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Research paper

Performance Enhancement of Solar Photovoltaic Cooling Using Water Sprinkler

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Abstract

Solar energy is free and the most abundant renewable energy available today. Solar Photovoltaic (PV) cells are one of the medium to extract this energy. This project focuses on using forced convection water cooling with water sprinkler to cool overheated solar cells and to help reducing the surface temperature of the solar panel for optimum operation in terms of output power. The cooling method involved was a water-type forced convection method using water sprinkler system. The water will flow on the top surface of the panel and this promotes the reduction of temperature of the cells. This study is aimed to decrease the temperature therefore it will result in increment of open circuit voltage of the panel. The increment of the open circuit voltage helps to convert much more sufficient amount of solar energy into useful electrical energy. Moreover, it will increase the rate of efficiency of the PV panel. This project was conducted at the Green Energy Research Centre (GERC), Kolej Teratai, UiTM Shah Alam.

Keywords: *Solar PV; forced convection; renewable energy; water cooling; solar energy*

1. Introduction

Solar Photovoltaic (PV) is one of the mechanisms to extract solar energy into useful electrical energy that can help in reducing the use of fossil fuels and sustain human needs [1]. This is due to the fact that it is completely cost free and renewable with the availability of the sun [2]. The use of solar energy is widely extracted in a lot of countries in the world and Malaysia is one of them [3]. Malaysia is a hot, humid country with an average irradiance of 1000 kWh/m^2 [3]. However, it is proven when the temperature of the PV modules overheats due to irradiance and ambient temperatures, the efficiency of the panel will be reduced [4]. The panel needs suitable cooling method in order to increase its rate of efficiency [5]. This project emphasizes on water-type forced convection cooling method by using water sprinklers.

There are two main reasons on efficiency of solar panel drops, they are optical losses and thermal losses [5]. Optical losses are the reflection of sunlight at the surface of the panel whereas thermal losses are the increment of temperature of the module [5]. This two loses hold a big role in either increasing the efficiency or reducing it. Insufficient use will result in efficiency drop [5]. The efficiency will drop at about 0.5% for every 1°C rise in temperature [4].

The conversion of energy form solar to electrical operates when the PV panel absorbs photons from the sun thus activating the electrons through the panel [6]. The electron will then fill the holes in the cells thus converting the energy from solar to electrical [6]. As the panel’s temperature increases, the electrons will have a change of speed thus increasing the cells’ resistance [7]. The drop of open circuit voltage will follow as the band gap shrink [8]. This is called as photovoltaic effect which is defined as a phenomenon chemically and physically caused by electric current and voltage in the cell [9].

Past experiments also indicated that a PV panel have an over going barrier in attaining better efficiency level where it is usually in the range of 8% to 12% only [10]. Increment of module temperature relies on the thermal management of PV which is the high and low concentration of system that promotes to the decrement of open circuit voltage hence decrement of electrical energy [11]. Based on the previous statement, the limitation holds the efficiency to not go over 12%.

There are many investigations regarding on increasing the rate of efficiency of PV cells. The panel’s main way of releasing heat is by radiation as well as convection [12]. Therefore, natural convection and forced convection methods are two of the most suitable methods [5]. Both methods are separated into two types: air and water type.

Comparing the methods, water-type force convection is the fastest way to reduce the temperature of the panel [13]. Not just that, panel’s surface temperature holds the master key for every change of conversion of energy in line with its efficiency [5]. The high reflection from the radiation from the sun can be overcome by water as water has an acceptable refractive index [1]. Thus, it is believed that when a panel’s surface is constantly poured with water evenly, the drop of panel’s temperature will increase its efficiency [14]. Furthermore, high conversion of energy will also be attained [14].

Dust is also one of the factors effecting the efficiency of PV panel [15]. Dust deposition accumulated on the surface is usually cleaned naturally with the presence of wind and water droplets from the rain [15]. However, hot, humid countries like Malaysia specifically in Shah Alam usually do not undergo droplets like rain and instead often experience heavy rain conditions [16]. Thus, it is much better to install a cooling method rather than naturally

waiting for it to clean itself. Constantly pouring water under high irradiation, will help clean the PV under hot weather. Hypothetically, the more dust means the more loss of efficiency [15].
The installation of PV is renowned as one of the world's fastest growing power-generation technology as it is being use all around the world [17]. Its capacity has been added in more than 100 countries and 17 GW of PV capacity was estimated thus bringing a total about 40 GW which is seven times bigger than in 2007 [18]. Based on the current statistics, the global installed capacity of PV has been increasing drastically and in 2016 about 76.6 GW were added and Asia Pacific (APAC) and China leas the market of installation in 2014 [19].
Whereas in Malaysia, the installed capacity of PV is also increasing drastically in 2017 at a number of 39.35 MW with only 3.83 MW in 2016 [20]. However, water-type cooling method in Malaysia is not widely used despite the fact that it can produce higher efficiency than a standalone PV panel. Indoor test of water cooling was done at Universiti Malaysia Perlis (UniMap) using halogen lamp in exchange of sunlight and resulted in 9% - 22% increment of power output [12]. This shows the effectiveness of cooling towards PV with the presence of photons.
However, despite there are many experimental approach using water-type forced convection cooling method, there are vaguely any result in the same hot, humid climate condition such as Shah Alam area. The weather conditions such as rain, air velocity and humidity were not considered in this project.

2. Methodology

2.1. Description of Solar Photovoltaic (PV) cell

Solar PV panels were installed at Green Energy Research Centre (GERC), UiTM Shah Alam (3°04N, 101°29E). Two monocrystalline solar panels were installed side-by-side on a ground roof titled at 45° and were given different operating conditions. One with a water-type forced convection cooling and another one is without any cooling, which acts as control for comparison with the panel mthat is cooled. Both panels were experimented under the same irradiance and ambient temperature for four days. Panels' specifications are listed in Table 1. The variables that are of interest to this work are irradiance (obtained from GERC online data logging system), ambient temperature, panel surface temperature for both the top and bottom surface and open circuit voltage from the solar panel. Fig. 1 shows a schematic on the cooling system for the experiment.

Table 1: 100W Monocrystalline Solar Panel (CSS-MSP-100M-36) Specifications

Dimension	
Module dimension (mm x mm)	1195 x 541
Weight	8 kg
Construction	High transmission low iron-tempered glass
Cell dimension (mm x mm)	36 cells in a series (4x9)
Electrical Specification	
Cell efficiency	17.76%
Peak power (Pmax)	100W
Maximum power voltage (Vmp)	18.72V
Maximum power current (Imp)	5.08A
Open circuit voltage (Voc)	22.28V
Short circuit current (Isc)	5.08A

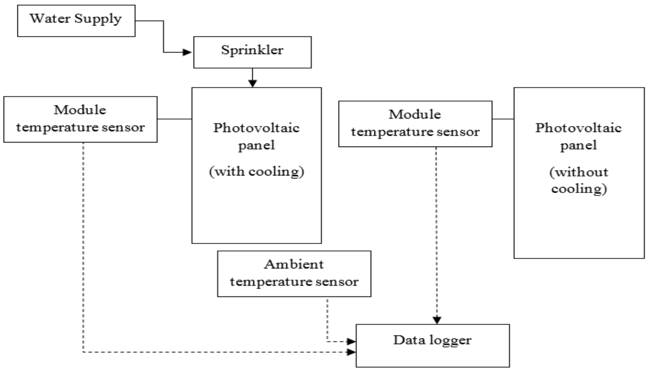
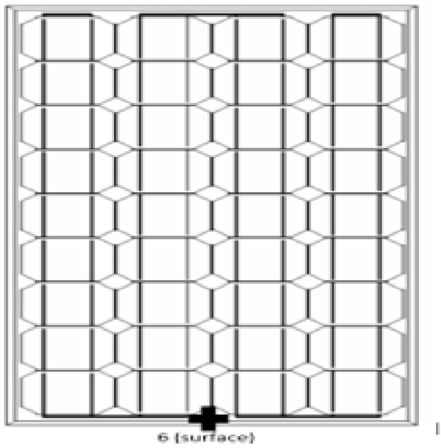


Fig. 1: Schematic Diagram for the experiment

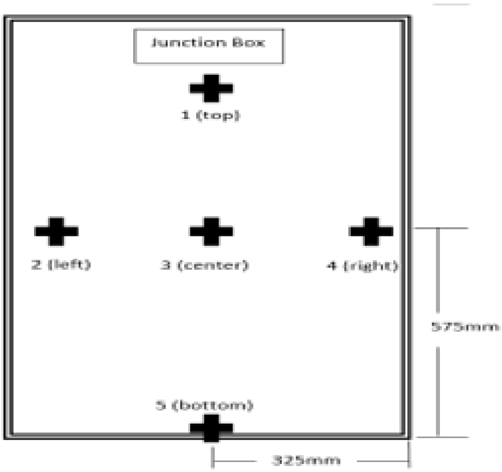
2.2. Water-type Forced Convection Cooling Method

2.2.1. Experiment Setup

The open circuit voltage was measured with a DT80 series 4 Data Logger. The module and ambient temperature was measured using portable Graphtec GL200 Data Logger. RS Pro K Type Thermocouples were used for temperature readings and placed at 6 different points, 5 at the back and one on the surface. The position of thermocouples are shown in Fig. 2.



(i)



(ii)

Fig. 1: Placing of thermocouples; (i) surface of panel, (ii) Back of panel

A dripper type sprinkler was uses as shown in Fig. 3 Position of sprinklers can be seen in Fig. 4 below;

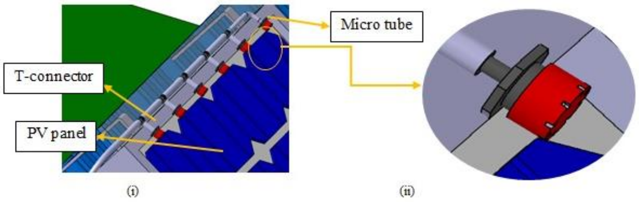


Fig. 2: (i) Position of sprinklers on the panel, (ii) Sprinkler (irrigation drippers)

2.2.2. Experiment equipment

The equipment used are:

1. Water pipe – operates at 12 L/h
2. Water Hose – Diameter of 200 mm
3. Micro tube – Diameter of 90 mm
4. Sprinkler - 6 Adjustable irrigation drippers ¼" barb sprinklers emitter drip system was used on top of panel

Thus, the actual experiment is as Fig. 4 below;

Fig. 3: Experiment setup at GERC, UiTM Shah Alam

3. Results & Discussion

This project was run for two identical monocrystalline solar panel under direct sunlight for 5 hours from 11am till 4pm for 4 days. The days chosen were;

1. Day 1 – 27th of April 2018, Friday
2. Day 2 – 2nd of May 2018, Wednesday
3. Day 3 – 4th of May 2018, Friday
4. Day 4 – 6th of May 2018, Sunday

3.1. Ambient Temperature and Irradiance

The two panels were exposed with the same range of ambient temperature and irradiance. Based on Fig. 5, the ambient temperature varies according to the irradiance. When the irradiance increases, the ambient temperature also increases and vice versa. The average irradiance is at 304.9 W/m^2 while, for the ambient is at 34.81ºC. From Fig. 6 and 7, it can be shown that the ambient temperature varies daily and corresponds directly to the irradiance of the particular day. Higher irradiance will result in higher ambient temperature. When there is overcast, the irradiance will drop drastically, but the ambient temperature remains high as the temperature will drop slowly with time, and the drop in irradiance measured can be quite significance.

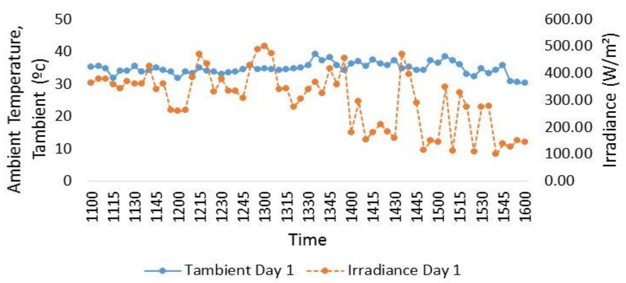


Fig. 4: Relationship between ambient temperature and irradiance for day 1

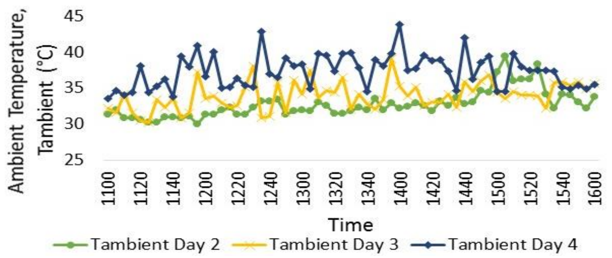


Fig. 5: Graph of Ambient Temperature against Time for Day 2, 3 and 4

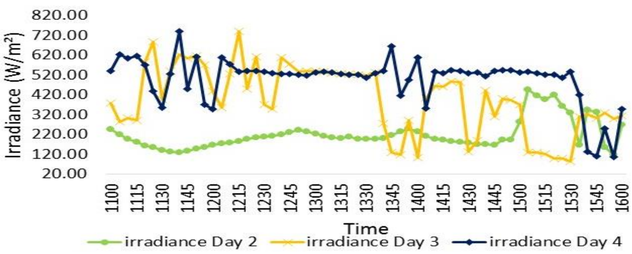


Fig. 6: Graph of irradiance against time for Day 2, 3, and 4

Fig. 6 and 7 also shows that day 4 line has the highest range of temperature with an average of 37.32ºC comparing with day 2 and 3 with average of 32.7ºC and 33.95ºC respectively. Whereas from Fig. 7, we can see the same pattern where day 4 has the highest range following with day 3 and day 4 where their average irradiance is 489.90 W/m^2, 396.85 W/m^2 and 217.88 W/m^2 respectively. Therefore, the theory is accepted where the irradiance is proportional with ambient temperature.

3.2 Effect of Irradiance and Ambient Temperature

3.2.1. Open Circuit Voltage

Fig. 8 and 9 are the relationships of open circuit voltage (Voc) and irradiance obtained from the 4 days. Fig. 8 is the result for day 1 where we can see that three lines have almost the same pattern. Thus, when irradiance increases, open circuit voltage also increases. However, at the circled period V_{oc} for the panel without cooling decreases despite irradiance to be high. This is highly related to this project purpose where when the irradiance is too high, the ambient temperature also increases and further overheats the panel until it is insufficient to convert energy. Whereas, the panel with cooling, V_{oc} still increases despite the hot condition. Other than that, for cooled panel, the V_{oc} is higher than the non-cooled panel. This shows higher conversion of energy. Next, Fig. 9 is the result for day 2, 3 and 4. There are days where irradiance varies inconsistently (referring day 2 lines) thus, resulted in the inconsistent of V_{oc}.

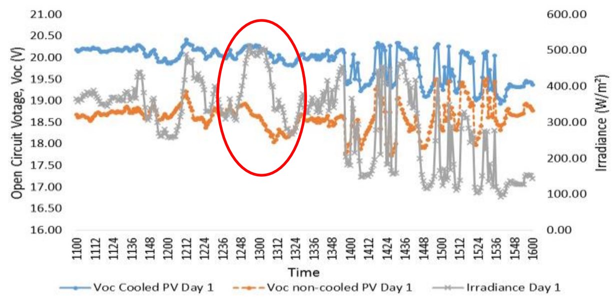


Fig. 7: Relationship between open circuit voltage and irradiance for day 1

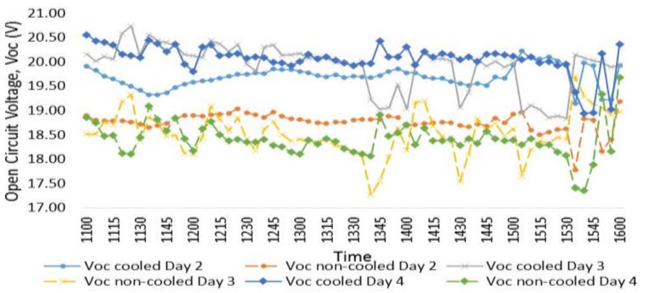


Fig. 8: Relationship between open circuit voltage and irradiance for day 2, 3, and 4

3.2.2 Module's Temperature

The top module temperature against time is shown in Fig. 10 and 11. Fig. 10 is the result for day 1 and observed that the two lines have the same pattern despite temperature for cooled panels is at lower range of temperature. Thus, comparing with V_{oc}, we can say that, cooled panels generate more output and carried to increase its efficiency. The graph for the 3 other days also shows the same result.

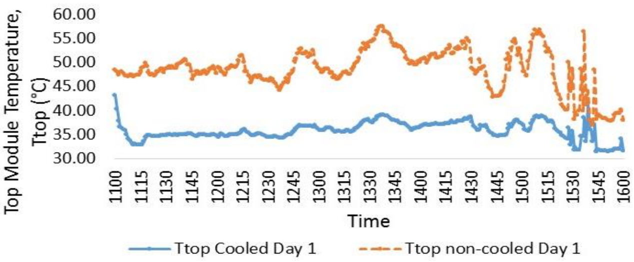


Fig. 10: Graph of Top module temperature against time for day 1

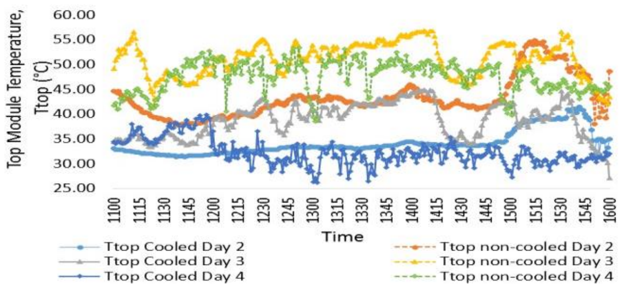


Fig. 11: Graph of Top module temperature against time for day

Fig. 12 is the relationship between the center module temperature against time for the 4 days. As shown in Fig.12, between the left, right and center position, center position has the highest temperature difference among the three. Similarly, with Fig. 10, the temperature for cooled panels achieve significant drop. The highest average temperature is on day 1 with a value of 14.34ºC. The highest temperature difference and highest temperature for the non-cooled panel on day 1 are 20.2°C and 59.4°C respectively. Day 2, 3 and 4 in Fig. 12 continues to show the same result and does not show any oblivious change than day 1 and top module temperature.

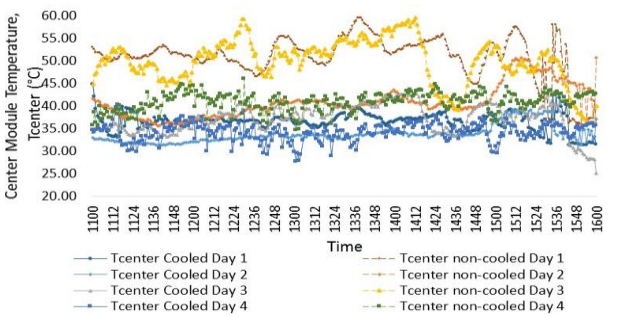


Fig. 12: Center module temperature against time for day 1 till day 4

Fig. 13 and 14 are graphs of module temperature against time for the bottom position for day 1 and day 2 till 4 respectively. We can still see the same pattern as other positions at the backside of the module. Highest difference of temperature for Fig. 13 is 19.9°C and the highest temperature of non-cooled panel to be 58.1°C. The highest temperature drop is 23.1°C. Same patterns go for the other days. The highest temperature within day 2, 3 and 4 is at 65.5°C which is on day 4 with the highest average irradiance.

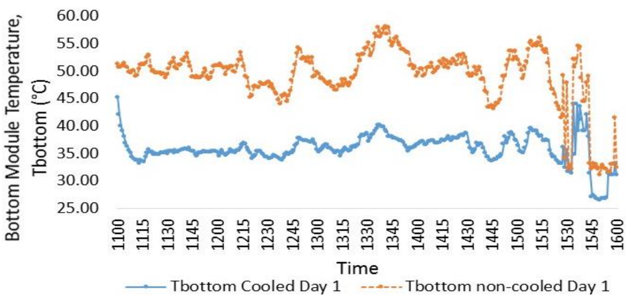


Fig. 13: Graph of Bottom module temperature against time for day 1

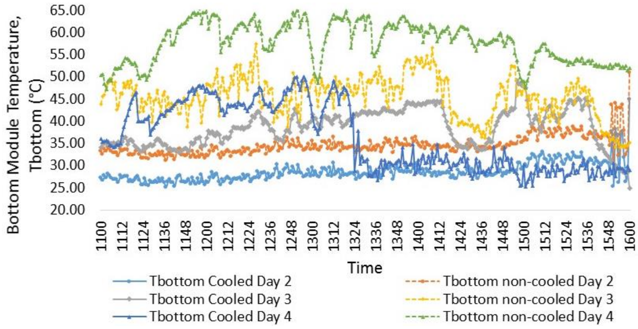


Fig. 14: Graph of Bottom module temperature against time for day 2, 3 and 4

The module's temperature at surface position has the same result where cooled panel possessed the lower temperature lines and non-cooled panel is hotter. This can be seen from Fig. 15 and 16. However, since the position is measured at the surface directly exposed to the sun, there is a slight difference where despite its temperature drop to be the highest as it reached 60°C which is 21.8°C. The average difference is on 10°C which appears to be the smallest out of all position. This is due to the exposure to the sun and the direct contact with water from the sprinkler.

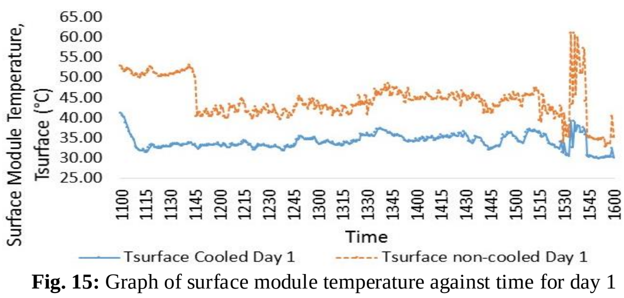


Fig. 15: Graph of surface module temperature against time for day 1

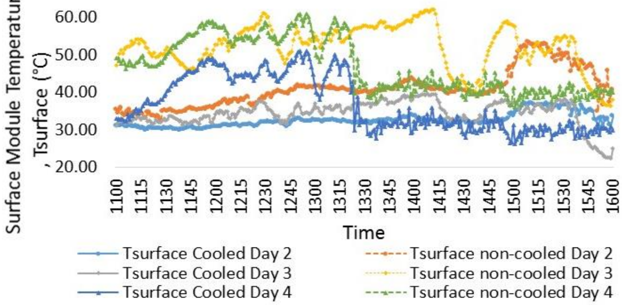


Fig. 16: Graph of surface module temperature against time for day 2, 3 and 4

Fig. 17 shows the combination chart that compares the average of temperature difference at every position of the module and its relation with the average of ambient temperature. Based on the graph, it can be seen that day 4 has the highest temperature difference at top and bottom position of 15.24°C and 2.84°C respectively. This may be due to the fact that day 4 has the highest average ambient temperature among the 4 days which is 37.32ºC. However, for the center position, day 1 hold the highest difference at 14.34°C and day 3 hold the highest difference of 17.76°C at surface position. This irregular result may be due to the amount of water poured in a day.

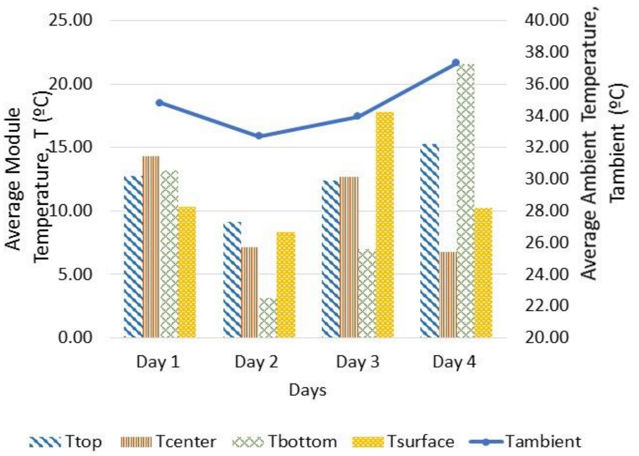


Fig. 17: Comparison of average temperature difference with its relation to ambient temperature

The average open circuit on the other hand can be compared with the average irradiance which can be seen in Fig. 18. For the past 4 days, the experiment gives a positive feedback on the increment of open circuit voltage. We can see the conversion of energy is higher when the panel is cooled to a temperature nearer to its ambient temperature as its average value appear to be higher than the non-cooled panel for all 4 days. Other than that, it shows in the graph that; higher average irradiation produces higher average open circuit voltage. This is because, day 4 has the higher irradiance out of the four days following with day 3, 1 and 2. Similarly to the open circuit voltage where day 4 takes the lead also followed by day 3, 1 and 2.

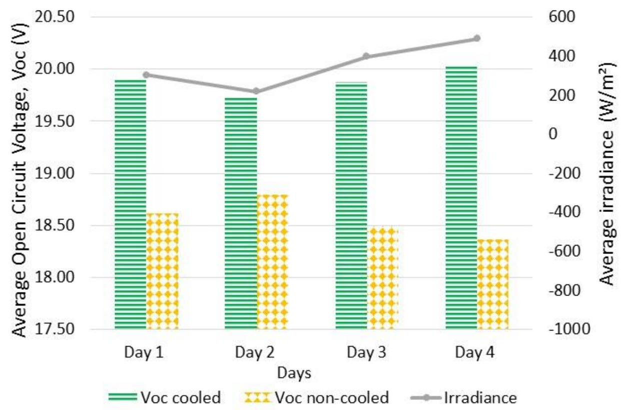


Fig. 18: Comparison of open circuit voltage with its relation to irradiance

The exact numbers of average temperature difference, open circuit voltage, ambient temperature and irradiance is listed in Table 2.

Table 2: Average values for day 1 till day 4

Day	Day 1	Day 2	Day 3	Day 4
T_{top} (ºC)	12.77	9.13	12.38	15.27
T_{center} (ºC)	14.34	7.13	12.66	6.74
T_{bottom} (ºC)	13.19	3.12	6.97	21.54
$T_{surface}$ (ºC)	10.29	8.35	17.76	10.24
$T_{ambient}$ (ºC)	34.81	32.70	33.95	37.52
Irradiance (W/m²)	304.19	217.88	396.65	489.91
V_{oc} cooled (V)	19.89	19.72	19.88	20.02
V_{oc} non-cooled (V)	18.61	18.79	18.49	18.36

From literature, the efficiency of a PV panel will increase if there are increase of output [4]. V_{oc} is higher for all cooled panel than the non-cooled ones. This is relating to its temperature drop at each position of the panel thus the whole panel itself. Therefore, the closer the module's temperatures to the ambient temperature, the higher its output voltage in terms of V_{oc}. When V_{oc} is higher, the efficiency of the panel also increases. The main reason for this is that voltage is directly proportional to current [7] thus, the current produced by the panel will increase proportionally with the V_{oc}. Therefore, conversion of energy for the cooled panel is higher than for the non-cooled panel, as shown from the results obtained in this study.

4. Conclusion

This project studies on the water sprinkler forced convection cooling method towards PV solar cells and were conducted at Green Energy Research Centre, UiTM Shah Alam. The PV panel was heated under hot climate area. The results of the current investigation showed that the maximum improvement for V_{oc} was at 9%. This is significant as this will help in producing more output from a single solar panel. With water sprinkler system, the panel does not only produce higher output due to cooling but the sprinkler system also provides a dust free environment for the panels to operate. The study achieved its aim to reduce the overall temperature of the solar panels by using a simple sprinkler system.

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