

# Impact of cell temperature on the performance of a rooftop photovoltaic system of 2.56 kWp at Universitas Pamulang

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## ABSTRACT

The performance of solar panels greatly determines the electrical energy production of a solar power generation system. The decrease in performance has an impact on efficiency, output power, output voltage and current. Currently, at Universitas Pamulang a solar photovoltaic system (PV) is installed with a capacity of 2.56 kWp since 2018. However, no performance test and analysis have been conducted to determine its level of efficiency and reliability. This paper presents an experimental method used for performance testing of a 320 W mono-crystalline solar panel, measuring from 08.00 AM to 4.00 PM, using the solar survey 200R to measure solar irradiation, ambient and cell temperature. A digital multimeter CD800a was used to measure Voc and a PV200 tester used to measure voltage and current output. The results revealed that at an ambient temperature of 38°C and cell temperature 50.9°C, the intensity of solar radiation was 702.7 W/m<sup>2</sup> and output voltage of 42.9 V with a performance of 78.37% and an efficiency of 27.73% was due to an increase cell temperature. Low-efficiency values with high cell temperatures indicate that this system requires an external solar panel cooling system.

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## 1. INTRODUCTION

The performance of solar panels greatly determines the results of the production of electrical energy in a solar power generation system [1]. The decreased performance will certainly have an impact on the efficiency of the solar panel itself, especially on the output power, both the output voltage and the electric current [2], [3]. A rooftop solar power generation system at University of Pamulang, currently installed with a capacity of 2.56 kWp since 2018. Since then, performance testing has not been carried out so that it requires experimental testing to determine its efficiency level in generating electrical energy continuously [4]–[6].

From the literature, an experimental method was used to study the solar panel performance with the type of solar panel mono-crystalline, poly-crystalline and thin film with a capacity of 10 W. The measurements were taken from 10:30 AM to 3:30 PM and the measurement instrument used was a solar power meter to measure solar irradiation, temperature and humidity meter were also used to measure temperature. The results presented were only at a cell temperature of 33°C with an intensity of the solar radiation of 659 W/m<sup>2</sup> and output voltage of 13 V [7]. Does not display the calculation of efficiency and performance as well as the capacity of solar panels is still very small so it requires additional analysis.

Similarly, an experimental method was used in [8] with the type of solar panel poly-crystalline with a capacity of 5 W. The results obtained were only at a cell temperature of 50°C with an output voltage of 2.8 V and does not calculate the performance. Another experimental method was conducted with the type of solar panel 40 cylindrical solar cells made of CIGS with a capacity of 200 W and measurements were carried out from 6:00 AM to 6:00 PM. The measurement instrument used was a solarimeter to measure solar irradiation, infrared thermometer with K to measure temperature, compact digital multimeter to measure voltage and current. The results obtained only at an ambient temperature of 30.5°C and a cell temperature of 54°C, with an efficiency of 10.18% has been reported [9] and does not calculate the output voltage and performance.

Consequently, an experimental method was used in a study by [10] in which a solar panel poly-crystalline was measured from 8:30 AM to 4:00 PM. The results obtained were around temperature of 50.5°C with an intensity of the solar radiation of 700 W/m<sup>2</sup> and an output voltage of 21.5 V. The capacity of solar panels is not known, the measurement tools used and efficiency and performance are not calculated, this can be said to be a deficiency in a study.

The experiment method was conducted by [11] used a poly-crystalline type solar panel with a capacity of 50 W and measurements were taken from 10:00 AM to 4:00 PM. The results obtained were only at an ambient temperature of 33°C and a cell temperature of 49.1°C. With an intensity of the solar radiation of 594 W/m<sup>2</sup> and an output voltage of 22.1 V, the resulting efficiency was 15.6% compared to the module's efficiency of 17.4%. This study still has deficiencies in that the capacity of solar panels is still small, the measurement time starts at 10:00 AM, does not mention the measuring instrument used and does not calculate performance.

From the literature [7]–[11], similar techniques based on experimental approach were used the related study. The material identification methods were used for measuring environmental parameters such as solar irradiation, cell temperature and ambient temperature; electrical parameters such as: open circuit voltage, output voltage, and current. Furthermore, empirical methods were carried out to determine the power output, efficiency and performance of the system with a larger solar panel capacity of 320 Wp. This is the contribution value in this research.

## 2. METHOD

### 2.1. Solar irradiation conditions

The solar irradiation condition was evaluated based on preliminary assessment of the photovoltaic electricity production. Location at University of Pamulang Viktor, Puspipetek street, Serpong, South Tangerang 15315, Banten, Indonesia, Geographical coordinates -6.346191°, 106.691699° [12]. The solar panels used for testing the performance was a 2.56 kWp On-Grid solar power generator installed at rooftop of building A University of Pamulang Viktor. This solar panel is used to supply electrical power to the server room.

### 2.2. Materials

The solar panel used in this study is iSOALR-1 with mono-Si cell technology with a capacity of 320 W. A total of 8 panels in series. The total output power of this system is 2.56 kW which is used to supply server room power. Table 1 provides the specification of the solar panels.

Table 1. Specifications of iSOALR-1 [13]

Description	Specification
Model type	SPU-310 M
Peak power (Pm)	320.0 W
Output tolerance	±3%
Open circuit voltage (Voc)	46.63 V
Short circuit current (Isc)	8.90 A
Peak volage (Vmp)	37.28 V
Peak current (Imp)	8.60 A
Nominal operating cell temp. (T <sub>NOCT</sub> )	45±2°C
Dimension	1956x992x50 mm
Maximum system voltage	1000 V
Maximum series fuse rating	14 A
Cell technology	Mono-Si
All technical data at standard test condition (STC)	
Air mass (AM)	1.5
Solar irradiance (E)	1000 W/m <sup>2</sup>
Cell temperature (Tc)	25°C

**2.3. Measurement**

For measuring solar irradiation. Seaward’s solar survey 200R is used. Table 2 gives the specification of the instrument used in this study. This 200R solar survey can then be used to measure PV and ambient temperature. Consequently, for measuring open circuit voltage and output voltage. Sanwa digital multimeter CD800a was used. Detailed specifications listed in Table 3. Voltage measurements are carried out on all installed PV modules.

Table 2. Specification of solar survey 100/200R series [14]

Description	Specification
Display range	100-1500 W/m <sup>2</sup> or 30-500 BTU/hr-ft <sup>2</sup>
Measurement range	100-1250 W/m <sup>2</sup> or 30-400 BTU/hr-ft <sup>2</sup>
Resolution	1 W/m <sup>2</sup> or 1 BTU/hr-ft <sup>2</sup>

Table 3. Specification of digital multimeter CD800a [15]

Parameter	Measuring range	Accuracy	Resolution
DCV	400 m/4/40/400/600 V	± (0.7%+3)	0.1m V
ACV	4/40/400/600 V	± (1.6%+9)	0.001 V
DCA	40 m/400 mA	± (2.2%+5)	0.01 mA
ACA	40 m/400 mA	± (2.8%+5)	0.01 mA
Resistance	400/4 k/40 k/400 k/4 m/40 mΩ	± (1.5%+5)	0.1 Ω
Capacitance	50 n/500 n/5 μ/50 μ/100 μF	± (5.0%+10)	0.01 nF
Frequency	50Hz~100 kHz	± (0.5%+3)	-
Duty cycle	20%~80%	± (0.5%+5)	-
Continuity	Buzzer sound at between 10 Ω and 120 Ω open voltage: approx. 0.4 V		
Diode test	Open voltage: approx.1.5 V		

Meanwhile, the current measurement in this study uses the PV200 PV tester. Table 4 shows the specification of solar PV tester used. This meter can also be used to measure the voltage of solar panels.

Table 4. Specifications of PV200 tester [16]

Description	Specification	Description	Specification
Display range (Open circuit voltage)	0.0 VDC-1000 VDC	Display range (Short circuit current)	0.00 ADC-15.00 ADC
Measuring range resolution	5.0 VDC-1000 VDC	Measuring range	0.50 ADC-15.00 ADC
Accuracy enunciators	0.1 VDC maximum	Maximum power	10 kW
Display range	± (0.5%+2 digits)	Resolution	0.01 ADC maximum
Measuring range resolution	DC Voltage polarity correct or reversed	Accuracy	± (1%+2 digits)

Figure 1 shows the instrument that were used to measure solar irradiation. The solar survey 100/200R is a product from Seaward. This measuring instrument can also measure the temperature of the environment and solar panels.

Whereas the open circuit voltage (Voc), output voltage and current measurements were using the digital multimeter CD800 a and PV200 PV tester. Voltage and current measurements as shown in Figure 2 are processes measurement, for Figure 2(a) is a Voc measurement while Figure 2(b) is a measurement of voltage and current.



Figure 1. Solar irradiance measurement

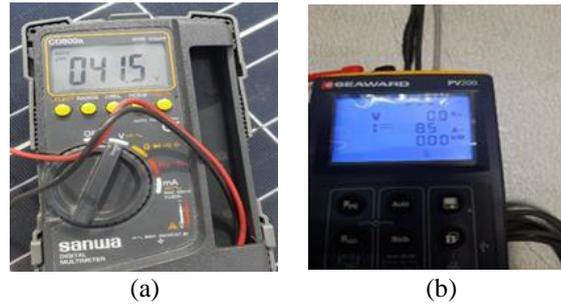


Figure 2. Measurement (a) Voc and (b) voltage and current

#### 2.4. System design

For the system under testing. A 2.56 kWp system with 8 pieces series connection of 320 Wp solar panels was considered. Figure 3 shows the arrangement of the solar array [17]. Then measurements of solar irradiation conditions, module and array circuit voltage, solar irradiance and cell temperature, as well as the output voltage and current of the system will be carried out.

An overview of the considered rooftop solar system under study is shown in Figure 4. The system is installed at building A University of Pamulang Viktor. Installed capacity of 2.56 kWp with a total of 8 solar panels of 320 Wp each.

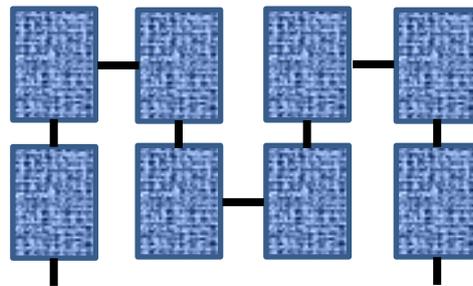


Figure 3. Solar panel arrays



Figure 4. Solar power plant of 2.56 kWp

#### 2.5. Empirical analysis

An empirical approach was used to evaluate power output, performance and efficiency of the system. Power generation from solar panels can be determined using the (1)-(4) [18]. The (1) is used to calculate the power generation of solar panels.

$$\text{Power Generation (kW)} = \frac{V_{mp} \times I_{mp}}{1000} \quad (1)$$

Where  $V_{mp}$  and  $I_{mp}$  is the maximum voltage and current at STC, respectively. The fill factor (FF) can be defined as the ratio of the theoretical power to the maximum power which can be represented mathematically as [19]–[21]. The (2) is used to calculate the fill factor.

$$Fill\ Factor\ (FF) = \frac{V_{mp}}{V_{oc}} \times \frac{I_{mp}}{I_{sc}} \tag{2}$$

Where  $V_{oc}$  and  $I_{sc}$  are the corresponding open circuit voltage and short circuit current of the cell, respectively. Solar panel performance can be identified by comparing the rated output power divided by the generated power at STC [22]–[24]. The (3) is used to calculate the performance of solar panels.

$$Power\ Performance\ (\%) = \frac{P_{max} \times FF}{P_{max\ of\ STC}} \times 100 \tag{3}$$

Where  $P_{max}$  represents the maximum output power. Efficiency is the ratio of output power ( $P_{out}$ ) to input power ( $P_{in}$ ) [25] where the conversion efficiency is the output electric power divided by the result of solar irradiation ( $E$ ) and the surface area ( $A$ ) of the solar panel. Multiplying the measured output voltage and current equal to the output power [26], [27].

$$Efficiency\ (\eta) = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{E \times A} \tag{4}$$

Based on the results of the measurements taken, the efficiency and performance values of the solar panels will be calculated. Thus, in this study used two methods, namely measurement and calculation. So that it can be known in full both the efficiency and performance based on the two methods.

### 3. RESULTS AND DISCUSSION

#### 3.1. Solar irradiation conditions

The direct normal irradiation  $W/m^2$  according to the Global Solar Atlas (GSA) in 2022 as shown in Figure 5. The lowest value was in February of  $143.50\ W/m^2$  and the highest value in August was  $267.08\ W/m^2$ . While this research was conducted in April 2022 with direct normal irradiation of  $229.67\ W/m^2$  [12].

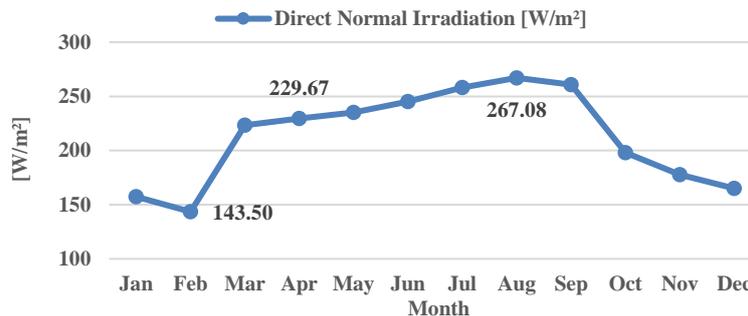


Figure 5. GSA report serpong

#### 3.2. Module and array open circuit voltage

Measurement of open circuit voltage ( $V_{oc}$ ) aims to determine the performance of each solar panel. So that the percentage of degradation in the quality of solar panel materials in generating electrical energy can be identified [28]. The open circuit voltage ( $V_{oc}$ ) measurement results are shown in Figure 6.

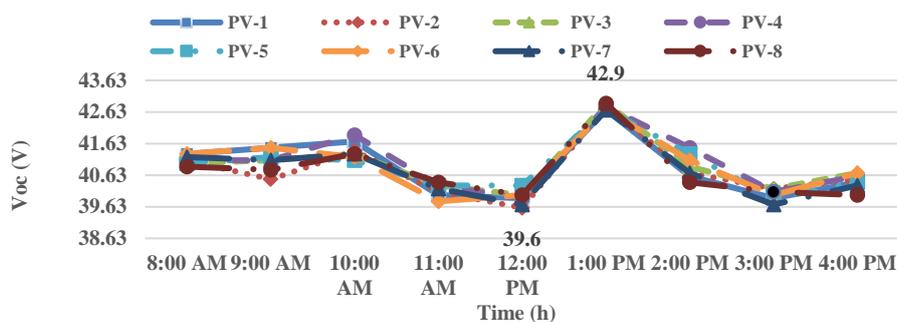


Figure 6. Module open circuit voltage

From Figure 6 the measured Voc from each solar panel with the lowest value occurred in solar panel number 2 at 12:00 PM of 39.6 V, while the highest value occurred in solar panels number 3 and 8 at 1:00 PM of 42.9 V. Solar panels installed as many as 8 panels connected in series to form an array. The measurement results for each solar panel, the average total Voc for 8 panels was obtained as shown in Figure 7.

From Figure 7 the average total Voc with the lowest measured value of 319.4 V at 12:00 PM, while the highest value of 342.2 V at 1:00 PM. This shows that the performance of the solar panel can be assumed to be good because it is still at 87.9% of the standard Voc of the solar panel from the standard Voc of 46.63 V with a total of 8 panels connected in series so that the total Voc is 371.9 V.

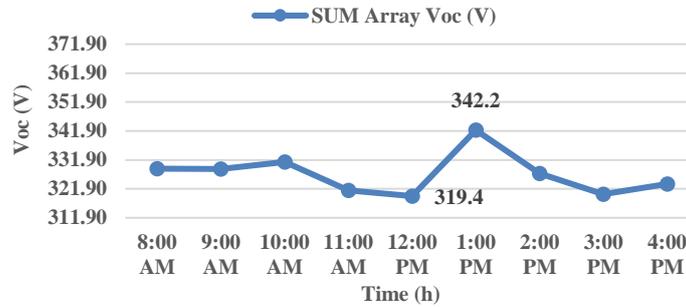


Figure 7. Array open circuit voltage

### 3.3. Solar irradiance and cell temperature

To determine the value of solar radiation. Solar irradiance measurements use the solar survey 200R product from Seaward, where Figure 8 presented the results of the measurement. From Figure 8, solar irradiance is measured with the lowest value of 509 W/m<sup>2</sup> at 11:00 AM this indicates cloudy weather conditions, while the highest value of 944 W/m<sup>2</sup> at 13:00 PM with an average solar irradiance of 702.7 W/m<sup>2</sup>. This indicates sunny weather with ideal solar radiation values close to the STC value at 1000 W/m<sup>2</sup> [29], [30]. Same as solar radiation measurements, cell temperature measurements were carried out for each solar panel using the solar survey 200R product from Seaward as shown in Figure 9.

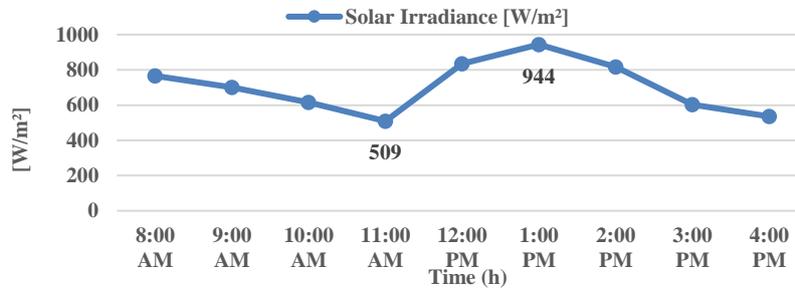


Figure 8. Solar irradiance

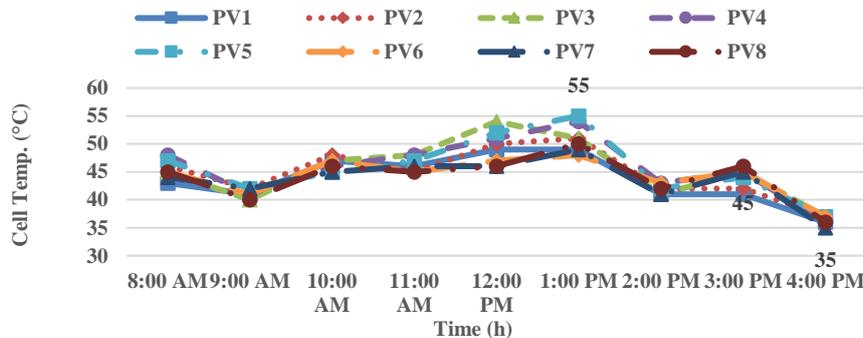


Figure 9. Cell temperature

From the Figure 9, cell temperature measured from 8 panels obtained the highest value of 55°C for solar panel number 5 at 13:00 PM, this indicates the weather is sunny. While the lowest value is 35°C for solar panel number 7 at 16:00 PM, this indicates that in the late afternoon. The level of solar irradiation begins to decrease and has a strong effect on the cell temperature level [31].

Figure 10 shows the relationship between solar irradiance and cell temperature where there is a strong relationship between the high value of solar irradiance at 944 W/m<sup>2</sup>. The increase in cell temperature of 50.9°C at 13:00 PM. This condition will certainly have an impact on the efficiency of solar panels [32].

According to Figure 11, the increase in cell temperature of 50.9°C. An average cell temperature of 44.5°C has reached 94.68% of the cell temperature condition based on the nominal operating cell temperature (NOCT) of 45±2°C.

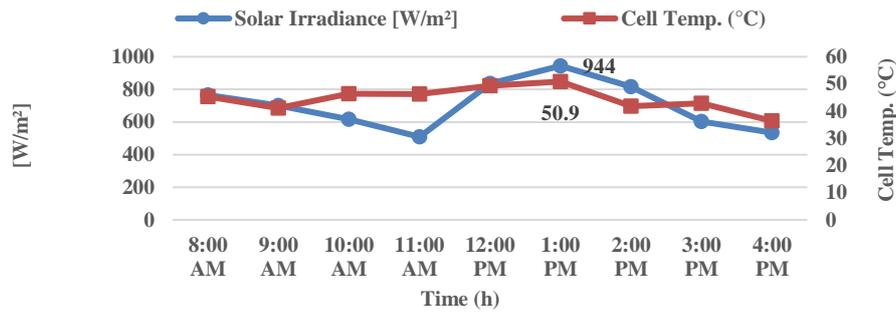


Figure 10. Solar irradiance and cell temperature

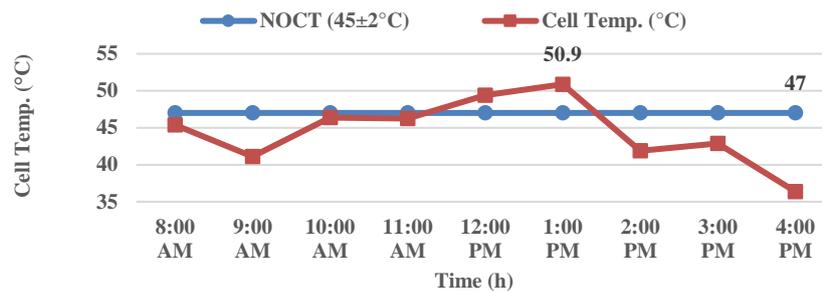


Figure 11. NOCT and cell temperature

### 3.4. Output voltage and current

Output voltage measurements were carried out using a digital multimeter CD800a. While current measurements are carried out using the PV200 tester product from Seaward. Figure 12 shows the output voltage and current measured.

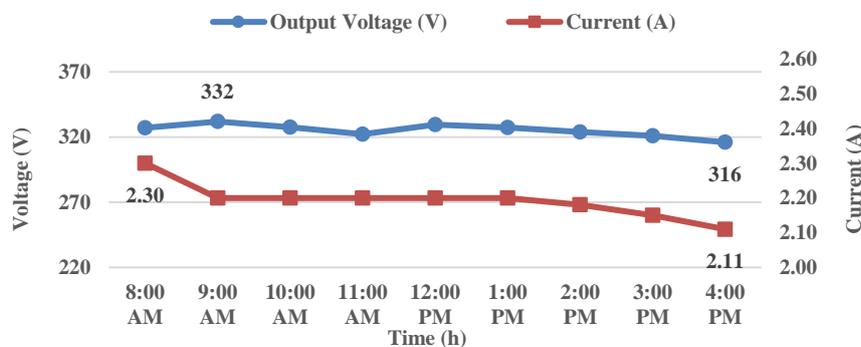


Figure 12. Output voltage and current

From the Figure 12, the highest current value is 2.30 A at 8:00 AM with the highest output voltage of 332 V at 9:00 AM, this is caused by the load starting condition. While the lowest voltage value is 316 V and the current is 2.11 A at 16:00 PM. This changes output voltage and current are caused by the condition of solar irradiation and load which has begun to decrease [33]. The condition of the output voltage of 327 V. The current increase of 2.30 A correlated strongly with the increase in output power of 752 W at 8:00 AM. This was caused by the starting load as shown in Figure 13 [34].

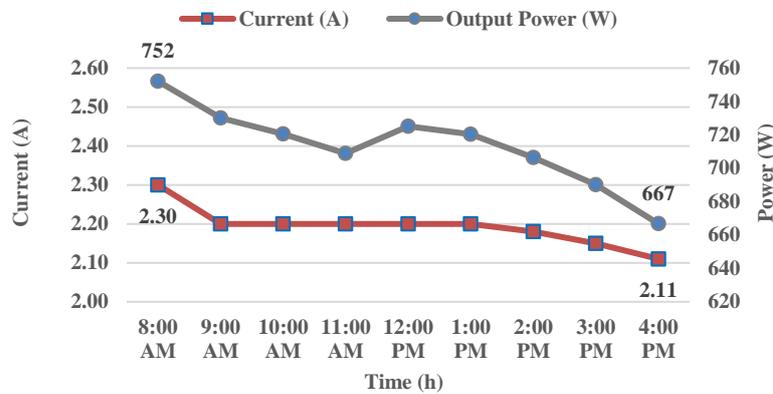


Figure 13. Current and output power

### 3.5. Performance and efficiency

The amount of power performance of solar panels in this study is 78.37%. Meanwhile efficiency ( $\eta$ ) of 27.73%. This is strongly influenced by the increase in cell temperature [35] which reaches an average increase of 50.9°C.

## 4. CONCLUSION

An experimental investigation has been conducted to evaluate the performance of the existing rooftop solar system at Universitas Pamulang. The effects of cell's temperature to the output power were studied considering hot climate throughout the day. In the late afternoon, the level of solar irradiation begins to decrease and affects the cell's temperature level. An increase in cell temperature will certainly have an impact on the efficiency of solar panels. From the analysis, an average cell temperature has reached 94.68% of the cell temperature condition based on the NOCT. At the same time, solar irradiation and load energy consumption begins to decrease. From the results of the experimental investigations, power performance of solar panels was measured around 78.37% and efficiency of 27.73%. This result strongly influenced by the increase in cell's temperature. Therefore, the low efficiency value with a cell temperature of 50.9°C indicates that this system requires an external solar panel cooling system.

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