# STUDY ON THE INFLUENCE OF THE ANGULAR DIRECTION OF ALUMINUM COOLING FINS ON THE WORKING TEMPERATURE OF SOLAR PANELS

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**ABSTRAK**

Pemanfaatan energi matahari melalui panel surya sebagai sumber energi listrik untuk rumah tangga dan penerangan jalan semakin meningkat pesat. Namun, panel surya menghadapi masalah terkait suhu kerja. Ketika penyerapan radiasi surya terlalu tinggi, mengakibatkan penurunan efisiensi. Suhu yang tinggi menyebabkan panel surya menghasilkan energi lebih rendah dibandingkan pada kondisi dingin. Oleh karena itu, tujuan penelitian ini adalah untuk mengeksplorasi pengaruh sirip pendingin aluminium pada panel surya, dengan variasi sudut kemiringan sirip 30° dan 45°, serta dibandingkan dengan panel tanpa sistem pendinginan. untuk menurunkan suhu kerja panel surya dengan menggunakan media sirip pendingin dan hembusan udara. Hasil penelitian menunjukkan bahwa pada sudut 30°, didapatkan hasil suhu panel sekitar 43,60°C pada Iterasi ke-13, dengan penurunan suhu sekitar 3,13%. Pada sudut 45°, suhu yang didapatkan 41,80°C dengan penurunan suhu sekitar 6,8%. Sementara itu, kondisi tanpa pendingin mencapai suhu tertinggi 44,40°C. Tanpa pendinginan, menyebabkan suhu panel menjadi lebih tinggi, dan sudut 45° memberikan efek pendinginan yang lebih baik dibandingkan sudut 30°, meskipun perbedaannya tidak terlalu signifikan jika dibandingkan dengan kondisi tanpa pendingin.

**Kata kunci:** panel surya, sirip pendingin aluminium, sudut sirip, temperatur panel surya.

***ABSTRACT***

*The utilization of solar energy through solar panels as a source of electrical energy for households and street lighting is increasing rapidly. However, solar panels face problems related to working temperature. When the absorption of solar radiation is too high, it results in a decrease in efficiency. High temperatures cause solar panels to produce lower energy than in cold conditions. Therefore, the purpose of this study was to explore the effect of aluminum cooling fins on solar panels, with variations of fin inclination angles of 30° and 45°, and compared with panels without a cooling system to reduce the working temperature of solar panels by using cooling fins and air blowing media. The results showed that at an angle of 30°, the panel temperature was 43.60°C at the 13th iteration, with a temperature drop of about 3.13%. At an angle of 45°, the temperature obtained was 41.80°C with a temperature drop of about 6.68%. Meanwhile, the uncooled condition reached a maximum temperature of 44.40°C. No cooling causes the panel temperature to be higher, and the 45° angle provides a better cooling effect than the 30° angle, although the difference is not very significant when compared to the uncooled condition.*

***Keywords:*** *solar panel, aluminium cooling fin, fin angle, solar panel temperature.*

## 1. INTRODUCTION

Electrical energy is an energy that is widely used and cannot be separated from everyday life. In today's technological era, the need for electrical energy continues to increase along with the development of technology [1]. As each year passes, the population and industrial economic growth continue to increase rapidly, resulting in the need for electrical energy in Indonesia also experiencing a very rapid increase [2]. Solar cell systems can convert solar energy into electrical energy using photovoltaics [3].

For that reason, the use of solar panels in Indonesia can be said to be quite promising, considering Indonesia's geographical location on the equator, meaning that Indonesia is always exposed to sunlight all year round. Given the potential of solar power as an environmentally friendly energy source and does not cause pollution [4]. The use of solar energy in Indonesia has very good prospects, considering that geographically Indonesia is a tropical country, it has quite good solar energy [5].

Solar energy is also the largest renewable energy source on earth, and can be used to meet the increasing demand for global energy consumption [6]. Renewable energy sources are increasingly important because the excessive use of traditional energy sources causes increased energy consumption and climate degradation. Solar energy, as one of the renewable energy sources that has abundant reserves, wide distribution coverage, and simple and environmentally friendly technology, has been widely used to produce photovoltaic energy in recent years [7]. Solar panels work based on the photovoltaic principle, namely a material or device that has the ability to convert photon energy into light into electrical voltage and current [8].

The cooling of photovoltaic panels can be improved by adding metal materials equipped with fins on the back of the panel, which serve to improve air circulation and increase heat dissipation more effectively [9]. Currently, various types of renewable energy, such as solar energy, are developing rapidly, because they have the least negative environmental impact [10]. Therefore, high temperatures behind solar panels can affect overall efficiency. If the temperature of the solar panel is too high, there can be an increase in internal resistance and a decrease in the energy conversion efficiency of the solar panel [11].

The power generation capacity of PV modules is affected by temperature; when the temperature of solar PV modules increases, the current slightly increases but the voltage decreases [12].The performance and effectiveness of solar cell panels are influenced by the position of the panel in relation to the sun. To produce optimal electrical energy from solar cells, solar cell panels must be perpendicular to the direction of incoming sunlight [13].

The power generated from photovoltaics is determined by the amount of solar intensity received by the solar modules [14]. The selection of the right material is based on higher thermal conductivity. Aluminum is commonly used because of its good thermal conductivity, lower cost, and lighter weight During testing [15]. The development of a cooling system is one way to overcome the problem of temperature in solar panels. The cooling system used can use water media, either mineral water, sea water, or water droplets. Most of this cooling research is done using experimental or simulation methods [16]. The development of a cooling system is one way to overcome temperature problems in solar panels [17].

In the comparison of photovoltaic performance with different types of cooling, photovoltaics with fan cooling showed the highest voltage, current, and power, as well as the lowest operating temperature compared to photovoltaics without cooling and photovoltaics with heat sink cooling [18]. During testing with cooling, the average efficiency obtained was 3.151%. An increase in wind speed of 1 m/s will result in a temperature drop of 0.7 °C and an increase in average power of 0.03 W, thereby increasing the average power efficiency of the solar panel by 0.02% [19]. In the CFD validation with the difference in fin spacing and thickness, it can be shown that the larger the fin spacing, the lower the average temperature of the photovoltaic module, and the greater the fin thickness, the simulation results show that the average temperature of the photovoltaic module decreases [20].

From previous literature above, there is no mention specifically about cooling fins (heat sink) with angle 30° and 45°. Therefore, the objective of this experimental research uses three solar panels equipped with cooling fins at angles of 30°, 45°, and without cooling. The three panels were placed in a special box called the cooling box, and thermocouples were installed on the top of the panels to evaluate the temperature changes that occurred during the experiment.

## 2. METHOD

In this study, the purpose of this study is to determine the influence of the angle of aluminum cooling fins of 30°, 45°, and without cooling fins on the working temperature of solar panels. Each condition will be tested under direct sunlight exposure, and the temperature of the panels will be measured using a thermocouple. In addition, the intensity of light received by the panel will also be measured using the Transceiver Solar Tracker to ensure the uniformity of the experimental conditions. The data obtained will be analyzed to see the temperature difference between the three conditions. The results of this study are expected to provide insight into the influence of the cooling fin angle on the working temperature efficiency of solar panels.

### 2.1 *Tools and Materials*

In this research, several tools were used, including solar panels, a blower, pipes, a thermocouple, aluminum, an anemometer, solar tracker transceivers, DC motors, a cooling fin box, and a protractor. With the research flow described as follows:

## 2.2 *Flowchart*

The flow begins with a Start, followed by a literature review as a theoretical basis and reference. Then it proceeds to the experimental design stage to determine methods, variables, and testing procedures. Next, tools and materials are prepared, followed by the assembly of the cooling fins and the installation of the solar panels. After installation is complete, the researcher enters a test scenario that includes several conditions, namely, without cooling and at angles of 30° and 45°. In each condition, measurements of inlet and outlet air temperatures and air flow velocity are taken (incoming and outgoing air temperatures and velocities). The measurement results are then evaluated at the "Measurement Results" decision node; if the results are not in accordance (No), the process returns to the measurement stage to be repeated until the data meets the criteria. If the results are in accordance (Yes), the flow continues with data analysis, presentation of results, and discussion, then closes with conclusions and suggestions, and ends at Finish. For more detailed is mentioned in Figure 1 as follows:

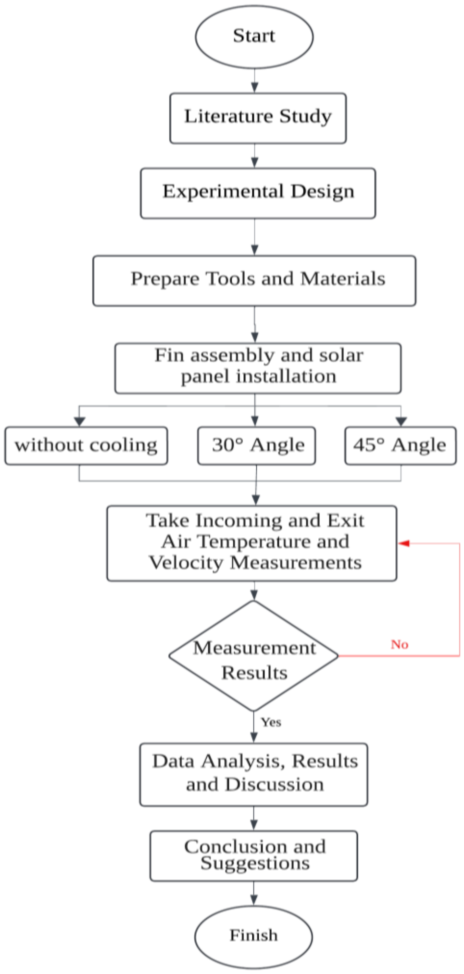


**Figure 1. Research Flowchart**

Figure 1 shows the flowchart of the study of the effect of the angular direction of aluminum cooling fins on the working temperature of solar panels, starting with preparing solar panels fitted with cooling fins with angles of 30°, 45° and without cooling. Next, environmental conditions such as light intensity are measured to ensure that external variables are under control.

## 2.3 *Shape of Uncooled Solar Panel Fin Model, 30° and 45° Angle*

In this study, aluminum cooling fins are used to help air flow properly around the solar panel, so that the temperature of the solar panel can drop. These cooling fins are installed on solar panels with two different angles, the first with an angle of 30°, the second with an angle of 45° and the third without cooling fins to see the comparison between the three solar panels and how it affects the working temperature of the solar panels, as shown in Figure 2.


(a) (b) (c)

**Figure 2. Variable of experiment (a) without cooling (b) 30° angle (c) 45° angle**

## 3. RESULT AND DISCUSSION

### 3.1 *Surface Temperature of Solar Panels*

The temperature on the surface of the solar panel is the temperature above the panel which is directly exposed to sunlight, where the data is taken every twenty minutes when temperature data is taken. When the panel absorbs sunlight, most of the energy is converted into heat. The more light the panel receives, the higher the temperature on the surface of the solar panel, but a temperature that is too high can reduce the efficiency of the panel to produce electricity. Thus, even if the solar panel functions well, a temperature that is too high can reduce efficiency, here is data in Table 1. on the temperature of the solar panel at an angle of 30°, 45° and without cooling, testing every 20 minutes.

**Table 1. Angle temperature 30°, 45° and without cooling measurement every 20 minutes**

| No. | 30° Angle (°C) | 45° Angle (°C) | Without Cooling (°C) |
|---|---|---|---|
| 1 | 36.00 | 35.30 | 38.10 |
| 2 | 37.30 | 36.20 | 38.20 |
| 3 | 39.50 | 38.20 | 40.90 |
| 4 | 41.60 | 39.80 | 43.70 |
| 5 | 42.30 | 40.50 | 44.40 |
| 6 | 41.90 | 40.60 | 43.40 |
| 7 | 41.80 | 40.40 | 43.00 |
| 8 | 41.60 | 39.90 | 42.40 |
| 9 | 41.20 | 39.80 | 42.30 |
| 10 | 42.40 | 40.90 | 43.60 |
| 11 | 42.20 | 40.10 | 43.40 |
| 12 | 43.40 | 41.70 | 44.40 |
| 13 | 43.60 | 41.80 | 44.30 |
| Average | 41.14 | 39.63 | 42.47 |

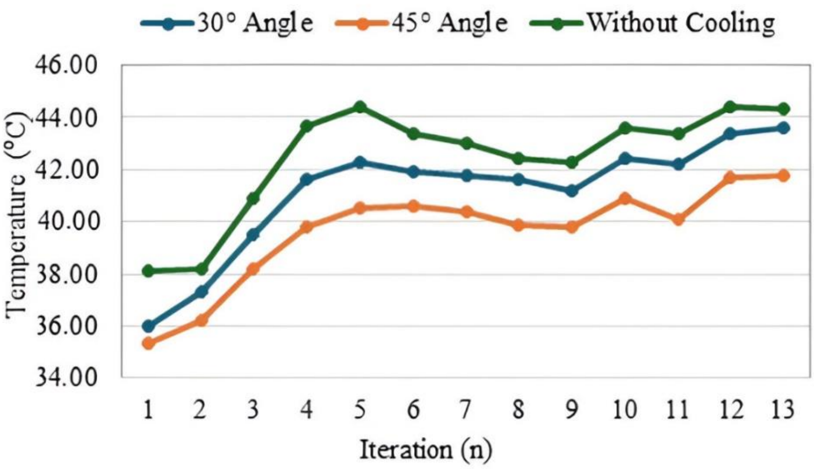


**Figure 3. Temperature comparison graph with iteration**

Figure 3. Based on the analysis of the temperature results on solar panels at an angle of 30°, the temperature obtained tends to increase gradually. Starting at the 1st iteration, the results of 36.00°C were obtained, and reaching the peak point at the 13th iteration, the results were 43.60°C. This temperature shows a tendency to rise steadily, despite a decrease in the 8th and 9th iterations. Overall, the temperature continues to increase, resulting in a temperature drop of about 3.13% at an angle of 30°.

While in the 45° angle condition, the temperature increases, although not as rapidly as in the 30° angle condition. At an angle of 45°, the temperature obtained results in around 35.30 °C at the first iteration and reaches a maximum of around 41.80 °C by the end of the measurement. Similar to the 30° angle condition, the temperature occasionally experiences small increases and decreases; however, the graph indicates an overall rise in temperature from the beginning to the end of the measurement. The temperature drop is obtained at an angle of 45 °, resulting in a 6.68% decrease.

In the condition without cooling, the temperature obtained is higher than in the condition using cooling. Starting from the 1st iteration, the result is 38.10°C and reaches a maximum temperature of about 44.40°C in the last measurement. The temperature increase in this condition is more significant than in the two-angle conditions, indicating that the lack of cooling causes higher temperatures. These measurements show that the 45° angle provides a better cooling effect than the 30° angle. Although the use of cooling with an angle shows a significant difference in temperature reduction, the temperature difference between measurements is not too large when compared to the condition without cooling.

### 3.2 *Sunlight Intensity and Input Power*

Sunlight intensity plays a crucial role because it is directly related to the amount of energy the solar panel receives. The higher the intensity of sunlight received, the more energy that can be converted into electricity. However, this light intensity can also cause solar panels to heat up, especially if the sunlight is directly on the solar panels for an extended period. The following data is presented in Table 2. Sunlight Intensity at an Angle of 30°, 45°, and without cooling.

The input power on the solar panel is the amount of energy received by the panel from the sun and converted into electricity. Several factors affect this power, including temperature, tilt angle, and the light intensity received by the panel. The following data obtained on solar panels is presented in Table 3.

**Table 2. Sunlight intensity at angles of 30°, 45° and without cooling**

| No. | 30° Angle ($W/m^2$) | 45° Angle ($W/m^2$) | Without Cooling ($W/m^2$) |
|---|---|---|---|
| 1 | 289.48 | 338.40 | 258.90 |
| 2 | 337.05 | 368.98 | 309.86 |
| 3 | 418.10 | 438.44 | 352.67 |
| 4 | 413.83 | 554.49 | 366.94 |
| 5 | 485.18 | 603.42 | 342.48 |
| 6 | 421.99 | 483.14 | 383.11 |
| 7 | 458.68 | 498.68 | 448.68 |
| 8 | 487.22 | 498.10 | 458.68 |

**Table 2. Sunlight intensity at angles of 30°, 45° and without cooling, continued**

| No. | 30° Angle ($W/m^2$) | 45° Angle ($W/m^2$) | Without Cooling ($W/m^2$) |
|---|---|---|---|
| 9 | 454.60 | 470.91 | 432.56 |
| 10 | 478.29 | 558.57 | 421.30 |
| 11 | 441.99 | 486.83 | 398.80 |
| 12 | 391.41 | 452.56 | 372.79 |
| 13 | 320.06 | 328.21 | 312.33 |
| Average | 415.22 | 467.74 | 373.77 |

**Table 3. Input power, 30° angle, 45° angle and without cooling**

| No. | 30° Angle (W) | 45° Angle (W) | Without Cooling (W) |
|---|---|---|---|
| 1 | 188.162 | 219.96 | 168.285 |
| 2 | 219.0825 | 239.837 | 201.409 |
| 3 | 271.765 | 284.986 | 229.2355 |
| 4 | 268.9895 | 360.4185 | 238.511 |
| 5 | 315.367 | 392.223 | 222.612 |
| 6 | 274.2935 | 314.041 | 249.0215 |
| 7 | 298.142 | 324.142 | 291.642 |
| 8 | 316.693 | 323.765 | 298.142 |
| 9 | 295.49 | 306.0915 | 281.164 |
| 10 | 310.8885 | 363.0705 | 273.845 |
| 11 | 287.2935 | 316.4395 | 259.22 |
| 12 | 254.4165 | 294.164 | 242.3135 |
| 13 | 208.039 | 213.3365 | 203.0145 |
| Average | 269.894 | 304.0365 | 242.955 |

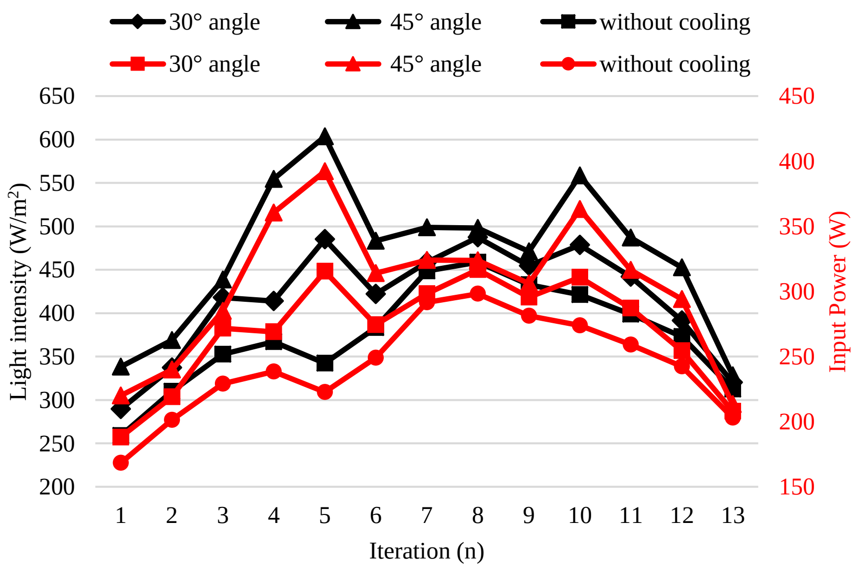


**Figure 4. Comparison chart of light intensity and input power with iterations**

In Figure 4. shows the intensity comparison graph in units of Watts per meter squared ($W/m^2$) with input power. The sunlight intensity data shows that the 30° fin angle shows fluctuations in sunlight intensity which tends to be lower than the 45° fin angle. The sunlight intensity starts at 289.48 and increases gradually until it reaches its highest peak at 487.22. Despite the increase, overall the data at 30° angle has a smaller variation compared to 45° angle.

Meanwhile, the 45° fin angle shows a consistently higher light intensity. The intensity value starts from the 1st iteration at around 338.4 and experiences a sharper increase with the highest value reaching 603.2 at the 5th iteration. This shows that the greater the fin angle, the more sunlight the surface receives. The fluctuations are also more pronounced, indicating the effect of steeper angles on intensity.

There is no cooling condition that shows a lower intensity when compared to the two fin angle conditions. The lowest intensity is recorded at 258.9 and although there is an increase in some iterations, the value obtained is still lower than the condition using the fin angle. This data shows that the use of a 45° fin angle results in higher daylight intensity compared to the 30° angle and the uncooled condition. Meanwhile, the drastic decrease in intensity at the end of the iteration may be due to a decrease in system efficiency over time, accumulation of excess heat, or possible degradation of system component performance.

Figure 4. also shows that the input power at a 30° angle shows significant fluctuations in input power. The input power values range from 188.16 W to 316.69 W, with the highest peak at the 8th iteration. In general, the input power at this angle tends to be lower compared to the 45° angle. The 45° angle data shows higher input power results compared to the 30° angle and no cooling. The input power at 45° angle ranges from 219.96 W to 392.22 W, with the highest peak occurring at the 5th iteration. The power results ranged from 168.29 W to 298.14 W. The lowest power was recorded at the 1st iteration, and the highest power was recorded at the 8th iteration. This indicates that in the absence of cooling, the solar panel operates at a lower power as the higher temperature might affect the energy conversion performance of the panel.

### 3.3 *Solar Panel Voltage*

The voltage of solar panels is a measure of how much electrical power solar panels can produce after absorbing sunlight. However, the temperature of the solar panel can reduce the voltage it produces, because high temperatures can increase the resistance of the solar panel system thereby reducing efficiency and output voltage, the following data on the results of the voltage on the solar panel is in Table 4.

**Table 4. Electrical voltage 30° angle, 45° angle and without cooling**

| No. | 30° Angle (V) | 45° Angle (V) | Without Cooling (V) |
|---|---|---|---|
| 1 | 17.17 | 17.61 | 11.32 |
| 2 | 17.71 | 18.38 | 11.45 |
| 3 | 18.45 | 19.44 | 11.86 |
| 4 | 17.91 | 19.73 | 17.52 |
| 5 | 18.15 | 19.19 | 17.44 |
| 6 | 18.18 | 19.39 | 17.85 |
| 7 | 18.2 | 19.09 | 16.28 |
| 8 | 18.33 | 19.61 | 18.35 |
| 9 | 18.08 | 18.89 | 16.29 |
| 10 | 18.28 | 19.78 | 17.38 |
| 11 | 18.45 | 19.58 | 17.57 |
| 12 | 18.2 | 19.44 | 17.32 |
| 13 | 17.96 | 18.3 | 17.21 |
| Average | 18.08 | 19.11 | 15.98 |

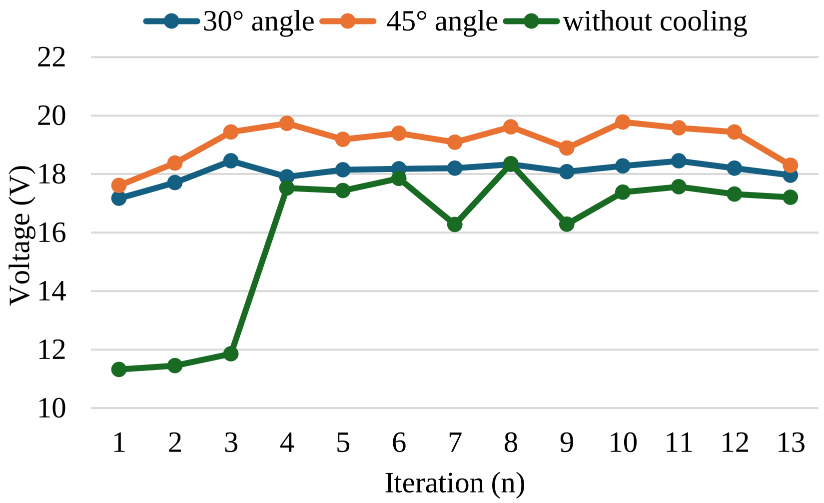


**Figure 5. Comparison graph of voltage with iteration**

In Figure 5. The voltage graph shows that at an angle of 30°, the recorded voltage shows a relatively stable value with a range between 17 V and 18 V. This voltage indicates that the 30° angle produces a fairly good efficiency in capturing sunlight and converting it into electrical energy. The fluctuations at an angle of 30° are fairly small, and the average voltage value tends to be in the range of 18 V, indicating optimal performance for solar panels installed at this angle. This indicates that the panel position at a 30° angle allows for better absorption of sunlight, resulting in a stable voltage and a 13.14% increase in voltage at the 30° angle.

While at an angle of 45° the voltage obtained is slightly higher than the angle of 30°, the voltage range recorded is between 17 V and 19 V. This shows that the 45° angle gets a slightly optimal performance in keeping the input power stable at a voltage of 19.25% increase in voltage at an angle of 45°.

In the uncooled condition, the resulting voltage is noticeably lower than the other two angles, with a voltage range between 11 V to 18 V, suggesting that in the absence of cooling, the solar panel may be working under less than optimal conditions. The large fluctuations in the data suggest that temperature or load factors may affect the performance of the panel, causing a significant voltage drop at each iteration. The uncooled condition shows lower results overall, indicating that cooling plays an important role in keeping the voltage generated by the solar panel stable.

### 3.4 *Electric Current Solar panel*

In solar panel systems, electric current (I) is an important factor that indicates how fast electrons flow during the photovoltaic energy conversion process. Sunlight intensity, panel energy conversion efficiency, and temperature management affect the working temperature of solar panels. This study investigates the relationship between iteration (n) and current (I) in three system configurations to measure the effect of using cooling fins on the performance and stability of solar panels, and the data obtained are listed in Table 5.

**Table 5. Electric current 30° angle, 45° angle and without cooling**

| No. | 30° Angle (A) | 30° Angle (A) | Without cooling (A) |
|---|---|---|---|
| 1 | 1.24 | 1.43 | 1.24 |
| 2 | 1.64 | 1.71 | 1.49 |
| 3 | 1.69 | 1.95 | 1.69 |
| 4 | 1.94 | 2.03 | 1.76 |
| 5 | 1.64 | 1.89 | 1.64 |
| 6 | 2.83 | 2.95 | 2.56 |
| 7 | 2.2 | 2.53 | 2.2 |
| 8 | 2.43 | 2.53 | 2.2 |
| 9 | 2.17 | 2.5 | 2.17 |

**Table 5. Electric current 30° angle, 45° angle and without cooling, continued**

| No. | 30° Angle (A) | 30° Angle (A) | Without cooling (A) |
|---|---|---|---|
| 10 | 2.96 | 3.08 | 2.68 |
| 11 | 2.23 | 2.57 | 2.23 |
| 12 | 2.18 | 2.27 | 1.98 |
| 13 | 1.6 | 1.85 | 1.6 |
| Average | 2.05 | 2.25 | 1.95 |

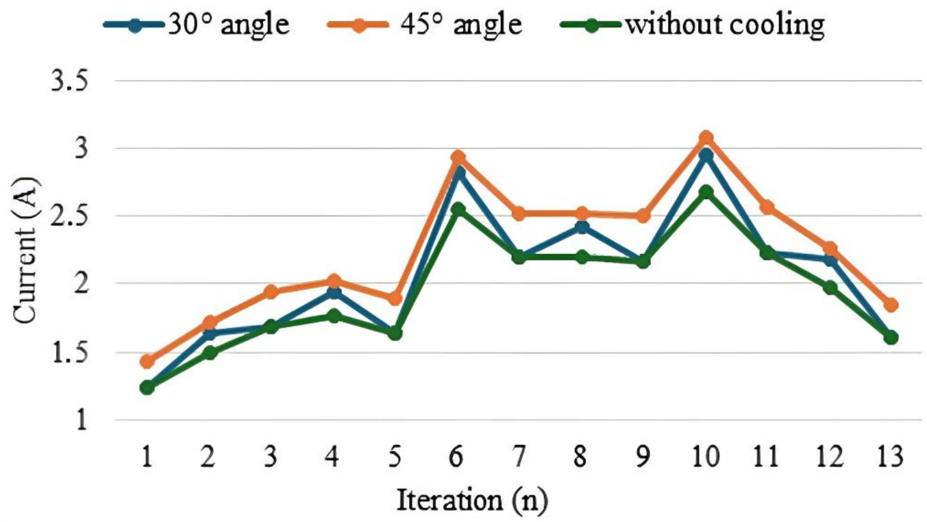


**Figure 6. Comparison chart of current with iterations**

In Figure 6, the current shows that at an angle of 30°, the current recorded tends to be stable with values ranging from 1.24 to 2.96. The highest peak was recorded at the 10th iteration with a result of 2.96 A, and the lowest value at the 1st iteration was around 1.24 A. Although there was a significant increase at a certain point, overall the current generated was not as much as at the 45° angle. This shows that the 30° angle tends to receive sunlight at a lower angle, so the current generated is also lower despite the cooling system and there is a 5.13% increase in current at a 30° angle.

The 45° angle showed consistently higher results compared to the 30° and Uncooled angles. The electric current ranged from 1.43 A to 3.08 A, with the highest peak at the 10th iteration with a result of 3.08 A. At this angle, the solar panel receives more sunlight which has the potential to produce a larger current. In addition, the use of a cooling system at a 45° angle helps to keep the panel temperature low, which increases the efficiency in generating electric current and results in a 15.16% increase in current at a 45° angle.

Whereas in the No Cooling condition, the electric current generated is consistently lower, with values ranging from 1.24 to 2.68. The lowest value was recorded at the 1st iteration at around 1.24 A, and the highest value was recorded at the 10th iteration at 2.68 A. Without cooling, the temperature of the solar panel tends to be higher, which reduces the energy conversion efficiency, resulting in a lower current compared to the condition using cooling. These results show that a 45° angle provides optimal results in generating electric current, compared to a 30° angle and uncooled conditions.

### 3.5 *Solar Panel Output Power*

The output power produced by the intensity of sunlight, the working temperature of the solar panel, the efficiency of the photovoltaic material, and additional technologies such as cooling systems, affect the amount of power produced by the solar panel. The electrical power produced by a solar cell is the multiplication of its output voltage by the number of electrons flowing, or electric current. There are certain equations that explain the mathematical relationship between voltage and current in electrical power generation, the following output power data is contained in Table 6.

**Table 6. Output power 30° angle, 45° angle and without cooling**

| No. | 30° Angle (W) | 45° Angle (W) | Without Cooling (W) |
|---|---|---|---|
| 1 | 21.29 | 25.18 | 14.03 |
| 2 | 29.04 | 31.42 | 17.06 |
| 3 | 31.18 | 37.90 | 20.04 |
| 4 | 34.74 | 40.05 | 30.83 |
| 5 | 29.76 | 36.26 | 28.60 |
| 6 | 51.44 | 57.20 | 45.69 |
| 7 | 40.04 | 48.29 | 35.81 |
| 8 | 44.54 | 49.61 | 40.37 |
| 9 | 39.23 | 47.22 | 35.34 |
| 10 | 54.10 | 60.92 | 46.57 |
| 11 | 41.14 | 50.32 | 39.18 |
| 12 | 39.67 | 44.12 | 34.29 |
| 13 | 28.73 | 33.85 | 27.53 |
| Average | 37.30433 | 43.26187 | 31.95368 |

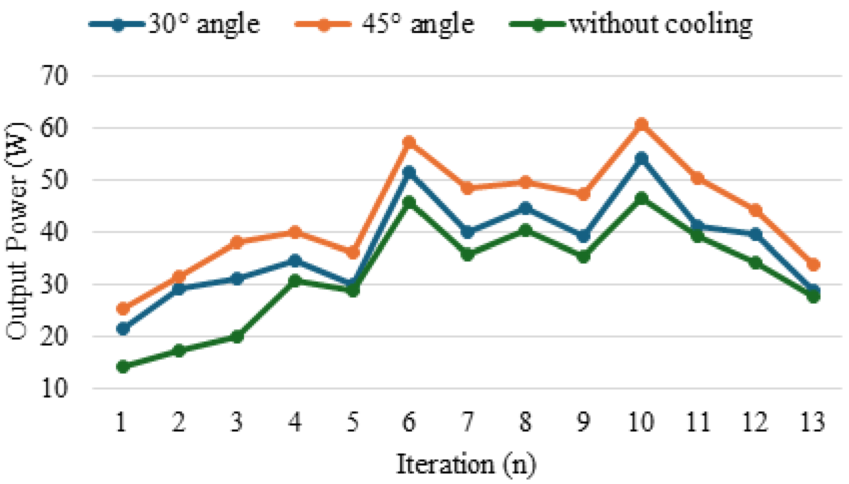


**Figure 7. Comparison chart of output power with iterations**

Figure 7. shows the comparison of the output power generated in the three conditions, where the output power at 30° angle shows significant fluctuations, with output power values ranging from 21.29 W to 54.11 W. The highest peak of output power was recorded at the 10th iteration. Overall, the power generated tends to be lower than the 45° angle, but still shows a significant increase in solar energy reception compared to the no cooling condition.

At 45° angle, the output power shows more optimal results than 30°angle and no cooling. The output power ranges from 25.18 to 60.92 Watts, with the highest peak recorded at the 10th iteration with a result of 60.92 Watts. At this angle, it shows that the 45° cooling fin angle can produce greater output power at certain times, especially if solar radiation conditions are optimal and at the no cooling condition, the output power produced is consistently lower. The output power values ranged from 14.04 to 46.57, with the lowest power recorded at the 1st iteration of 14.04 and the highest power recorded at the 10th iteration of about 46.57. Without cooling, the solar panel's temperature is higher, which can reduce the energy conversion efficiency and result in lower power compared to the condition using cooling. We can conclude that the 45° angle provides the most optimal output power among the three conditions.

### 3.6 *Efficiency of Solar Panels*

Solar panel efficiency refers to several factors affecting solar panel efficiency, such as light intensity, temperature, and mounting angle. The optimal light intensity and mounting angle determine the efficiency of the solar panel. Without cooling, the panel's efficiency may decrease due to an increase in temperature, which reduces the solar cell's performance. In other words, although solar panels without cooling can generate more power under certain conditions, their performance may not be optimal in the long run due to excessive heating effects, following the efficiency result data in Table 7.

**Table 7. Efficiency 30° angle, 45° angle and without cooling**

| No. | 30° Angle (η) | 45° Angle (η) | Without Cooling (η) |
|---|---|---|---|
| 1 | 11.31% | 11.44% | 8.34% |
| 2 | 13.25% | 13.10% | 8.47% |
| 3 | 11.47% | 13.30% | 8.74% |
| 4 | 12.91% | 11.11% | 12.92% |
| 5 | 9.43% | 9.24% | 12.84% |
| 6 | 18.75% | 18.21% | 18.35% |
| 7 | 13.42% | 14.90% | 12.28% |
| 8 | 14.06% | 15.32% | 13.54% |
| 9 | 13.27% | 15.42% | 12.57% |
| 10 | 17.40% | 16.77% | 17.00% |
| 11 | 14.32% | 15.90% | 15.11% |
| 12 | 15.59% | 15.00% | 14.15% |
| 13 | 13.81% | 15.86% | 13.56% |
| Average | 13.7741% | 14.2795% | 12.9166% |

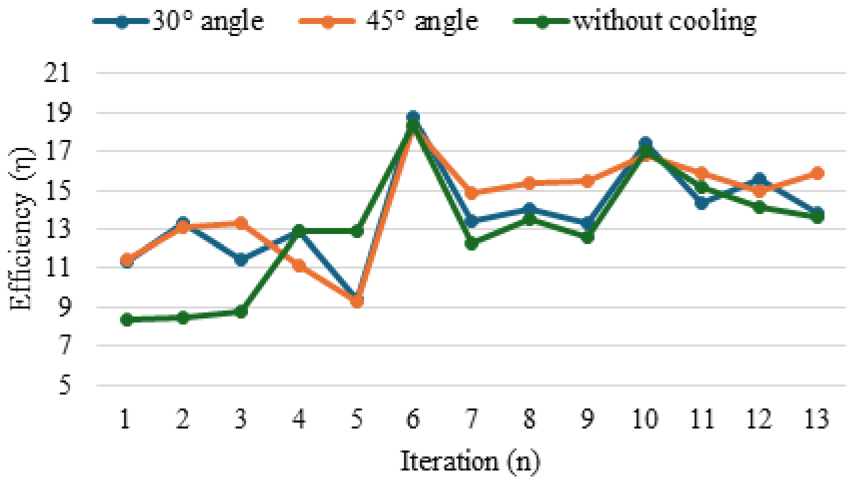


**Figure 8. Efficiency Graph with Iterations**

Based on Figure 8. efficiency data that has been obtained, in conditions with an angle of 30 °, the efficiency of solar panels is obtained on average by 13.77%, this efficiency is higher than the condition without cooling, which shows that this angle helps solar panels to capture more solar energy. Although it sometimes increases and decreases at each iteration.

The efficiency at 45° angle is slightly higher than that at 30° angle, with an average of 14.27%. This shows that the 45° angle can provide better results in converting solar energy into electricity than the 30° angle, although the difference is not too significant, but it sometimes also decreases.

Meanwhile, without cooling, the efficiency of solar panels tends to be lower, with an average of only 12.91%. This shows that solar panels cannot operate at optimal efficiency levels without cooling, as high temperatures can reduce the panel's ability to convert solar energy into electricity. Overall, it can be concluded that the use of cooling on solar panels can significantly increase efficiency compared to conditions without cooling.

## 4. CONCLUSION

The experimental investigation into the effect of the angular orientation of aluminum cooling fins on solar panel temperature reveals that fin inclination has a significant influence on the thermal performance and efficiency of photovoltaic modules. At an inclination angle of 45°, the panel exhibited a temperature reduction of approximately 6.68%, resulting in an average electrical efficiency of 15.10%. In comparison, an inclination angle of 30° resulted in a temperature reduction of approximately 3.13% with a corresponding average efficiency of 11.83%. These findings suggest that increasing the fin inclination enhances heat dissipation from the panel surface, resulting in improved thermal regulation and higher conversion efficiency.

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