

Comparing the Effect of Using DC Fans and Heatsinks As Cooling Systems on Photovoltaic Efficiency

Muhammad Fuad Abdul Hakim^{1*}, Mohammad Alexin Putra², Otong Nurhilal³

¹Prodi Magister Teknik Mesin, Institut Teknologi Nasional Bandung
Jl. Phh. Mustofa No. 23 Neglasari, Cibeunying Kaler, Kota Bandung, Jawa Barat, Indonesia

²Fakultas Teknologi Industri, Institut Teknologi Nasional Bandung
Jl. Phh. Mustofa No. 23 Neglasari, Cibeunying Kaler, Kota Bandung, Jawa Barat, Indonesia

³Departemen Fisika, Fakultas MIPA, Universitas Padjadjaran
Jl. Raya Bandung-Sumedang km 21 Jatinangor, Sumedang, Jawa Barat, Indonesia

*Corresponding author: muhammadfuad.a.hakim@gmail.com

Abstract

One of the utilizations of solar energy is to be converted into electricity using photovoltaics (PV). The most important performance parameter of PV is efficiency. The efficiency will decrease as the PV temperature increases. Therefore, a cooling system is needed to increase PV efficiency. The objective of the research is to determine and compare the effect of DC fan and heatsink as a cooling system on PV efficiency. Four PV units with a capacity of 30 WP are used. The experiment is conducted as follows, the first PV is equipped with DC fan cooling, the second PV with heatsink cooling, the third PV with a combination of DC fan and heatsink cooling, and the fourth PV is without cooling as a reference. The result shows, that the combination of DC fan and heatsink cooling system provides the highest efficiency improvement, namely 32.08%, followed by DC fan cooling, namely 16.04%. As for heatsink cooling, there is no improvement in efficiency. The combination of DC fan and heatsink cooling system can dissipate heat from the PV more effectively than DC fan cooling system, so the PV temperature is lower and produces higher output power and efficiency. The heatsink cooling system is not effective in dissipating heat because of limited natural airflow due to the low PV stand which is only 30 cm from the ground. **Keywords:** cooling system, DC fan, efficiency, heatsink, photovoltaic.

1. Introduction

The sun provides a friendly renewable energy source, unlike fossil fuels which will be depleted and contribute to air pollution. One way to utilize solar energy is to convert it into electricity using solar panels or photovoltaic (PV). The most significant performance parameters of PV are output power and efficiency. The output power and PV efficiency are influenced by the PV surface temperature. In research [1] it was found that the higher the PV surface temperature, the lower the power produced, namely 45.36 W at 34.46 °C and 42.51 W at 50.92 °C. In research [2] it is stated that efficiency increases when the PV temperature decreases, where tests were carried out at ambient temperatures of 50 °C, 30 °C, and 10 °C with analysis using Matlab. Meanwhile, in research [3], an experimental study was carried out by measuring the V_{OC} (open circuit voltage) on the PV, where the V_{OC} is directly proportional to the PV output

power. The result is that the largest V_{OC} is obtained at a temperature of 25 °C, namely 22.45 V, while the smallest V_{OC} is obtained at a temperature of 69 °C, namely 19.05 V.

Several studies have been carried out to reduce the increase in PV temperature by using a cooling system. Some use water, air, DC fans, wick ropes, heatsinks, and phase change materials (PCM). In research [4] water flowed to the top of the PV surface as a cooling system. This system succeeded in reducing the PV surface temperature from the range of 41-57 °C to 30-38 °C. There was an increase in PV output power by 35%, and an increase in efficiency by 5%. In research [5] a mixture of water coolant and pure water flowed to the top of the PV surface as a cooling system. There was an increase in average output power of 17.88% and an average increase in efficiency of 17.82%. Water as a cooling medium also flowed to the bottom of the PV surface as per research [6]. The result was an increase in PV output

power of 4 W. Then research [7] channeled water through copper pipes arranged across the bottom of the PV surface according to the heat exchanger principle. This research uses a solar simulator, namely halogen lamps, the results can reduce the PV temperature by up to 6 °C.

In research [8] water spray was used as a PV cooling system. Water is released via water spray using Arduino control and hits the top surface of the PV. From the results of measurements and calculations, an increase in efficiency of 1.26-7.34% was obtained. In another research [9], an increase in output power of 10% was obtained by using water as a PV cooling system. Research [10] also used water as a PV cooling system, resulting in an increase in output power and efficiency of 9.27% and 0.71%. In another research [11] water was flowed through a PVC pipe attached to the back of the PV surface. The result was an increase in output power of 14.1%.

Apart from using water, air can also be used as a PV cooling medium. In research [12] air was flowed using a blower to the bottom of the PV surface with light generated from a solar simulator. The results showed an increase in efficiency from 3.06% to 3.15%. In other research [13], DC fans with various configurations were used to circulate air to the bottom of the PV surface for convection cooling. By using 4 DC fans, an increase in output power of 44.34% is obtained. Research [14] used a single blower to circulate air compared to several DC fans distributed below the PV surface. The results show that using a DC fan can increase PV efficiency by 2.1%, while using a blower only increases PV efficiency by 1.34%. Research [15] added fins (heatsinks) at the bottom of the PV surface where air flows naturally without using a DC fan or blower. From the experiment, it was found that the average PV temperature decrease was 3 °C. This research is also equipped with simulations. In research [16] a heatsink was also added to the bottom of the PV surface, which resulted

in reducing the PV temperature by 7.5 °C. Meanwhile, research [17] varied the air flow rate supplied for PV cooling using a blower. It is stated that the largest output power occurs at the fastest air flow rate, namely 31.66 W at a speed of 6.6 m/s.

Research [18] uses a kind of cotton wick as a PV cooling medium. The wick rope is attached to cover the bottom surface of the PV and the top end of the wick rope enters the water reservoir. The process of evaporation of water on the wick string occurs due to the heat from the PV, causing an evaporative cooling effect that can cool the PV. With this method, an increase in output power and efficiency of 16.3 W and 53% respectively are obtained. In research [19] a graphite paraffin phase change material (PCM) layer was used as a PV cooling system. The result was an increase in efficiency of 19.49%. In research [20] PCM from crude palm oil was used, and the results were able to increase efficiency by 5.75%.

The various studies above, confirm that the addition of a cooling system can reduce the PV surface temperature and ultimately increase output power and efficiency. Each study of various cooling systems has different control variables from other studies, one of which is the watt peak (WP) capacity of the PV used. Then, different experiment sites, both indoors using a solar simulator and outdoors with direct sunlight, affect the amount of irradiation received by the PV.

In this research, experimental testing will be carried out, to compare the cooling system using DC fans with other cooling systems, namely heatsinks, and the combination of DC fans with heatsink on their effect on PV efficiency. In this way, more accurate comparative data for each cooling system will be obtained.

This research aims to determine and compare the effect of DC fans, heatsinks, and the combination of DC fans and heatsinks as a cooling system on PV

efficiency, and also compare it with PV without cooling as a reference.

2. Method

2.1 Experimental Components

The PV specifications used are the monocrystalline type with a capacity of 30 watt peak (WP). The outer dimensions of the PV are 630 mm x 360 mm x 25 mm, with cell dimensions of 590 mm x 320 mm. For the cooling components, the type of DC fan used is a brushless type with a voltage of 12 volts, a current of 0.09 ampere, and dimensions 40 mm x 40 mm x 10 mm. These DC fans are usually used to circulate air in personal computer components or other electronic equipment that requires cooling. As for the heatsink, it is made from aluminum with the same size, namely 40 mm x 40 mm x 11 mm. These heatsinks are usually used as heat dissipators for personal computer components and other electronic equipment. The DC fan and heatsink are shown in Figure 1.

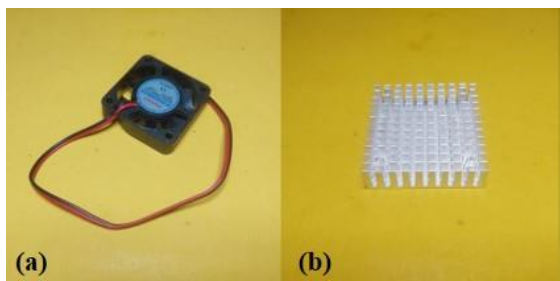


Figure 1. Cooling components

(a) DC fan (b) heatsink

This experiment collects data on solar irradiation, ambient temperature, PV temperature, and PV output power. The measuring instruments used can be seen in Figure 2. Solar irradiation is measured using an illuminance meter (lux meter) in units of watt/meter² (W/m²). Ambient temperature is measured using a thermocouple in °C units, while PV temperature is measured using an infrared thermometer (thermo gun). The output power of each PV is measured using a wattmeter in watt (W).



Figure 2. Measuring instruments (a) thermo gun

(b) wattmeter (c) thermocouple (d) lux meter

To run the DC fan, an AC power source is used which is converted to DC using a power supply which is usually used in installing CCTV cameras. The power supply used has an output voltage of 12 V and a current of 10 A.


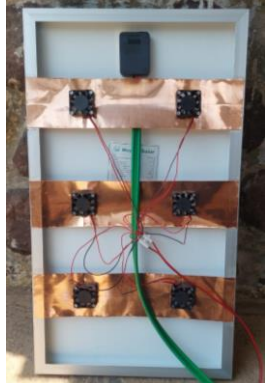


2.2 PV Cooling System

The experiment was carried out using four PVs with their respective adjustments, as presented in Table 1. The first PV was left without any additional cooling system. This PV was used as a reference.

For the second PV, 6 DC fans were added which were installed along with a copper plate on the back of the PV surface. The DC fan is attached to the copper plate using screws as shown in Figure 3. The airflow from the DC fan can cause heat transfer by forced convection which can reduce the PV temperature.

For the third PV, 6 heatsinks are directly attached to the bottom surface using thermal glue. Heatsinks can dissipate heat from PV so that the temperature decreases. heat in the heatsink will be wasted through convection from air flowing naturally under the PV.

Table 1. PV Cooling systems

Cooling System	Figure
1. Without cooling	
2. DC fan cooling	
3. Heatsink cooling	
4. Combination DC Fan and heatsink cooling	

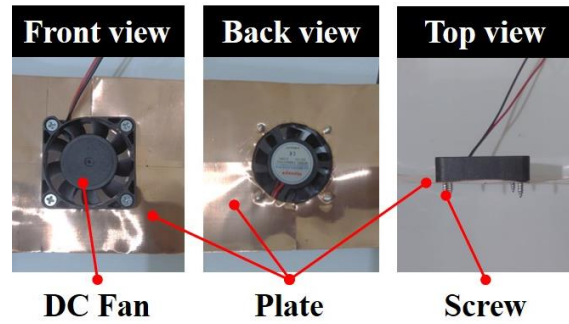


Figure 3. Attaching a DC fan to a copper plate

For the fourth PV, a combination of DC fans and heatsinks are used as cooling units arranged as in Figure 4. The number of combination DC fans and heatsinks is the same as the previous PV, namely 6 units. Each DC fan is attached to a heatsink using screws, where the surface of the heatsink is directly attached to the bottom surface of the PV using thermal glue. With this combination, the heat in the heatsink will be wasted through forced convection from the DC fan airflow.

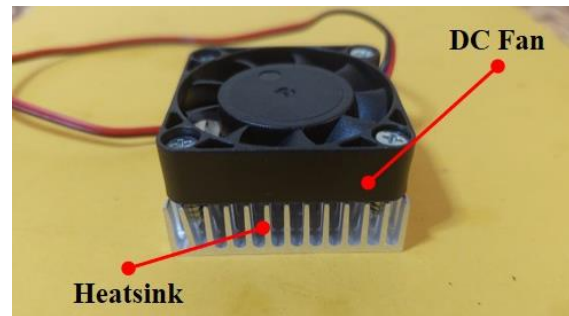


Figure 4. Combination of DC fan and heatsink

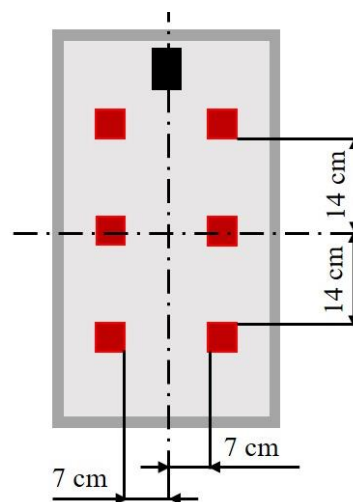


Figure 5. Location of the cooling components on the bottom surface of the PV

The location of the cooling components (represented by a red square shape) on the bottom surface of the PV is shown in Figure 5.

2.3 Experimental Set-up

PVs are assembled with other components as in Figure 6. Each PV has been connected in series with the wattmeter, then connected in parallel to the solar charge controller (SCC), and finally goes to the battery. SCC prevents reverse current flow from the battery to the PV and stabilizes electrical charging to the battery.

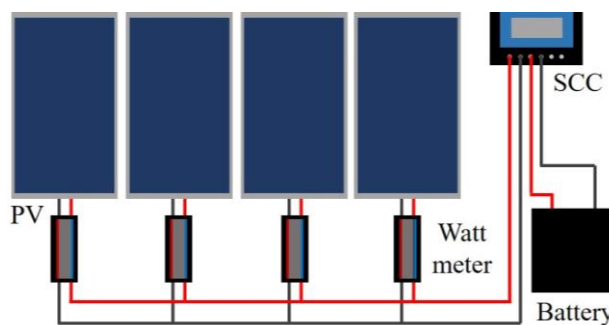


Figure 6. PV circuit sketch

For all DC fans used are connected in parallel, and then connected to a power supply. The power supply itself is connected to an AC power source.

The experiment was conducted outdoors in direct sunlight, on November 11, 2023, located in Kecamatan Tanjungsari, Sumedang (6°54'09"S and 107°48'05"E). The four PVs were placed on a stand that has a height of 30 cm above the ground surface, as can be seen in Figure 7.

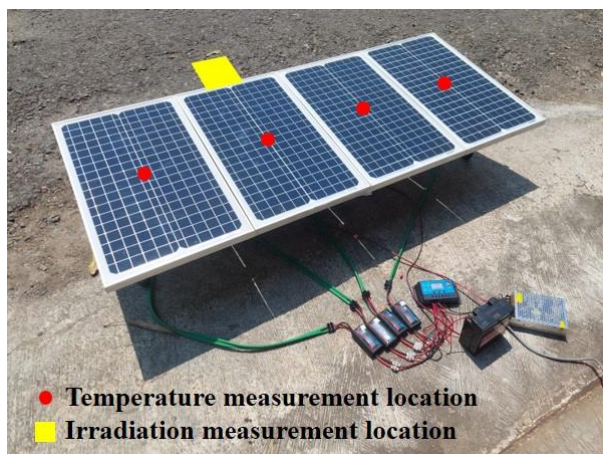


Figure 7. Experiment set-up

The red dot in Figure 7, is the location of the PV temperature measurement, so the thermo gun is directed at that point. The yellow square shape is the location for irradiation measurements, where the probe from the lux meter is placed parallel to the PV surface. Data collection was carried out manually without using a data logger within one day from 11.15 to 13.15 every 15 minutes.

2.4 Efficiency and Output Power Improvement

The efficiency (η) of PV is obtained by dividing the output power (P_{out}) by solar irradiation (E) and PV surface area (A) [21], according to equation 1.

$$\eta = \frac{P_{out}}{E \cdot A} \quad (1)$$

To determine the improvement in power between cooled PV and uncooled PV (ref PV), equation 2 is used [22].

$$P_{improvement} = \frac{P_{outcooled} - P_{outref}}{P_{outref}} \cdot 100\% \quad (2)$$

With the same approach, to determine the improvement in efficiency of cooled PV with PV without cooling, equation 3 can be used.

$$\eta_{improvement} = \frac{\eta_{outcooled} - \eta_{outref}}{\eta_{outref}} \cdot 100\% \quad (3)$$

3. Result and Discussion

3.1 Irradiation and Ambient Temperature

Information on irradiation and ambient temperature during the experiment is presented in Table 2.

The average irradiation was 473.2 W/m² with the highest value of 590.9 W/m² occurring at 11.30 WIB. The average ambient temperature is 32.2 °C with the highest value being 34.2 °C. Weather conditions were based on visual observations, from the start of the

experiment it was sunny with thin clouds so it was not too hot. Then at 13.00 WIB conditions began to become cloudy, so solar irradiation decreased sharply.

Table 2. Irradiation and ambient temperature

Time	Irradiation (W/m ²)	Ambient Temperature (°C)
11.15	541.9	30.9
11.30	590.9	33.4
11.45	534.8	33.8
12.00	580.7	34.2
12.15	503.2	31.2
12.30	550.6	32.4
12.45	469.3	31.7
13.00	207.0	31.3
13.15	280.5	30.9
Average	473.2	32.2

3.2 Effect of Cooling System on PV Temperature

The average temperature data for the four PVs is presented in Table 3. PV with the combination of DC fan and heatsink cooling has the lowest average temperature followed by PV with DC fan cooling, both of which have a lower average temperature than PV without cooling. The combination of DC fan and heatsink cooling can dissipate heat from the PV better than DC fan cooling, so that the PV temperature is lower.

Table 3. Average Temperature of PVs

No.	PV Cooling	Average Temperature (°C)
1	Without cooling	39.6
2	DC fan	35.2
3	Heatsink	40.2
4	DC fan & heatsink	34.9

PV with heatsink cooling has a higher average temperature than PV without cooling. This can happen because the heat absorbed by the heatsink from the PV is not properly dissipated into the environment by the natural airflow under the PV due to the stand being too close to the ground. This is

different from research [16], which was carried out on the roof of a building and with a high PV stand, thus getting more natural airflow.

In addition, this can be proven by comparing the average temperature of the heatsink on the third PV (heatsink cooling) and fourth (combination of DC fan and heatsink cooling). The heatsink on the third PV has an average temperature of 40.3 °C, greater than the heatsink on the fourth PV, namely 37.3 °C.

3.3 Effect of Cooling System on PV Output Power

In Figure 8, four graphs of the output power of each PV and its temperature versus time are presented. From each graph, it can be seen that when the PV temperature decreases, the produced output power increases. Conversely, when the PV temperature increases, the produced output power decreases.

This is consistent at least in sunny weather conditions until 12.45 WIB. When the weather conditions started to become cloudy at 13.00 WIB, the decrease in PV temperature no longer had much of an effect on the increase in output power. This can happen because the decrease in PV temperature is also accompanied by a decrease in solar irradiation due to the sun being covered by clouds. Figure 9 shows the solar irradiation versus time.

When the average output power of each PV is compared as in Figure 10, PV with a combination of DC fan and heatsink cooling is the highest, followed by PV with DC fan cooling, both of which are higher than PV without cooling. This follows the average temperature data, where the lower the PV temperature, the higher the output power produced. PV with heatsink cooling produces less output power than PV without cooling. This is also following the average PV temperature data, where the higher the PV temperature, the lower the output power produced.

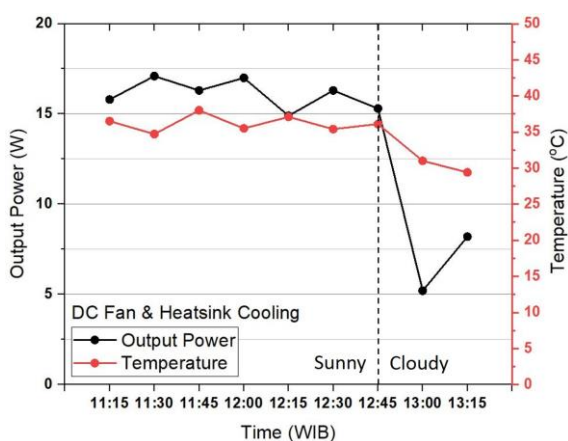
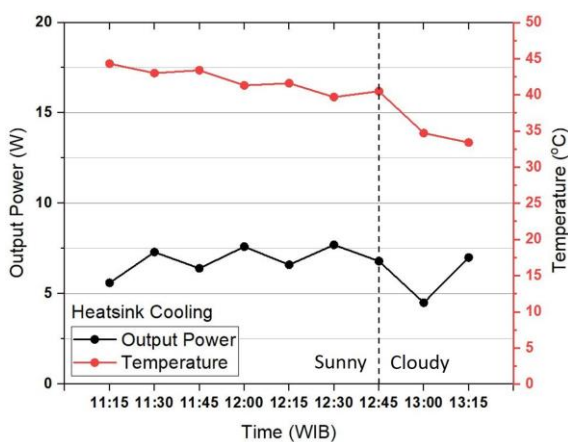
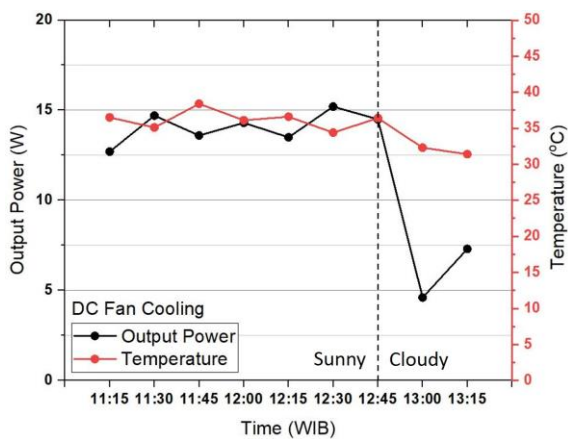
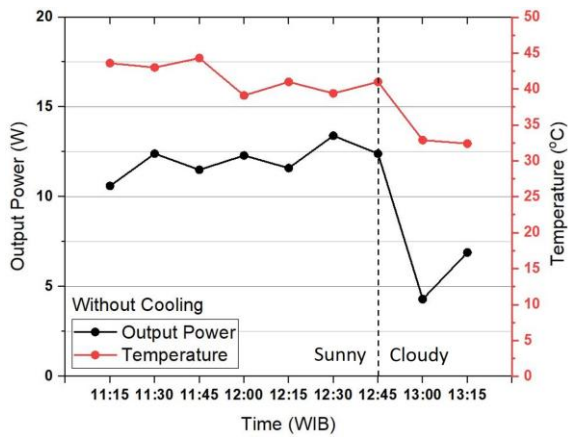


Figure 8. PV output power

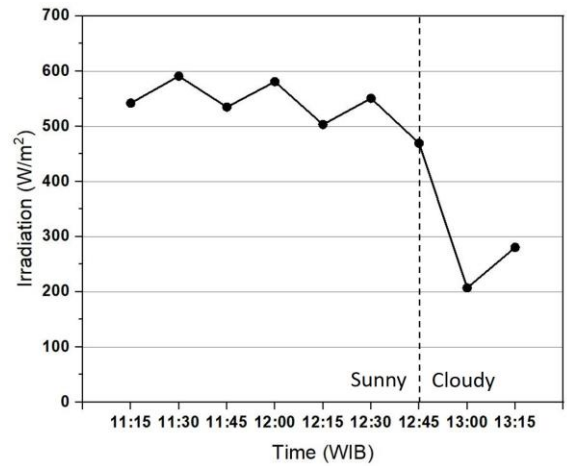


Figure 9. Solar irradiation

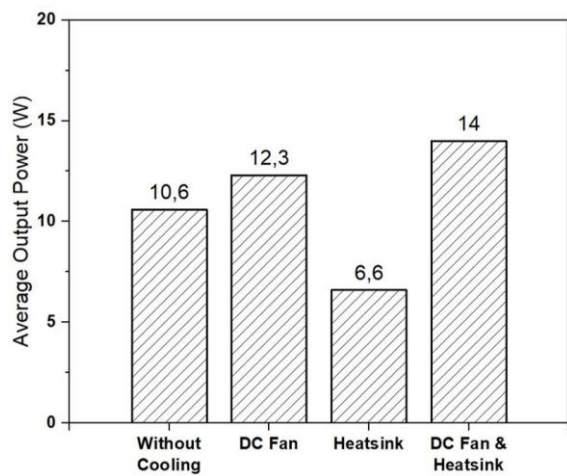


Figure 10. PV average output power

3.4 Effect of Cooling System on PV Efficiency

The efficiency of each PV is calculated using Equation 1. Figure 11, presents a comparison of the average efficiency for the four PVs.

From Figure 11, it can be seen that PV with a combination of DC fan and heatsink cooling has the highest efficiency compared to the others, because it has the highest average output power.

The improvement in PV efficiency with cooling, relative to PV without cooling, can be seen in Table 4. This improvement is calculated using Equation 3. PV with a combination of DC fan and heatsink cooling has the highest efficiency improvement, while PV with heatsink cooling has a negative efficiency improvement because of limited natural airflow due to low PV stand.

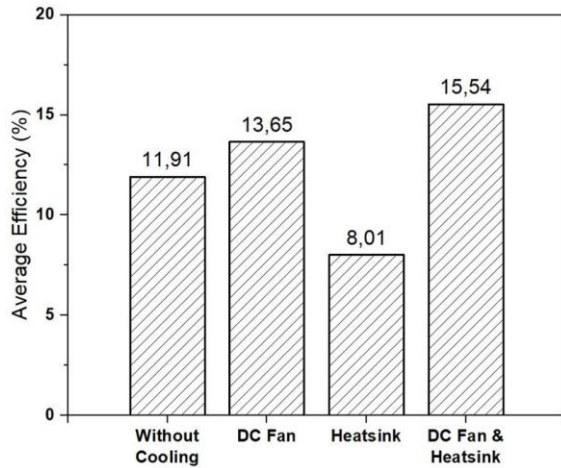


Figure 11. PV average efficiency

Table 4. PV efficiency improvement

No.	PV Cooling	Efficiency Improvement (%)
1	Without cooling	0
2	DC fan	16.04
3	Heatsink	-37.77
4	DC fan & heatsink	32.08

3.5 Comparison with other research

In Table 5, a comparison of the increase in efficiency with the results of other research is presented. It can be said that this research has the same trend as other research, namely increasing PV efficiency due to the addition of a cooling system. Research [13] compared to this research has a higher increase in efficiency, due to the use of a larger DC fan. Meanwhile, research [14] compared to this research has a lower increase in efficiency, because cooling is not carried out continuously, where the DC fan is only run for 15 minutes every hour.

Table 5. Comparison with other research

Research	PV Cooling	Increased Efficiency (%)
[13]	DC fan	44.34
[14]	DC fan	2.1
This research	DC fan	16.04
This research	DC fan & Heatsink	32.08

As for heatsink cooling, in research [16] it can reduce the PV temperature by 7.5 °C, whereas in this research, on the contrary, it increases the PV temperature by 0.6 °C.

This can happen because research [16] was carried out on the roof of a building with a high PV stand, thus getting more natural airflow.

3.6 Comparison If the Electric Power Consumption of DC Fans is Taken Into Account

If the electrical power consumption to run a DC fan is taken into account, then the resulting PV output power is reduced by the electrical power consumption. Electric power consumption can be measured using a wattmeter installed between the power supply and the DC fan. From measurements it is known that the electrical power consumption for 6 DC fans is 6.9 W. Thus the net output power from each PV is as presented in Table 6 below.

Table 6. The net output power of PVs

No.	PV Cooling	Net Output Power (W)
1	Without cooling	10.6
2	DC fan	5.4
3	Heatsink	6.6
4	DC fan & heatsink	7.1

From Table 6, it is known that when the electrical power consumption of the DC fan is taken into account, the output power of PV without cooling is higher than PV with cooling. This is still understandable considering that the PV capacity used in this experiment is only 30 WP, so the output power that can be produced is limited.

4. Conclusion

The results of this research show that the combination of a DC fan and heatsink as a PV cooling system is relatively more effective, which can significantly increase the output power produced. The combination of DC fan and heatsink cooling system increases the PV efficiency by 32.08%, compared to the PV without a cooling system. The DC fan cooling system could increase PV efficiency by 16.04%. Meanwhile, cooling using heatsink in this research cannot increase PV efficiency, because the heat absorbed by the heatsink from the PV is not properly dissipated into the environment by the natural airflow under

the PV due to the stand being too close to the ground.

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