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The effect of fins on PCM containers on solar panel cooling performance

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ABSTRACT

Solar energy is a renewable energy source that is abundant and emits low emissions. The operating temperature of a solar panel has a significant impact on its efficiency. A 50 Wp polycrystalline solar panel was tested in this experiment using PCM (paraffin) as a passive cooling solution and without it. The PCM was placed on the backplate of the solar panel using a container equipped with fins to enhance cooling efficiency. Simulations were conducted using a solar simulator with varying light intensities of 470 W/m², 650 W/m², 900 W/m², and 1000 W/m², while a blower was used to simulate constant airflow around the surrounding area.Evaluating the panel temperature and calculating the error rate in experimental findings were the goals of the simulation. According to the simulation, the average temperature of a solar panel without cooling reached 59.4°C at an intensity of 1000 W/m2, but the temperature dropped to 57.8°C and 55.4°C, respectively, when PCM cooling with 5 and 10 fins was used.This experiment demonstrated that the application of PCM with a modified container can lower the maximum temperature of the solar panel and increase its maximum efficiency by 1.15% at an intensity of 1000 W/m². This passive cooling system has proven to be effective in reducing the operational temperature of solar panels.

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1. INTRODUCTION

Increasing concerns about population growth and rapid technological developments have a major impact on the increasing need for energy. Renewable energy in recent years has received a lot of attention and has become a hope to meet the world's energy reserves, while also offering a more sustainable and environmentally friendly alternative compared to non-renewable energy sources such as fossil fuels which are the main contributors to the greenhouse effect, such as methane gas, carbon dioxide and nitrogen oxides which are emitted in large quantities during the combustion process, and this effect will also continue to increase along with increasing energy consumption (Olabi and Abdelkareem, 2022).

Renewable energy, particularly solar energy, has become a major focus in efforts to reduce dependence on fossil fuels and combat climate change. Solar energy offers a variety of benefits, from reducing carbon emissions to providing a source of energy in remote areas (Ngonda, 2023).Solar panels or photovoltaic (PV) are

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a technology used to utilize solar energy by converting solar radiation into electrical energy, which can be used for various purposes, from lighting homes to driving water pumps (Harahap, 2023; Pulungan et al. 2019).There are several types of solar panels, one of which is polycrystalline solar panels, which are quite popular because their prices are relatively affordable, with varying energy conversion efficiencies, generally ranging from 15% to 20%, which is still relatively low (Monika et al. 2023; Mulyadi et al. 2021). The efficiency of solar panels depends on various factors, including temperature, surface conditions, weather, and the monitoring techniques used.

One of the main factors that affects the efficiency of solar panels is temperature, the efficiency of solar panels tends to decrease as the module temperature increases (Achmad 2023; Laksana et al. 2022). Therefore, an effective cooling system, such as the use of water to cool the panel surface, the use of wind flow, the addition of an active cooling system and also the use of materials that can absorb heat in the module such as phase change materials (PCM) can significantly increase efficiency, in addition, the use of proper cooling can also help in the maintenance of solar panels because high temperatures can damage the components of the module and even burn.

Research by Achmad shows that the use of a cooling system can increase the output power of solar panels by up to 6.98 Watts compared to panels without cooling(Achmad, 2023).Another effective method is active cooling with the use of nanofluid-based photovoltaic (PV/T) thermal collectors, which leads to an increase in electrical efficiency of up to 4.7% (Arifin et al. 2023).In a study conducted by Saputra, the addition of heatsinks to solar panels resulted in better efficiency compared to panels without a cooling system. They noted that the efficiency of flexible solar panels equipped with heatsinks reached 19.39%, higher than vertical panels that only used heatsinks (Saputra and Ramadhan, 2023). Previous studies have shown that the use of heatsinks can improve the efficiency of solar panels, the installation of heatsinks can significantly reduce the temperature of solar modules, thereby increasing the output voltage and overall system efficiency (Denk, Pandria, and Firnanda, 2022).

In solar panel cooling methods, there are two, namely active and passive cooling, which each have their own advantages and disadvantages (Arifin et al. 2020). Active cooling has more effective cooling capabilities but uses external energy sources to operate such as adding pumps for water or air circulation in the cooling process. While passive cooling does not require additional energy sources to operate, namely by relying on design and materials to reduce the temperature of the solar panels (Seto et al. 2024).In general, active methods tend to be more expensive and complex than passive methods, as they require external energy to operate. Therefore, this study will focus on passive methods, which are attractive due to their simplicity and potential cost savings in both initial investment and ongoing operational costs for solar panel cooling. Several passive methods can be combined to improve cooling efficiency, including the use of phase change ametraial (PCM). PCM has high latent heat capability due to its large capacity during phase change phenomena at a certain level making it an excellent choice for various energy storage and temperature control applications (Veva, Fitri, and Wardhana, 2023). A modified PCM container incorporating fins will be used in this application, with the fins serving as an alternative approach to increase the heat transfer rate in the PCM. This fin addition method is also interesting because the cost is relatively affordable and the maintenance costs are minimal. which will be combined with the design of the modified PCM container with the addition of fins in it.

A PCM container modified with the addition of fins will be applied in this study. Fins serve as an alternative method to enhance the heat transfer rate in PCM. This method is particularly appealing due to its relatively low cost and minimal maintenance requirements. It will be combined with a modified PCM container design that incorporates fins within it.

2. RESEARCH METHODS

The commonly sold polycrystal solar panel module with its characteristics and specifications described in Table 1, was used in all of these experiments. The installation of solar panels together with PCM containers with a thickness of 2 mm, 5 aluminum fins is illustrated in Figure 1. Figure 1 describes the PCM container made to adjust to the shape of the back of the solar panel to be used so that it can be installed properly to obtain maximum results.

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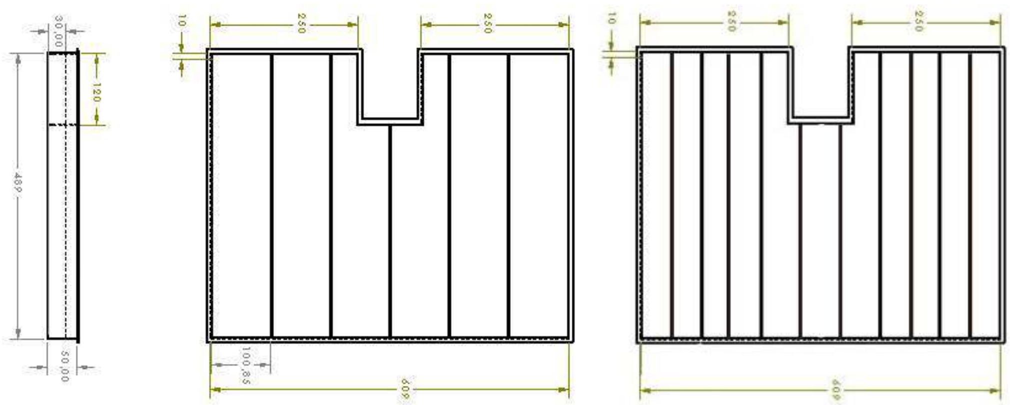
Table 1. Specifications of the Yingli 50 Wp solar panel

Spesification	Information
Panel surya	Polycristalline 156mm x 52 mm
Open-circuit voltage (VOC)	22.9 V
Short-circuit current (ISC)	2.87 A
Maximum power (PMPP)	50 Wp
Efficiency Panel	14 %
Operating panele temperature	-40 - 85°C
Dimensions (P/L/T)	660 mm /540mm / 25mm
Temperature coefficient of power	-0.45 % per °C



a b

Figure 1. Dimensions of PCM containers with, a. 5 fins and b. 10 fins

The Organic PCM chosen in this experiment is paraffin. Organic PCM has a fixed melting point temperature range, is non-toxic, colorless and most importantly easy to obtain. Paraffin is one of the most common organic PCMs on the market, paraffin has a lower melting point temperature and higher latent heat of fusion compared to conventional heat storage materials, such as water, which makes it an attractive option to improve the efficiency of cooling and heating systems (Nadjib et al. 2023).Paraffin is non-corrosive and therefore safe for solar panel components. Its low thermal conductivity not only limits its cooling performance during the day but also affects its heat dissipation to the surrounding at night. This can be improved by inserting metal fins in the PCM container.

Figure 2. Paraffin material

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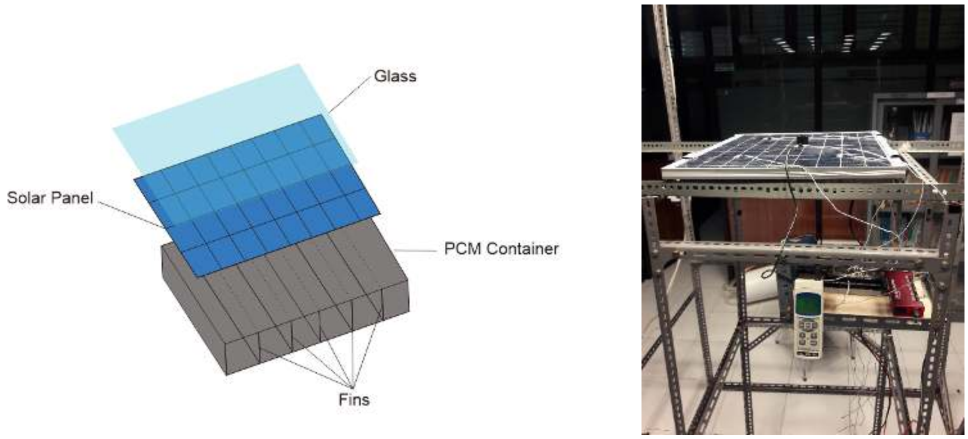
The experiment utilized a solar simulator with halogen lamp light as a substitute for sunlight. The solar panel was positioned 75 cm away from the halogen lamp, as illustrated in Figure 3.



a b

Figure 3. a. View of the solar panel module with a passive cooling system installed, b. Experiment setup

Temperature data collection using K-type thermocouples with an accuracy of 0.75% + 1°C. Thermocouples are placed above and below the solar panel which will later be connected to the U6 Pro lab jack data logger as a temperature reader. Paraffin PCM is added to the back of the solar panel which aims to maintain the normal working temperature of the solar panel. The paraffin PCM is melted and then poured into a PCM container that has been equipped with fins in it with a depth of 50 mm. Data collection is carried out after the paraffin PCM has solidified again after being left overnight at room temperature. The passively cooled solar panel was mounted on a solar simulator equipped with two halogen lamps. A dimmer was used to regulate the current supplied to the lamps, allowing control over the light intensity. The light intensity was measured using a Lutron SPM-1116SD solar power meter, with an accuracy of ±5%. Data were collected at light intensities of 470W, 650W, 900W, and 1000W, with measurements taken for 30 minutes at each intensity level to observe the variation in temperature and power output of the solar panel. In addition, a multimeter was used to monitor the open-circuit voltage and short-circuit current of the PV module at various light intensities.

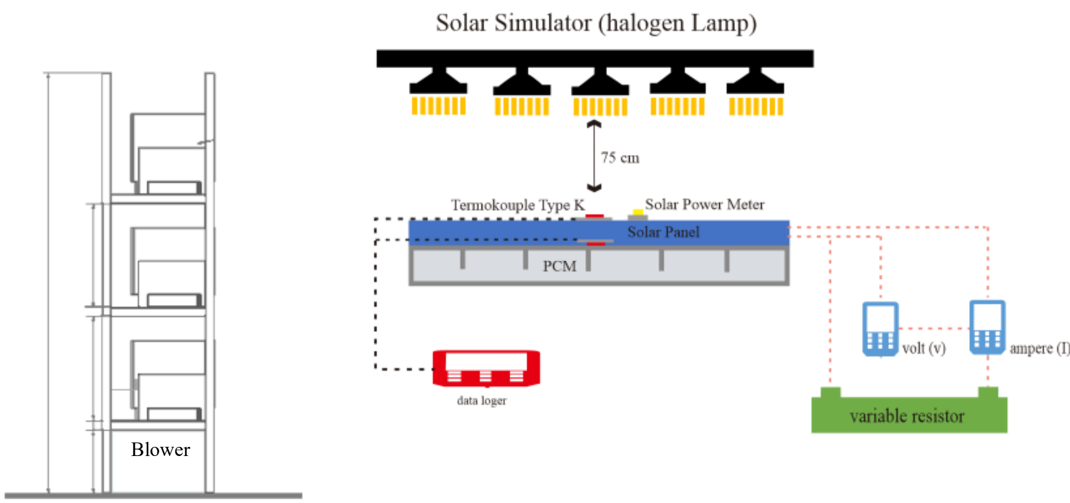


Figure 4. Experimental research work series

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The maximum power that a solar panel can produce during its working period can be calculated using the equation (Dahliya, Samsurizal, and Pasra, 2021):

$$P_m = I_m V_m = (FF) I_{sc} V_{oc} \quad (1)$$

Where Pm represents the maximum power, FF stands for the "Fill Factor," Im is the maximum current, Vm is the maximum voltage, Voc is the open circuit voltage, and Isc is the short circuit current. As the temperature rises, both Voc and FF tend to decrease.

Solar panel efficiency (η) is the ratio of Pm to the power from solar radiation received by the solar panel (P_{light}). Where Plight is the multiplication of sunlight intensity (I_{rad}) with the active area of the solar panel (A). If the panel has good efficiency, the power generated will be maximized and the losses will be smaller. The amount of panel efficiency can be calculated using the following equation (Benitez-Lara et al. 2025):

$$\eta = \frac{P_m}{P_{light}} = \frac{P_m}{I_{rad} \cdot A} = \frac{I_{SC} \cdot V_{OC} \cdot FF}{I_{rad} \cdot A} \quad (2)$$

3. RESULTS AND DISCUSSION

This article discusses the passive cooling system of polycrystalline solar panels with a combination of PCM (Paraffin) material and modifications made to the PCM container with the addition of fins to increase the efficiency of the solar panel by maintaining the condition of the sun at the optimal working range of the solar panel. This section compares solar panels without cooling systems using experimental assessments based on important variables such as average solar panel temperature, open circuit voltage, maximum power, and efficiency. Figure 5 shows how solar panel temperature is affected by light intensity.The experiment includes variations such as uncooled solar panels and panels equipped with passive paraffin PCM cooling, utilizing containers enhanced with 5 and 10 fins.

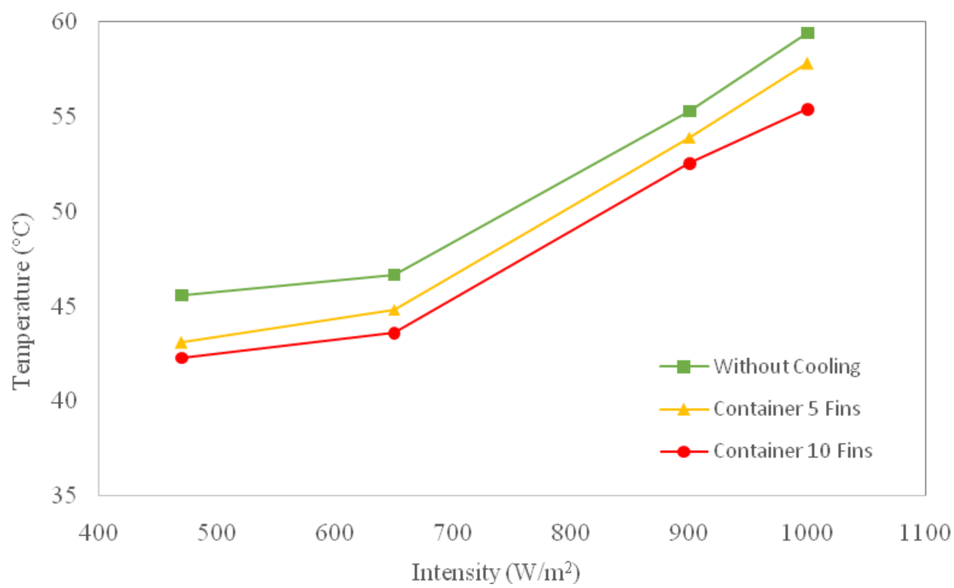

Figure 5. Relationship between solar simulator intensity (W/m^2) and PV temperature (°C)

Figure 5 shows that light intensity significantly affects the temperature of the solar panel, with higher light intensity causing an increase in the operating temperature of the panel (Laksana et al. 2022). For the uncooled solar panel, the maximum temperature reached 59.42 °C at a light intensity of 1000 W/m². Figure 5 shows that light intensity significantly affects the temperature of the solar panel, with higher light intensity causing an increase in the operating temperature of the panel. On the solar panel without a cooling system, the maximum temperature reached 59.42 °C at a light intensity of 1000 W/m². In contrast, the solar panel equipped with PCM and 5-fin housing reached a maximum temperature of 57.81 °C under the same conditions, while the panel with PCM housing and 10 fins recorded the lowest maximum temperature of 55.4 °C. The largest temperature decrease, 4.02 °C, was observed for the solar panel with PCM housing and 10 fins.

The maximum power of solar panels or Maximum Power Point (MPP) is an important parameter in photovoltaic systems that determines the efficiency of converting solar energy into electrical energy. Maximum Power Point is a certain point on the current-voltage (I-V) curve of solar panels which is the maximum point of

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the multiplication of current and voltage so that it produces the highest possible output power under certain environmental conditions, such as temperature and solar radiation intensity (Awan et al. 2022).

The maximum Power Point obtained in this experiment also shows that intensity has a large influence with the higher the intensity of solar radiation, the higher the maximum power produced, but because the working temperature of the solar panels is also high, the maximum power produced is not as expected. In solar panels with passive cooling, the maximum power produced increases compared to solar panels without cooling.

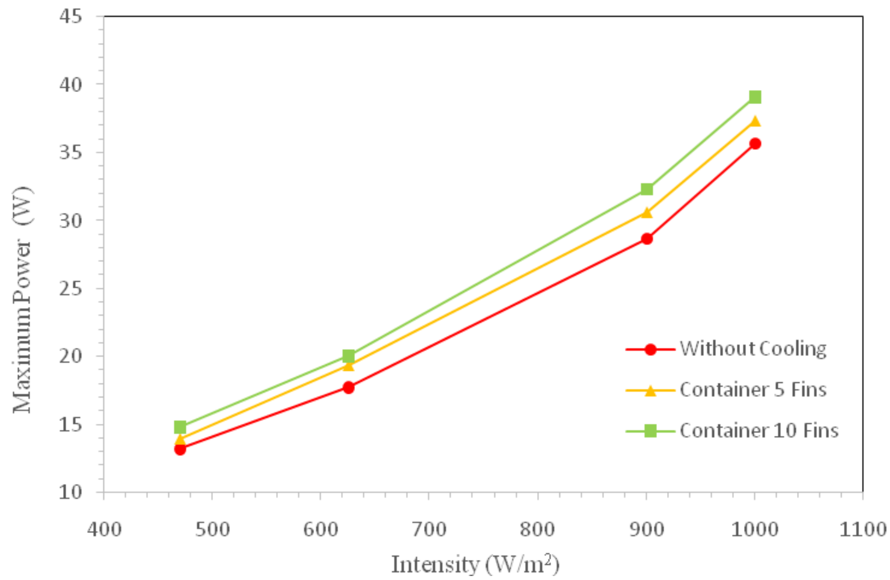

Figure 6. Effect of intensity (W/m^2) on maximum power (Watt)

From Figure 6. it can be seen that the maximum power obtained is different in the solar panel module without cooling and after the cooler is installed at the same light intensity. At a light intensity of 1000 W/m2 the maximum power produced by the solar panel without cooling is 35.70 W, while on the solar panel with a 5 fins PCM container cooler it is 37.39 W and the highest maximum power is obtained in the variation of the 10 fins PCM container cooler solar panel which is 39.11 W, a significant increase compared to the solar panel without cooling. On the solar panel with a variation of the 10 fins PCM container, the maximum power produced increases along with the increasing light intensity received by the solar panel, namely at an intensity of 450, 650, 900 and 1000 Watts reaching a maximum power of 14.80 W, 20.04 W, 32.35 W and 39.11 W respectively which are the highest maximum powers in this study.

The higher maximum power generated is a result of the efficient performance of the solar panel, achieved through the application of a passive cooling method to regulate the panel's temperature and maintain it within the optimal operating range. When the panel's working temperature is lower, its efficiency is higher compared to when the panel operates at higher temperatures under the same light intensity. Data collection process was conducted as a function of time, with each cooling variation being tested simultaneously. This included a 15-minute period for intensity stabilization followed by 15 minutes of solar simulator exposure. The efficiency results obtained in this study are presented in Figure 7.The data calculations indicate that the solar panel utilizing passive PCM cooling with a 10-fin container achieved the highest efficiency among all configurations, reaching 11.16% at a light intensity of 1000 W/m² and a panel temperature of 55.4℃. In contrast, the solar panel without any cooling system recorded a maximum efficiency of 10.01% under the same light intensity, with a working temperature of 59.4 ℃. This highlights that the solar panel with PCM cooling and a 10-fin container delivered a 1.15% higher efficiency compared to the non-cooled panel.

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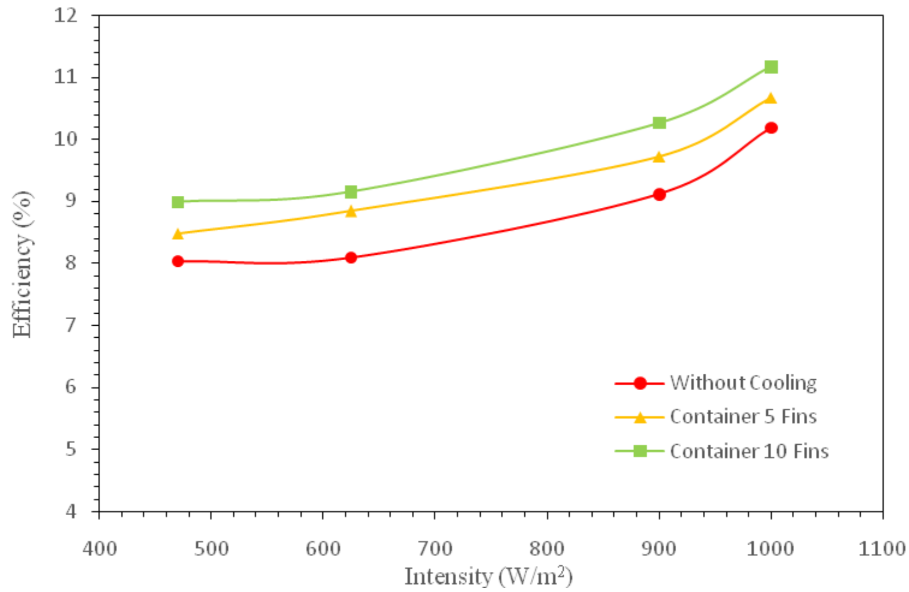

Figure 7. Effect of intensity (W/m^2) on efficiency (%)

The addition of fins shows an increase in performance in the cooling process, which is caused by several main factors. The addition of fins has an impact on increasing air flow around the container. Machi(Machi et al. 2021)noted that additional fins can accelerate the convection process around the surface of the container. Heat transfer through the convection mechanism becomes more optimal, thus accelerating the process of releasing heat from the system to the surrounding environment. According to Li (Li et al. 2020), the more fins used, the greater the surface area available to transfer heat. This has a direct impact on increasing cooling capacity because heat can be transferred more effectively from the surface of the container to the surrounding environment. In addition, increasing the number of fins also contributes to a more even temperature distribution. With a greater number of fins, the temperature on the surface of the container can be distributed more evenly, reducing the possibility of hot spots that can interfere with the performance of the cooling system.

From the addition of fins with two variations of 10 fins showed better performance compared to 5 fins. However, it should be noted that although increasing the number of fins provides better benefits, there are limitations to effectiveness that need to be considered. Cooling effectiveness will not increase linearly with the addition of the number of fins (Subekti, Wahyudi, and Gapsari, 2023). This is due to factors such as space constraints, decreased airflow that may occur in overcrowded areas, and the possibility of increased thermal resistance under certain conditions.

4. CONCLUSION

The experiments that have been conducted, there are several findings. The addition of fins to the PCM container shows an increase in the ability of the solar panel cooling system which occurs because the addition of fins increases the surface area of heat transfer from the solar panel to the PCM, the heat distribution in the container is more even and the convection process that occurs in the PCM container can work more optimally. This study shows that the use of PCM with 10 fins can reduce the temperature of the solar panel by 4°C lower than without cooling and also better than adding only 5 fins, with a maximum power output of 39.11 W, and the efficiency obtained is 11.16% showing an increase of 1.15% when compared to solar panels without cooling at a light intensity of 1000 W/m^2. This system is effective, simple, and cost-effective in maintaining optimal temperatures and improving solar panel performance.

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