The Experimental Study of the Use of Heatsink and Salt Hydrate as Passive Cooling System at Solar Modules

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Abstract: Photovoltaic cells formed into solar module devices are a system for converting solar energy to electrical energy. The performance capability of photovoltaic modules is generally influenced by several factors, including solar irradiance, solar module types, temperature and sunlight spectrum. The temperature on the surface of the solar module can have a direct impact on the voltage and current produced by the solar module. One way to reduce the influence of panel temperature can be overcome by implementing passive cooling techniques. This research analyzes the comparison of a passive cooling system by installing a heatsinks and salt hydrates material to increase the output parameters of solar module compared to standard module without passive cooling system. The measurement result shows that passive cooling system using the heatsink is better than using salt hydrate. Direct measurements carried out at the research location showed using a heatsink as a coolant is able to lower the temperature of the solar module by an average of 3.7 °C and for Salt hydrate cooler is 1.4 °C, that the heatsink was effective to reducing the average temperature 48.94 °C to 45.29 °C and the salt hydrate material was effective in reducing the average temperature from 48.94 °C to 47.57 °C. The average output voltage is 16.34 Volt and the output power reaches 72.79 Watt using heatsink as a coolant. Then the average output voltage is 15.62 Volt and the output power reaches 66.45 Watt using salt hydrate as acoolant , thus achieving an efficiency of 11.93% using heatsink and 10.92% with salt hydrate, compared to standard module without cooling system of 10.34% for an average irradiance of 896.67 W/m^2 at the time of measurement.

Keywords: Heatsink, salt hydrate, photovoltaic modules, passive cooling system

1. Introduction

The use of solar energy is considered very important as one of the cleanest and easiest alternative energies among various other energy sources. There are several methods for utilizing solar energy, including the use of thermal and photovoltaic cells [1, 2]. Researchers in the field of photovoltaics face many challenges with this energy conversion method, for example it is not possible to convert all sunlight irradiation into electrical energy because this is related to the technical performance problem of solar modules. Another problem is that the costs associated with utilizing and storing solar energy can be relatively high due to the larger system costs.

A solar module is an array consisting of several photovoltaic cells, which are specifically designed for the conversion of solar irradiation into electrical energy by utilizing the photovoltaic phenomenon. An innovative approach is needed to design solar panels capable of increasing conversion efficiency and reduce production and maintenance costs. In general, the performance of solar modules is influenced by various factors, including of solar module types, solar irradiance, module temperatures and distribution of sunlight across the modules surface. The surface temperature of the solar panel has a direct impact on the voltage and the current it produces. If the temperature of the solar panel can be lowered, it can increase its conversion efficiency, while solar irradiation and wind speed also has a significant influence on the performance of solar panels [3, 4]. Solar irradiation will always fluctuate based on location, time and weather conditions [5].

Solar cell energy conversion systems require a failure protection system to improve reliability, system stability, efficiency and safety [6, 7]. Several loss mechanisms in solar modules limit efficiency, such as photon losses, minority carrier losses, Joule heat losses, optical losses, resistive losses, recombination losses, and reflection losses. For the lifetime of monocrystalline and polycrystalline solar cells exceeds the lifetime of thin film solar cells, however the performance and efficiency of solar cells monocrystalline and polycrystalline decreased significantly with increasing temperature [8, 9].

Methods such as air cooling, liquid cooling, immersion cooling, and phase change material are used to increase the efficiency of solar panel modules. In recent years development of PV cooling techniques using hybrid nanofluids exhibit significant potential in enhancing solar collector efficiency due to their superior thermo-physical properties compared to conventional fluids [10–12].

Solar module cooling systems consist of two types, namely active cooling system and passive cooling system. Active cooling system require additional electrical energy to work to reduce surface temperature solar module, while the passive cooling system does not require electrical energy to reduce the panel temperature like using the heatsink installed under the solar module. The passive cooling technique for solar modules functions as a way to maintain or reduce the temperature of the solar module. Thermal resistance, defined as the ratio between the regulated temperature difference and heat dissipation, serves as important parameters for using a heatsink as a passive cooler. The thermal resistance of the heatsink is influenced by the air flow rates and heatsink geometry. Usually solar modules function optimally at a standard temperature of 25 °C [13, 14].

Sufficient wind speed will significantly help maintain the cell surface temperature around 25 °C [15]. Any increase in temperature beyond this threshold will weaken the voltage produced by the solar module [16]. An increase in solar modules surface temperature of 1 °C above 25 °C will affect the total power output of the panel [17]. Considering the sensitivity of solar modules performance to temperature, it is very important to regulate the surface temperature within permissible limits to achieve maximum output power [18]. If the temperature of the solar module rises for a long time, it will impact the conversion efficiency and potentially cause damage, then it is very important to regulate the surface temperature of solar module and remove excess heat efficiently [19, 20].

This research will analyze the comparison using two types of passive cooling system, namely heatsink and salt hydrate (C_aCl_2) as phase change material to increase the output parameters of solar module which will ultimately increase the conversion efficiency of the solar module. The solar module that will be used is a polycrystalline type with an output power of 100 W.

2. Photovoltaic Solar Modules

A solar module is a device capable of converting sunlight into electrical energy through a process involving negative and positive electron flows within its cells, driven by potential differences among these electrons. When a resistive load is connected, the current will be lower than the short-circuit current (I_{sc}), and the voltage will also be lower than the open-circuit voltage (V_{oc}). The cell's output power can calculated from Eq. (1).

$$P = I \cdot V \tag{1}$$

where the following conditions are always valid $I < I_{sc}$ and $V < V_{oc}$.

To obtain the maximum power conditions we derive the diode equation above and set it equal to zero, from Eq. (2):

$$dP = (IV) = IdV + VdI = 0 \tag{2}$$

And from Eq. (3) we get the maximum power output at:

$$P_{mp} = I_{mp} \cdot V_{mp} \tag{3}$$

Eq. (4) the fill factor of a solar cell (FF) is a parameter used to evaluate the quality of the current-voltage curve, it is given by:

$$FF = \frac{P_{mp}}{I_{sc} \cdot V_{oc}} =\cdot \frac{I_{mp} \cdot V_{mp}}{I_{sc} \cdot V_{oc}} \tag{4}$$

Thus, from Eq. (5) the solar cell's power conversion efficiency, η is determined by the ratio of the solar cell's output power to the incident light power entering the cell, also known as the input power.

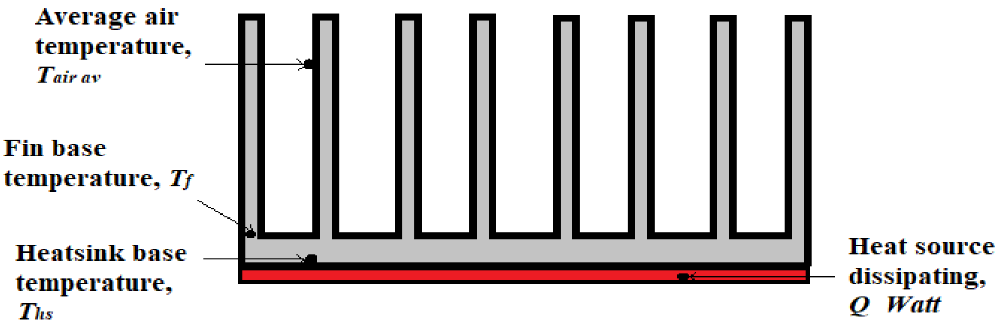
$$\eta = \frac{P_{out}}{P_{in}} = \frac{FF \cdot I_{sc} \cdot V_{oc}}{P_{in}} \tag{5}$$

The efficiency of various types of solar modules significantly varies. Polycrystalline solar module exhibit efficiency suited for equatorial regions like in Indonesia. These panels feature a random crystal arrangement. The characteristics of a polycrystalline type solar module at temperatures ranging from 25 °C. to 39 °C show a direct proportionality to output voltage of solar module. Many polycrystalline 100 Wp solar module brands demonstrate effective electricity generation when temperatures exceed 34 °C. They are capable of charging a 12 Volt 32 Ampere battery, starting from an initial voltage of 5 Volt and reaching the rated voltage of 13.8 Volt within 8 hours.

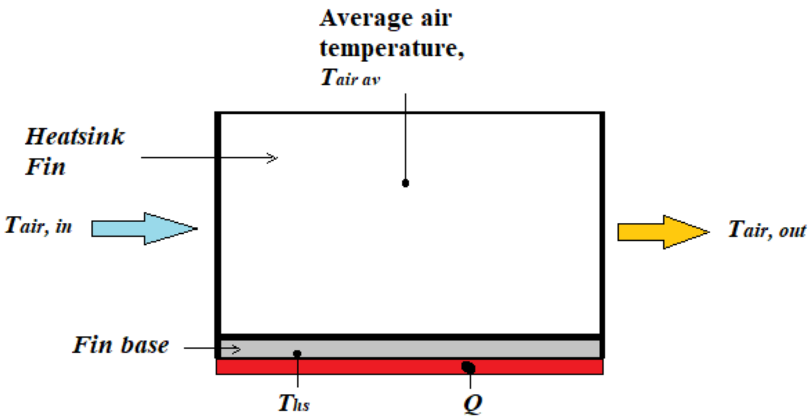
2.1. Heatsink as a Coolant

Standard heatsink can lower the temperature of solar cells and result in an increase in power output of 6% [21]. The heatsink installed on the panel functions to absorb and release or eliminate heat on the solar module and ensure the solar module operate at temperatures below the maximum temperature at which they occur. Intermediate thermal barrier the heatsink surface with solar module can limit heat transfer efficiency. Heatsink effectiveness also influenced by the thermal resistance value [22].

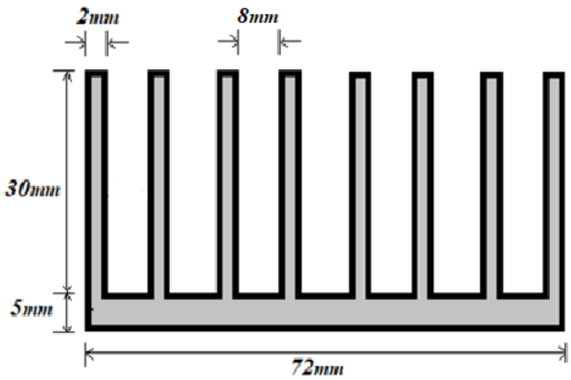
The heatsink material used in this cooling system is made from Aluminium bar. A total of three Aluminium bars are used and installed under the solar module. The size of the installed Aluminium heatsink is 650mm in length, with a fin height of 30 mm and a heatsink base height of 5mm. There are eight vertical fins in total each Aluminium bar.



(a)



(b)



(c)

Fig. 1. Heatsink (a) Volume Control (b) Fins air cooling (c) Heatsink Dimension.

Fig. 1. shows the heatsink designed to optimize heat absorption and dissipation. The function of fin shapes of the heatsink to expand the heat transfer areas, facilitating rapid heat dissipation. The material with high thermal conductivity are essential to achieve optimal fins efficiency values such as Aluminium heatsink which used in this study.

When selecting a material, thermal resistance measures a Heatsink's capability to dissipate heat effectively. A lower thermal resistance value in the heatsink indicates superior heat dissipation. Employing a heatsink, which relies on electrothermal heat transfer, can significantly enhance device performance [23]. The Heatsink is designed to optimize the absorption and dissipation of heat. Fins incorporated into the heatsink serve to amplify the heat transfer area, facilitating rapid heat dissipation. Materials boasting high thermal conductivity are essential for achieving optimal fin efficiency values.

Thermal transfer models applied to heatsinks with fins (passive cooling, natural convection) have been developed [20]. Thermal resistance signifies a material's capacity to impede the flow of heat when a temperature gradient exists between its surfaces. This property can be expressed using the following equation.

$$R = \Delta T/q \tag{6}$$

where R represents the Thermal Resistance of the material, ΔT indicates the Temperature difference, and q denotes the Heat transfer rate. The utilization of finned plate heatsinks aims to reduce thermal resistance and lower component operating temperatures. This objective is achieved by expanding the cooling surface area through the plate fins and enhancing the coefficient of convection heat transfer. One prevalent type of heatsink widely used today is the extruded finned plate. This heatsink configuration comprises an array of thin strip plate fins affixed to a common base plate. The fins on the heatsink plate have a square shape and relatively thin thickness, allowing for heat transfer analysis approaching the isolated end fins of the heatsink.

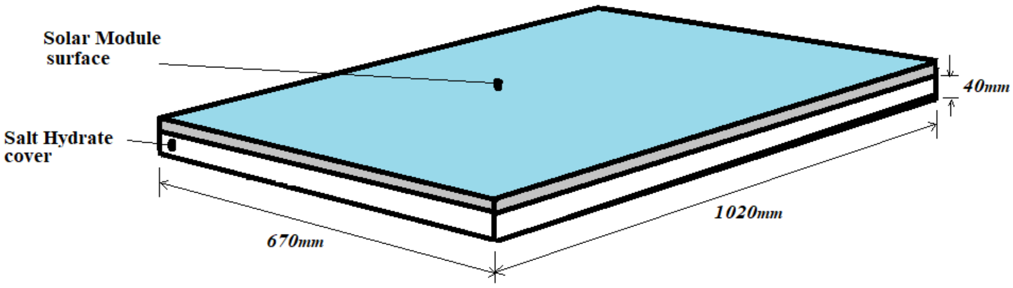
2.2. Salt Hydrate as a Coolant

Another method for cooling solar module surface is use phase change material or PCM. This material is capable of absorbing heat in the form of latent heat which is followed by a solid to liquid phase change over a range almost constant temperature and can dissipate heat as desired. In this work, we used salt hydrate (C_aCl_2) mounted on the back of the solar module. The advantages of salt hydrate include, have a low melting point but easily crystallizes at room temperature, high thermal conductivity. The good properties of this salt hydrate are that the latent heat of fusion per unit volume is high, the thermal conductivity is relatively high and the volume change during melting is small, not too corrosive, compatible with plastic materials [24, 25].

Salt hydrate as phase change materials (PCM) have gained widespread use and improved the performance of photovoltaic systems due to their ability to regulate temperature. Many researchers have incorporated these PCMs into photovoltaic system. However, the material tested is basically organic PCM. In this works a photovoltaic system using inorganic PCM is introduced. Salt hydrated generally have comparative properties like organic PCM and better from a safety and environmental point of view.

Fig. 2 shows the image of the salt hydrate used and the size of the cover where the salt hydrate is installed. The amount of salt hydrate installed on the back part of the solar module is 0.027 cubic meters for solar module.

(a)



(b)

Fig. 2. (a) Salt Hydrate (C_aCl_2) and (b) Salt Hydrate cover dimension.

3. Proposed Cooling of Solar Modules

3.1. Solar Modules Cooling Design

The heatsink functions as a cooling device utilized to lower the temperature of electronic components by transferring heat from the component to the air through metal fins connected to a flat base. These sinks find common use in electronic components like CPUs, GPUs, and solar panels. Various factors impact heatsink efficiency, including its size, shape, airflow volume, and thermal conductivity. Larger heatsink sizes and increased airflow generally lead to better heatsink performance. Additionally, the specific shape of the heatsink influences its efficiency, shapes with greater surface area facilitate improved heat dissipation. Moreover, thermal conductivity significantly affects heatsink efficiency, with superior materials exhibiting higher thermal conductivity.

The Heatsink working principle involves transferring heat from the installed electronic components to the surrounding environment through conduction, convection, and radiation processes. Conduction refers to the process of heat transfer through the materials comprising the heatsink. Heat flows through the material, moving from hot spots to cold spots. From Eq. (7) the heat transfer rate via conduction can be expressed as follows:

$$q = kA\frac{(T_1 - T_2)}{l} \tag{7}$$

where k is thermal conductivity, A is the surface area of an object, $(T_1 - T_2)/l$ is the heat transfer gradient. Convection involves transferring heat through the movement of fluids, like air or liquids. Here, the air gets heated by the Heatsink's surface and then moves away from the electronic components. The underlying principle for heat transfer via convection can be described from Eq. (8) as follows:

$$q = hA(T_w - T_f) \tag{8}$$

where h heat transfer coefficient, A is the surface area of an object, T_w is the objects surface temperature, and T_f is the fluid temperature.

3.2. System Arrangement

This study employs a passive heatsink due to its inherent advantages in natural air cooling, without the need for additional equipment. A passive heatsink is a component utilized for heat dissipation from a heat source without relying on a fan or an active cooling system. These heatsink are designed with shapes and structures that enhance the surface area, maximizing heat transfer to the surrounding air.

Heatsinks made from a material with high thermal conductivity, like aluminum or copper, utilize both heat conduction and radiation in passive cooling. Passive heatsinks function through heat conduction, transferring heat from the source to the broader surface of the heatsink. Subsequently the heat spreads uniformly across the fins surface. In this study, the heatsink used is made from aluminum rod material. Its fin shape is vertical and consisting of 8 fins.

Once the heat is evenly distributed within the heatsink, it dissipates into the surrounding air through both conduction and radiation. Passive heatsinks leverage the temperature variance between the heat source and the ambient air to facilitate efficient heat transfer, similar to an active heatsink. However, the effectiveness of passive heatsinks significantly relies on environmental conditions, especially adequate air circulation.

Solar module are employed to transfer heat from the source to the heatsink, which functions as a cooler. The design of the heatsink ensures an even and rapid distribution of heat received from the source across its surface. This facilitates immediate absorption by the surrounding airflow passing over the heatsink. The air acting as a cooling medium, carries the heat away from the heatsink and dissipates it into the surrounding environment, effectively eliminating heat from the solar module.

Fig. 3 shows the topology of experimental setup and it's evident that for optimal heat dissipation the solar panel needs maximum contact with the heatsink and salt hydrate, resulting in a decrease in the surface temperature of the solar panel. Consequently, the heatsink is connected to the solar panel to receive the generated heat from its surfaces. The heatsink then disperses the heat across its surface, allowing the surrounding airflow to promptly absorb it. This air subsequently disperses the heat into the surroundings, effectively cooling the heat source.

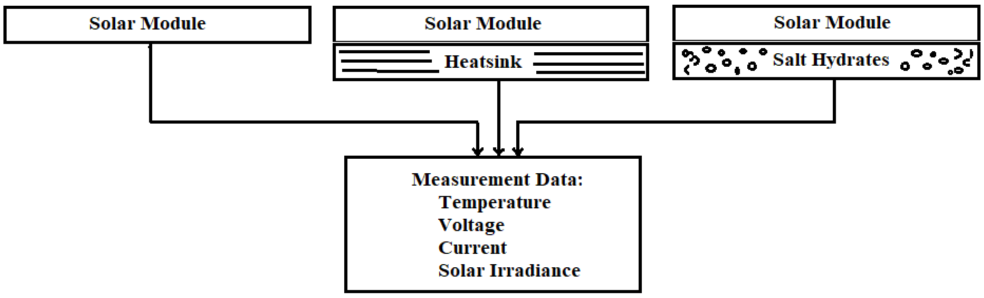
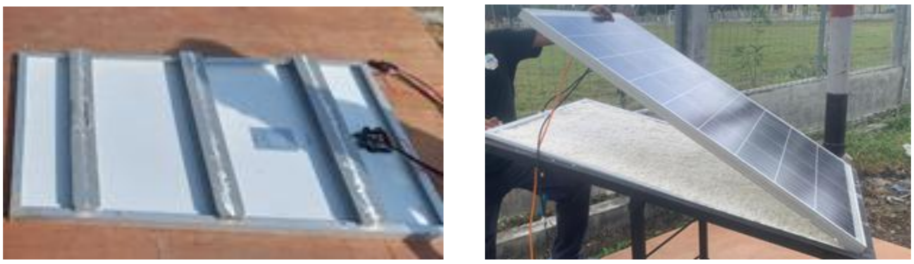


Fig. 3. Topology of the system measurement.

The design of this study encompasses design drawings illustrating solar panels equipped with heatsinks serving as coolers. The design arrangement for the experiments on cooling the surface of the solar module is in Fig. 4.



(a) (b)

Fig. 4. Design arrangement: (a) heatsink and (b) salt hydrate.

This tool is designed to assess the performance of heatsinks on solar panels under various sunlight intensity conditions. The primary components of this tool include solar panels, heatsink, solar light irradiance gauges, wind speed gauges, and temperature gauges. The specifications of the 100 Watt solar modules used in this research can be seen in Table 1 below.

Table 1. Solar Module Specifications

Specification	Unit
Rated maksimum power	100 W
Voltage at Pmax (V_{mp})	18 V
Current at Pmax (I_{mp})	5.56 A
Open-circuit voltage (V_{oc})	21.6 V
Short-circuit current (I_{sc})	5.99 A
Normal Operating Cell Temp (NOCT)	47 ± 2 °C
Cell Technology	Poly Si
Dimension (mm)	1020×670×30
E	1000 W/m^2
TC	25 °C

4. Results and Discussion

The solar module used in this experiment is the polycrystalline type with a length of 1020 mm and a width of 670 mm. The maximum output power is 100 Watt, from the module size we get the cross-sectional area value of module A = 0.68 m^2 , and to determine the input power the cross-sectional area of the module is multiplied by solar irradiance. The average solar irradiance obtained at the time of measurement was 896.67 Watt/m^2 , then to get power and efficiency using calculations based on Eq. (3) to Eq. (5). The measurements on this solar module system are located in Lhokseumawe city.

Measurements carried out on the module include module temperature, V_{mp} voltage, I_{mp} current and solar irradiance, which is carried out from 09.00 am to 05.00 pm. The temperature measurements were also carried out on the solar module which does not have a coolant installed under solar module as a comparison. The results of measuring the solar modules temperature show that there is a change in the surface temperature of the solar module compared to standard solar modules that passive cooling is not installed, thus affecting the V_{mp} voltage of the module.

Fig. 5 shows the graph of temperatures comparison of three solar modules. Polycrystalline solar modules, when equipped with a heatsink and module with salt hydrate, effectively lower the surface solar module temperature compared to standard modules without a passive cooling system installed. The values of temperature from three solar module show in Table 2.

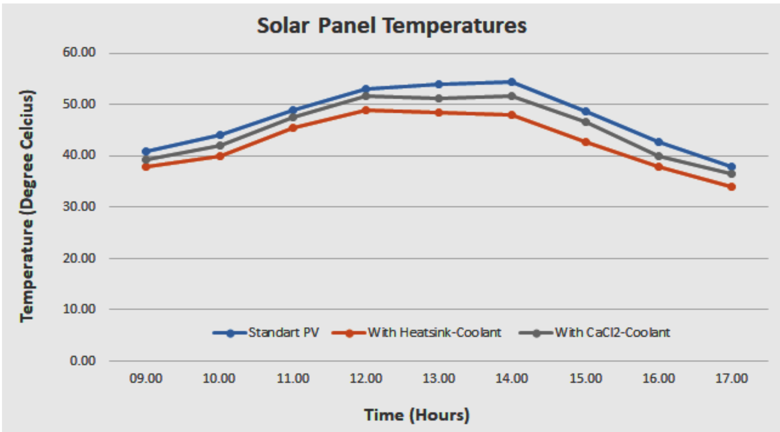


Fig. 5. The comparison of temperatures.

Table 2. Solar Module Temperature

Time (hours)	Standard PV (˚C)	Heatsink PV (˚C)	Salt Hydrate PV (˚C)
09.00	41.00	38.00	39.30
10.00	44.00	40.00	42.00
11.00	49.00	45.50	47.50
12.00	53.00	49.00	51.60
13.00	54.00	47.80	51.20
14.00	55.00	48.00	51.70
15.00	48.00	42.80	46.70
16.00	42.00	38.00	40.00
17.00	38.00	34.00	36.50

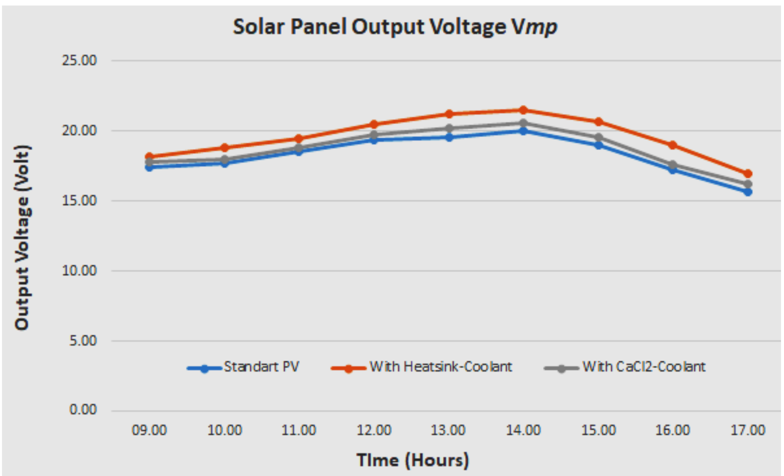


Fig. 6. The comparison of output voltage.

Fig. 6 shows the graph of voltage at maximum peak measurement of solar module, from graph, it can be seen that solar modules that have cooling will affect the increase in voltage compared to standard solar modules without cooling.

Fig. 7 shows the graph of current at maximum peak measurement of solar module, from graphs, it can be seen that solar modules that have cooling will affect the increase in current compared to standard solar modules without cooling, as well as the increase in current which is influenced too by variations in solar irradiance fluctuations during measurement.

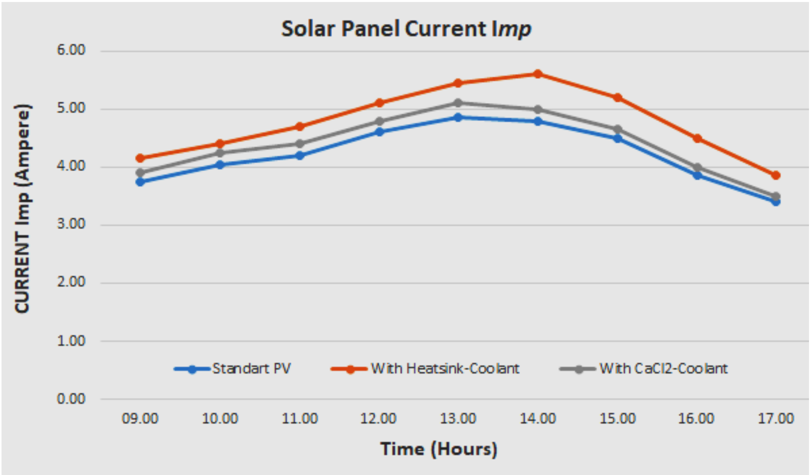


Fig. 7. The comparison of output current.

Fig. 8 shows graph of calculation result of the output power produced by the three solar modules in this system during the measurement. It can be seen that the solar module using heatsink cooling produces higher output power than the solar module using salt hydrate as coolant, reffered to the standard solar module. The solar irradiance level is high from 13.00 to 15.00 pm.

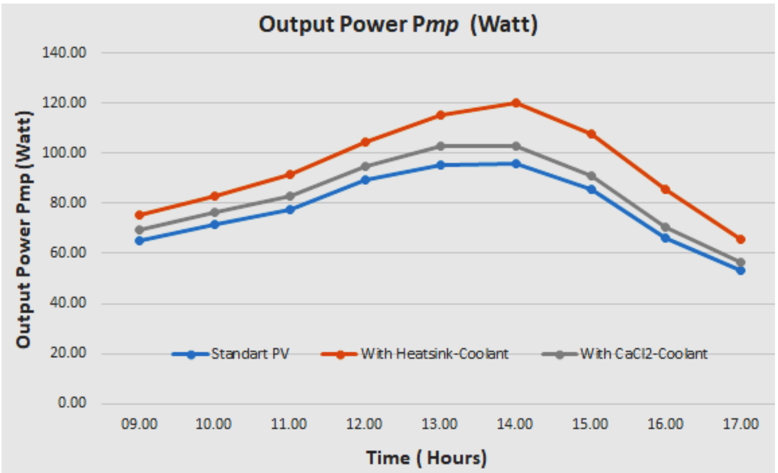


Fig. 8. The comparison of output power.

Tables 3 and 4 show the comparison of the values of the voltage and current of the solar module during the measurement. From the two tables, the difference in each solar module voltage is influenced by the passive cooler installed on the module, the standard solar module without passive cooler produces the lowest voltage. While the electric current produced is also influenced by solar irradiance.

Table 3. Solar Module Voltage (Maximum Peak)

Time (hours)	Standard PV (Volt)	Heatsink PV (Volt)	Salt Hydrate PV (Volt)
09.00	17.40	18.20	17.80
10.00	17.70	18.80	18.00
11.00	18.50	19.50	18.80
12.00	19.40	20.50	19.70
13.00	19.60	21.20	20.20
14.00	20.00	21.50	20.60
15.00	19.00	20.70	19.60
16.00	17.20	19.00	17.60
17.00	15.70	17.00	16.20

Table 4. Solar Module Current (Maximum Peak)

Time (hours)	Standard PV (Ampere)	Heatsink PV (Ampere)	Salt Hydrate PV (Ampere)
09.00	3.75	4.15	3.90
10.00	4.05	4.40	4.25
11.00	4.20	4.70	4.40
12.00	4.60	5.10	4.80
13.00	4.85	5.45	5.10
14.00	4.80	5.60	5.00
15.00	4.50	5.20	4.65
16.00	3.85	4.50	4.00
17.00	3.40	3.85	3.50

In this work, the utilized solar module was of the polycrystalline type, 1020 mm in length and 670 mm in width, with a maximum power output rating is 100 W. The temperatures were measured on the solar module with a standard solar module as reference and compared with solar module heatsink and solar module with salt hydrate coolant. The measurements indicate a noticeable decrease in temperature on the solar module equipped with the added heatsink coolant compared to salt hydrate coolant.

From Fig. 9 shows that during the measurement, the average solar irradiance recorded was 905.56 W/m^2.

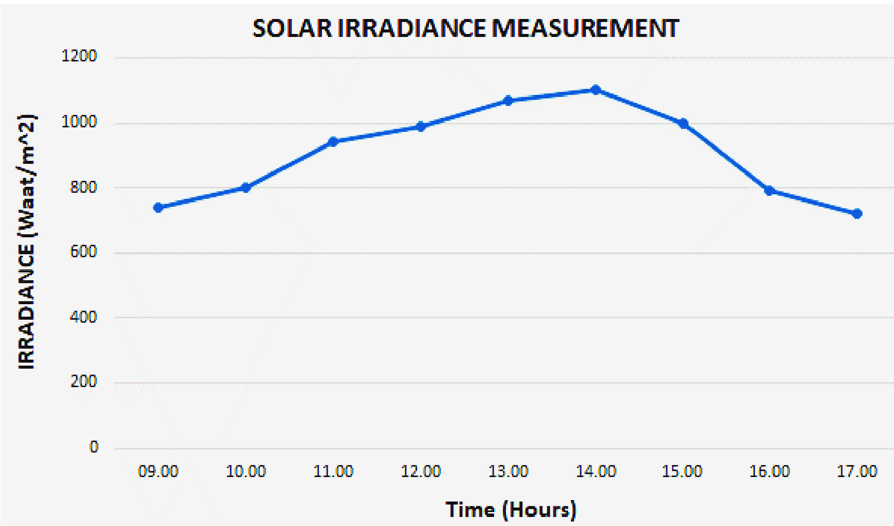


Fig. 9. Solar Irradiance profile when measurement taken.

Fig. 10 shows the graph of fluctuation of wind speed measurement at solar modules location. The measurement taken from 09.00 am to 17.00 pm and the average of wind speed is 1.3 m/s.

The output power and efficiency values were derived using calculations based on Eq. (3) to Eq. (5). The measurements carried out at the research location showed that the heatsink PV was effective in reducing the average temperature from 48.94 °C to 45.29 °C and salt hydrate *PV* was effective in reducing the average temperature from 48.94°C to 47.57°C compared standard solar module. The efficiency of the solar module with heatsink cooling is 11.93% and using salt hydrate coolant is 10.92% compared to standard solar modules without cooling 10.34%.

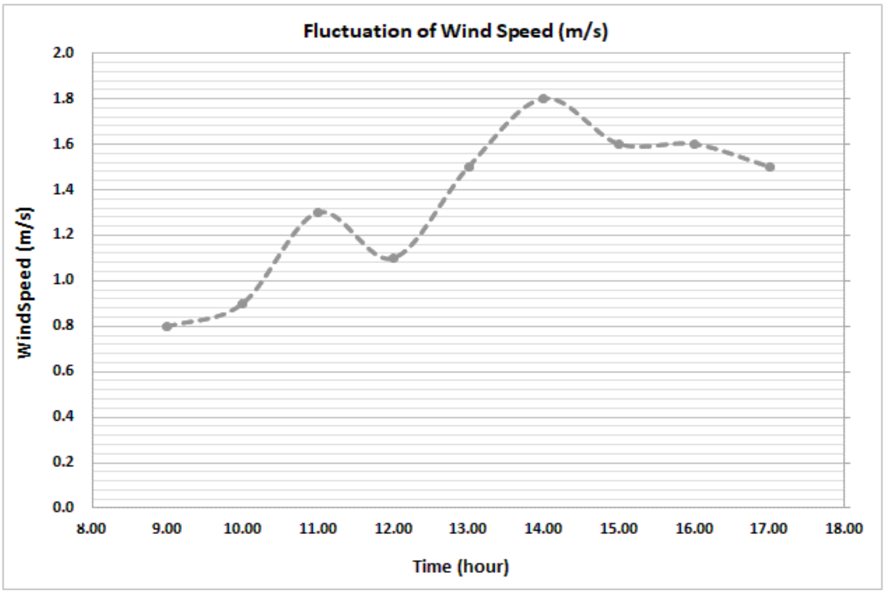


Fig. 10. Wind speed.

From the results of the measurements and calculations of the power produced, it shows that there is an increase in power and conversion efficiency of solar modules using the two types of passive cooling, but the solar module cooled by the heatsink has higher efficiency than the solar module cooled by the salt hydrate. The analysis results show that the power ratio produced by solar modules using heatsink cooling is 72.79 W, the solar module with salt hydrate cooling was 66.45 W, and the solar module without using cooling was 62.88 W, when the measurements were taken. The working efficiency value of solar modules using heatsink cooling reaches 11.93% and using salt hydrate coolant reaches 10.92%, compared to standard solar modules without coolant 10.34%. For this type of passive cooling system, using a heatsink is better than using salt hydrate cooling on the solar module.

The results of these measurements and comparative studies are only for polycrystalline solar modules. For other types of solar modules and different weather conditions during measurements, there may be different results.

5. Conclusion

The passive cooling system used in solar module is made from heatsink and salt hydrate as a coolant. The results of direct measurements showed that heatsink as a coolant was effective in reducing the average temperature to 45.29 °C and salt hydrate as a coolant reduces the average temperature to 47.57 °C compared to standard solar module without using a coolant 48.94 °C, where using a heatsink as a coolant is able to lower the temperature of the solar module by an average of 3.7 °C and for salt hydrate coolant is 1.4 °C. The module output power reaches 72.79 W using heatsink, the output power reaches 66.45 W uses salt hydrate as a coolant compared to a 62.88 W standard solar module. Furthermore, the efficiency of the solar module with heatsink is 11.93% and using salt hydrate coolant is 10.92% compared to standard solar module without cooling system 10.34%.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Asri, Ira Devi Sara, Suriadi conceptualization methodology, formulation of tasks, Asri, Ezwarsyah, Dela Andriani development of system, Analysis, writing original draft preparation, review and editing. All the authors have read and agreed to the published final version of the manuscript.

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