

Figure 8. Solar panel with heatsink and without heatsink

3. RESULT AND DISCUSSION

From the tests carried out, power, current, and temperature voltage were measured, which were carried out from 11:00 to 14:00. The intensity of sunlight at 11:00-14:00 is the peak value for that day. Because this time is the highest intensity of the day. Solar panels likely produce the most energy during that period. Ensuring the solar panels are exposed to sunlight without being covered directly will produce optimal solar panel characteristics. The V-I characteristic graph requires current and voltage at different sunlight intensity levels.

Graphic image 9 shows the V-I line, a data line from research by Pido & Himran, 2018 which is used as a reference for V-I characteristics from previous journals. The V-I graph on the two solar panels was carried out to evaluate the performance and responsiveness of each solar panel. The maximum conditions obtained from calculations based on solar panel characteristics (14) reflect how solar panels should behave in ideal conditions. The experiment shows how solar panels work by considering various external factors such as weather conditions, temperature, and actual use. Differences occur between the I-V curve between ideal and experimental values, including power loss values, efficiency, changing weather and temperature conditions, and factors that are difficult to predict during testing. The V-I line in (14) writings under optimal conditions is a reference. The difference in Voc and Isc values in data collection from the V-I plot in the experiment was obtained by varying the resistance.

Fig.9 shows no significant difference between the two solar panels, with a large deviation between solar panel 1 and solar panel 2 of ±1%. Comparison of the characteristics of solar panels with the deviation of differences between solar panels in reference journals was found to be ±1%. (15) The difference in the optimum line and the measurement result line is because the intensity of sunlight required to approach ideal conditions is difficult to fulfill. The uniformity of the deviation obtained from the two dotted lines in this study validates the measurement quality of each solar panel.

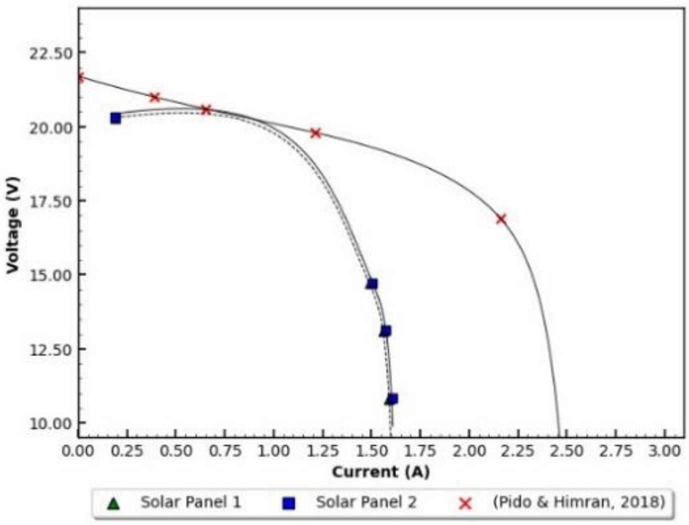

Figure. 6. Setup Apparatus

Measuring the error from thermocouple sensor readings is done by calculating the uncertainty of each thermocouple sensor. Uncertainty calculations were carried out at a temperature of 25° by taking 1000 samples at a sampling frequency of 1 Hz and obtaining an average uncertainty value from each sensor of 0.66. Investigation of error values was also carried out by analyzing the distribution of relative error values from each sensor, and it was found that the distribution of relative errors from the sensors followed a normal distribution, with a mean value of relative error of 0.03 with a standard deviation value of 0.12.

The performance review between solar panels with and without heat sink was carried out by comparing the Voc and Isc values at each time from 11:05 to 14:00. The time span with the highest power was 40.37 Watts. Based on the data, it is shown that the use of heat sink on solar panels increases the power of the solar panels.

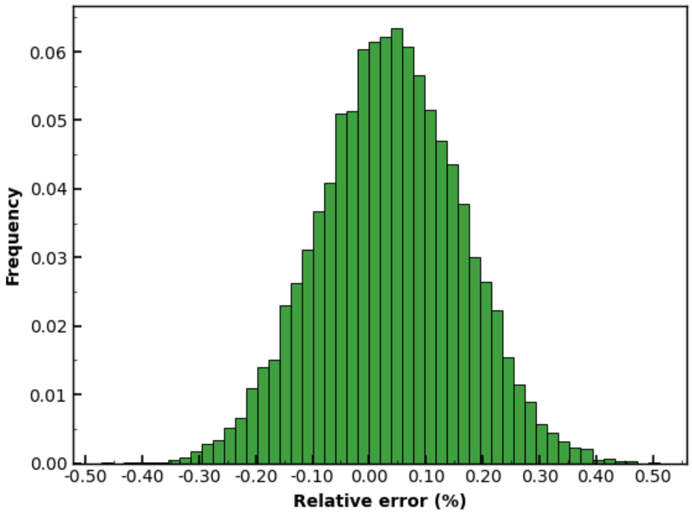

Figure 10. Relative error

Table 2. Power table data from both solar panels with heatsink and without heatsink

Time	Voc (V)	Isc (A)	P (W)
11:05	20.60	1.78	36.67
11:10	20.80	1.85	38.48
11:15	20.80	1.67	34.74
11:20	20.70	1.95	40.37
11:25	20.70	1.95	40.37
11:30	20.60	1.77	36.46
11:35	20.20	0.85	17.17
11:40	20.40	0.83	16.93
11:45	21.10	1.78	37.56
11:50	20.80	1.52	31.62
11:55	20.80	1.52	31.62
12:00	20.50	1.04	21.32
12:05	20.90	1.33	27.80
12:10	20.30	0.64	12.99
12:15	20.30	0.72	14.62
12:20	20.40	0.67	13.67
12:25	21.10	1.58	33.34
12:30	21.00	1.64	34.44
12:35	20.70	1.70	35.19
12:40	20.60	1.69	34.81
12:45	20.50	1.60	32.80
12:50	20.60	1.56	32.14
12:55	20.20	0.63	12.73
13:00	20.30	0.49	9.95
13:05	20.70	0.60	12.42
13:10	20.90	0.74	15.47
13:15	20.80	0.90	18.72
13:20	21.10	1.36	28.70
13:25	21.10	1.50	31.65
13:30	21.90	1.38	30.22
13:35	21.00	1.56	32.76
13:40	20.80	1.44	29.95
13:45	20.90	1.25	26.13
13:50	20.90	1.15	24.04
13:55	21.10	1.01	21.31
14:00	20.70	0.63	13.04

The results of temperature measurements on the top sheet of the solar panel module are shown in Fig. 11 and 12. Temperature measurements were performed at 10 temperature sensor points on each solar panel module. Based on the measurement results, there are quite significant temperature changes. The measurement results show that the highest temperature on the top sheet of the solar panel module using a heatsink is 46.75℃, while on the solar panel module without a heatsink, it is 55.15℃. This condition occurs due to the influence of sunlight intensity. However, temperature fluctuations can also occur due to weather changes. The temperature decrease on the top sheet of the solar panel module that uses a heatsink is 42.25℃, and on the solar panel module that uses a heatsink, it is 40.25℃. A significant decrease in temperature occurred due to weather changes. The trend of temperature changes over time appears to decrease gradually. A reduction in the intensity of incoming sunlight indicates a decrease in temperature in the solar panel module.

Fig. 11 and 12 show graphic images of the influence of the heatsink on the temperature of the solar panel module. The comparison in graphic images is carried out to show how much influence the heatsink has on the solar panel. Solar panel modules that use a heatsink and without heat sink are treated with the same conditions. It can be seen that the temperature of the solar panel module is higher compared to the solar panel module that does not use a heatsink. Apart from that, adding a heatsink to the back sheet of the solar panel module can reduce the overall temperature of the solar panel module by around 3-5℃.

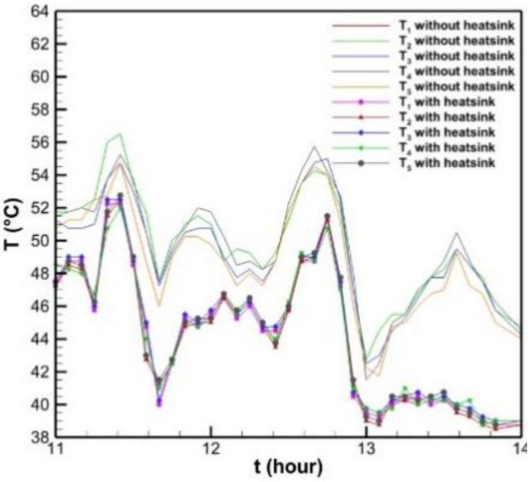

Figure 11. Comparison of solar panel top sheet temperatures

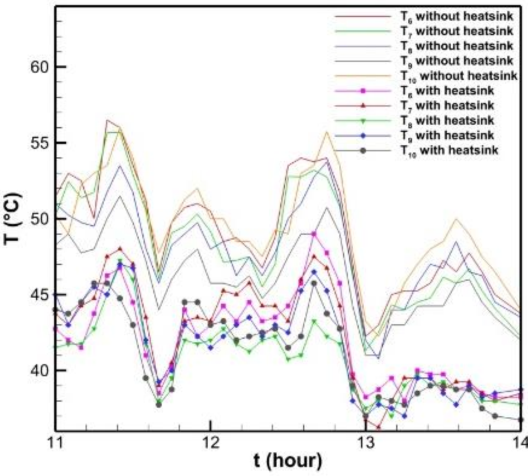

Figure 12. Comparison of solar panel backsheet temperatures

Fig. 13 shows the results of heat transfer rate experiments on solar panels. This image shows that the highest heat transfer condition is 127.42 W/m•K. In solar panels that use heat sink. Increases also occurred several times, as seen in the fluctuating graphs. However, the data presented in the graph state that the heatsink system installed on the solar panel works well because the results show that the heat transfer rate has increased in value on solar panels that use heat sink. Some data experiences phenomena, possibly due to the influence of the highest intensity of solar radiation, which affects the reading of measuring instruments.

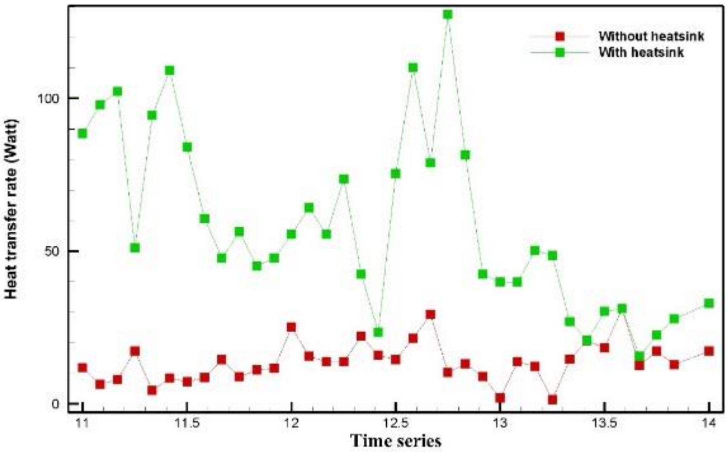

Figure. 1. Heat transfer rate

Temperature measurements on heat sink can be calculated by conduction heat transfer. That way, the temperature measurement results can be validated with the results of analytical calculations. Fig. 14 shows the temperature difference between the measurement results and analytical calculations is only around 5%. Thus, the measurement results are valid with analytical calculation results.

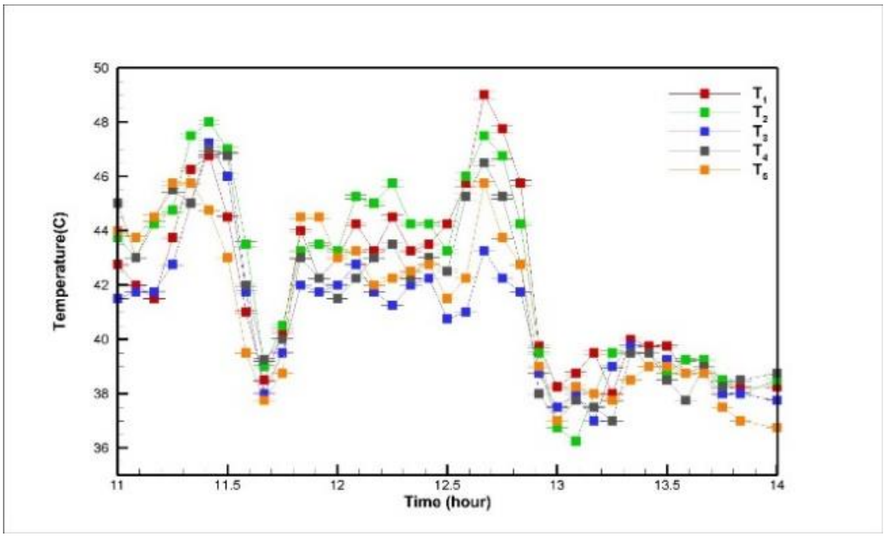

Figure 14. Temperature on thermocouple

The temperature on it influences the temperature on the heatsink fins. Adding a heatsink to the solar panel module causes natural heat transfer to the environment from the heatsink fins. Therefore, temperature measurements were carried out on the heatsink fins and environmental temperature. The results of measuring the temperature of the heatsink fins and the environmental temperature shown in Fig. 15 show a temperature difference between the heatsink fins and the environmental temperature, which represents the heatsink's performance in reducing temperature. The temperature measurement results show that there is a significant difference of 6-7℃.

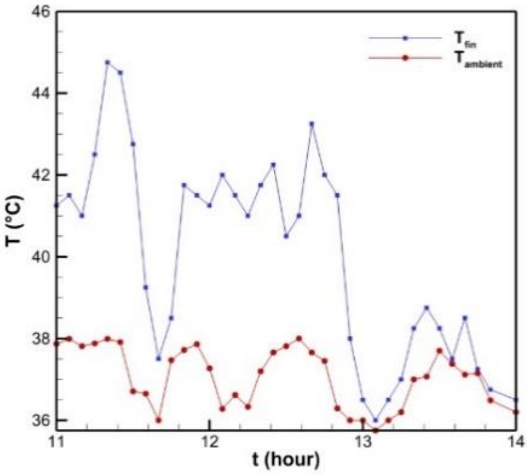

Figure 2. Temperature at the fin and ambient temperature

Fig. 16 is a graph of the convection rate. The test was carried out on a solar panel with a heatsink, and heat cooling occurred due to the wind. Judging from the convection rate value, the maximum value released is 18.43 W/(m²•K). The wind flows through the fins on the heatsink so that the heat in the solar panel can be reduced. In that case, at certain times, points in the graph get low convection rate values. The picture shows several points that look very fluctuating. The strongest possibility is that the wind passing through the fins on the heatsink decreases so that the heatsink produces the lowest rate value.

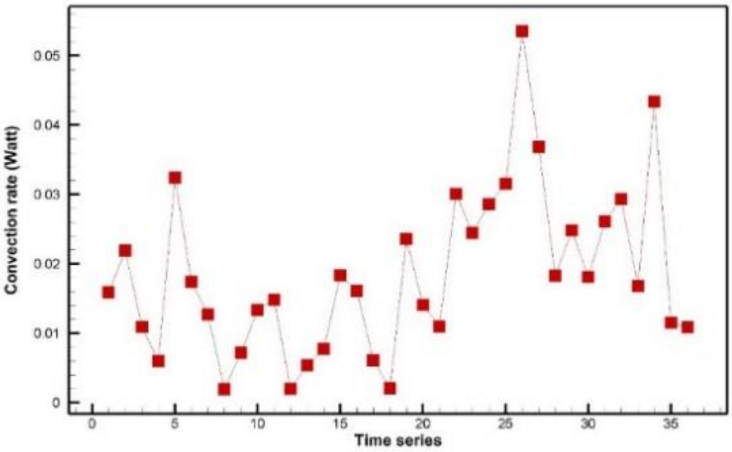

Figure 3. Temperatur convenction rate

Thermal efficiency in this research is the ratio between the convection heat transfer released by the heatsink to the environment and the conduction heat transfer flowing from the solar panel. If the resulting thermal efficiency is 100%, then the heat released by the environmental heatsink is the same as the conduction heat in the solar panel. On the other hand, if the thermal efficiency is low, the heat released to the environment is minimal compared to the conduction heat transfer in solar panels. Fig. 18 explains the thermal efficiency resulting from solar panels that use heat sink. Maximum thermal efficiency can be achieved at 12:45 with a thermal efficiency value of approximately 65%. After this time has passed, the resulting thermal efficiency value again decreases drastically. In general, the resulting thermal efficiency is below 40%. The resulting thermal efficiency value is below 10%, even at certain times.

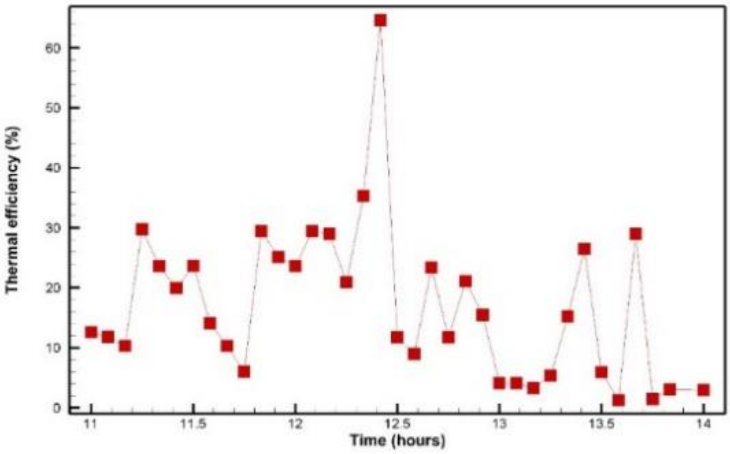

Fig. 4. Thermal efficiency

The results of measuring the power produced by the solar panel module are shown in Fig. 19. It can be seen that there is an increase in the performance of the solar panel module due to the applied heatsink. Without a heatsink, the average power produced is 16.46 Watts, with the highest power up to 26.40 Watts. Meanwhile, with a heatsink, the solar panel module can produce an average power of 17.93 Watts, with the highest power being 29.70 Watts. The graph shows the power output value from the test. Fluctuations in the graph are caused by the reduced light intensity captured by the solar panel. Thus, the increase in the performance of the solar panel module occurs due to the applied heatsink.

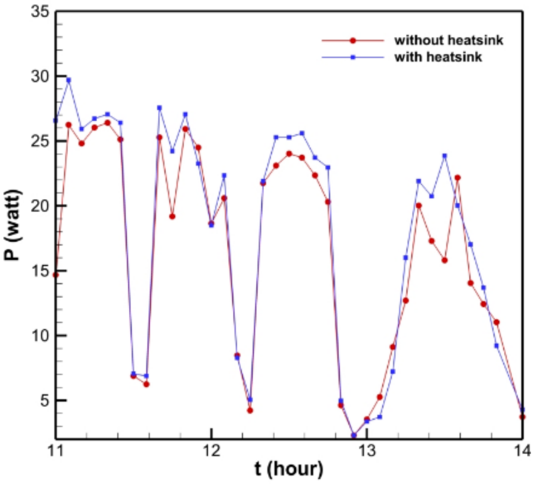

Figure 5. Power versus time

Below is a graphic image of the relationship between thermal efficiency and power increase with various time variations. At the start of the test, the power increased to 80% however, this cannot be a good reference because the solar panels do not capture the intensity of sunlight intensively. Therefore, the thermal efficiency value is not very good. Optimum results are obtained at 12:25 because the thermal efficiency and power produced are very good when compared to other time variations. The resulting increase in power was 19.31%, while the thermal efficiency was 20.88%.

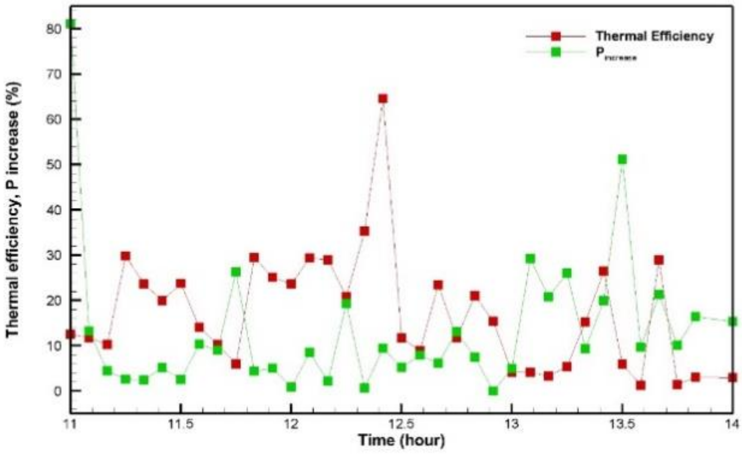

Figure 6. Increased power and thermal efficiency

4. CONCLUSION

Initial testing was carried out to see the characteristics of each solar panel module. By comparing the Voc and Isc values, the highest power produced was 40.37 watts. The thermocouple sensor installed on the solar panel produces a temperature comparison value between the top sheet and back sheet of the solar panel of around 4-5℃. Because conduction heat transfer occurs, the highest heat transfer condition value is obtained at 127.42 W/m•K. The heatsink in windy conditions looks effective because it reduces the temperature value seen from the ambient temperature, which has a difference of 6-7 ℃, and the convection value obtained is 18.43 W/(m²•K). The maximum thermal efficiency value is 65%, shows that the heat transfer that occurs is optimal. The power generated by solar panels using heat sinks is 29.70 watts, while solar panels without heat sinks are 26.40 watts. The increase in power obtained was 19.31%, with a thermal efficiency value of 20.88% at 12.25. This research shows that the use of heat sink can increase the power and performance of solar panels.

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