OPTIMIZATION STUDY OF WATER COOLED PV SYSTEM

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A project report submitted in partial fulfilment of the
requirements for the award of Master of Engineering (Electrical)

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"OPTIMIZATION STUDY OF WATER COOLED PV SYSTEM"** was prepared by **YIP WEI HAO** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electrical) at Universiti Tunku Abdul Rahman.

Approved by,

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Supervisor : Prof. Chong Kok Keong

Date : 28-11-2019

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Co-Supervisor : Dr. Lim Boon Han

Date : 28-11-2019

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In addition, I would also like to express my gratitude to my loving parents and friends who had helped and given me encouragement whenever I needed them.

Furthermore, I would also like to express my gratitude towards the laboratory staff who assisted me in using the equipment necessary to conduct the study.

ABSTRACT

This project demonstrates a method to optimize a water cooled PV system by means of software simulation to obtain the best design and then construction of the design. The average power for both cooled panel and uncooled panel were 75.15W and 73.0575W respectively which leads to a 2.864% power increase. The cooled panel had an average efficiency of 10.545% while the uncooled one was 10.41%.

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PV	photovoltaic

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Solar energy and other renewable energy sources is a growing field as conventional methods such as fossil fuels are depleting and would cause pollution to the world. Thus, researchers in the renewable energy field strive to improve the output of the renewable energy to compensate for the loss in power if fossil fuels are removed from the equation. In Malaysia, our goal is to have 20% clean energy generation (currently 2%) by the year 2030, a target set by The Energy, Science, Technology, Environment and Climate Change Ministry as reported by Eusoff (2018) from The Edge Markets.

1.2 Importance of the Study

The positive results of this project could potentially improve the output of solar PV plants due to its large amount of panels if employed in them even though the increase isn’t significant.

1.3 Problem Statement

Will modifying the existing water cooling system for a solar PV system have any effect on its temperature reduction and output power?

1.4 Aims and Objectives

1. To determine the optimum characteristics at which the solar panel can perform based on the change in several parameters of the water outlet through simulation.
2. To construct a solar PV system using the best design from the simulations

1.5 Scope and Limitation of the Study

The study aims to investigate several parameters such as water outlet width, number of holes, and the height of the water outlet from the PV panel through the use of simulation software (Solidworks) and then eventually construction.

1.6 Contribution of the Study

This study targets people who are in the solar panel field and also researchers who are interested in this field as well.

1.7 Outline of the Report

The literature review section describes the past work that researchers have done on water cooling and nanofluid cooling.

The Methodology and Work Plan section describes the method that is used to conduct the work throughout the project.

The results of the work will then be stated in the Discussion section.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Global warming is a worrying issue nowadays because it damages the environment and jeopardizes our comfortability while living. Fossil fuels and carbon emissions are some of the main causes for this. In the article written by Fogarty (2018) for the Straits Times, he stated that about 80% of global carbon dioxide emissions are from burning coal, oil, and gas. This would give rise to renewable energy sources such as solar power, wind power etc. to power our countries' necessities.

Solar panels are generally used in buildings such as our university, UTAR in KB-block, in homes by means of feed-in tariff and solar powered street lamps etc. However, their efficiencies (the percentage of solar energy being converted into useable electricity) are still considered low. Greentumble (2018) reports that most solar panels have 8-10% efficiencies while other traditional sources have around 40-55% efficiencies. Greentumble also says that the reason between this inefficiency is due to physical energy conversion which is restrained by a limitation called the Shockley-Queisser limit. So, methods such as solar panel cooling would help increase the efficiencies of solar panels by reducing the heat on the panels. Various methods such as water cooling and propylene glycol cooling are used in the industry and various other methods are being tested by researchers all over the world.

2.2 Literature Review

Solar power is a rather booming field nowadays. It is mostly used in hot countries which have a lot of sunlight. This could be due to factors such as the depletion of the ozone layer that brings in more sunlight, the need to power rural areas that have little to no access to conventional power usage from the grid and also the decreasing amount of fossil fuels in the world. However, the efficiencies (ratio absorbed from the sun to the energy absorbed by the solar panels) in solar power systems are still generally low even if they are paired with cooling systems that improve their efficiencies. The following are various techniques done by other people in the cooling of solar panels.

2.2.1 Water cooling

In Taiwan, Kuo et al. (2014) attempted to improve solar energy efficiency by means of a combination of concentrator photovoltaics and water cooling system. This cooling system increased the photovoltaic power capacity by 2%-15% and power generation efficiency by 2.29%-3.37%. They chose a water cooling system because it was readily available and saves a significant amount of energy. A neural network was also set up to predict when to start or stop the water cooling system by predicting the future photovoltaic power output. This could be a great idea since the point of Kuo’s research was to improve energy utilization and not loss of energy. This research shows that without a cooling system, the PV system would not be as efficient.

In 2015, an indoor test performance for PV panels using water cooling was conducted by Irwan et al. (2015). They found that there was a 5 – 23 ºC reduction in operating temperature while increasing the power output of the PV system by 9 – 22 % compared to the one without cooling (reference).

In 2016, Nižetić et al. (2016) demonstrated a water spray cooling technique that sprayed the front and back of the panel. The results of the study showed a reduction from 52 to an average of 24 ºC. The highest increase of power output was found to be 16.3 %.

In 2017, Zilli et al. (2017) analyzed the performance and effect of water-cooling on a microgeneration system of solar energy in Brazil. It was found that the use of cooling system at a high irradiation level has caused a 12.26% power increase and 12.17% efficiency increase. However, at low irradiation levels, the power and efficiency increase by 8.48% and 9.09% respectively. This shows that the systems responds to the irradiation and produces different power and efficiencies at different times of day.

Another attempt in 2017 was done by Matias et al. (2017). This study was done in a closed room and employed a reuse water flow system in which water pumped out onto the panel would flow back up to it eventually. It is also worth noting that this study uses an artificial light source to simulate constant solar irradiation. From the study, it was shown the generated power at 2 litre/min was higher than other flow rates. The flow path of the water was found to be random however a valve solved the problem. At the end of the study, it was found that 0.6 litre/min produced the most energy (78.74Wh) with an efficiency gain of 22.69%.

Another method of water cooling is called evaporative cooling and was demonstrated by Haidar et al. (2018). The results showed a 20°C reduction and 10% to 14% increase in electrical power generation efficiency. Evaporative cooling is the reduction in temperature of an object which results from the evaporation of a liquid that removes latent heat from the surface at which the evaporation takes place. Water was channeled to the back of the PV panel by means of gravity in the system. The water used in their research for cooling was excessive, so an intermittent supply of water was proposed for future works.

In the same year, a jet collision system was applied directly to the backside of PV panels using water as demonstrated by Abdulrasool et al. (2018). The system managed to obtain average PV, thermal, and PV/T energy efficiencies of 11%, 81%, and 92% respectively. Despite the results, this system would probably no be practical due to the high price of water jets in the market. The results could also be arguable because the sunlight was simulated and heat from the sun and the simulated sunlight used would probably be different.

Another PV panel cooling method was done in 2018 by Yang et al. (2018). They attempted to enhance the efficiency of PV panels by means of a spray cooling system with a geothermal heat exchanger. It was found that the UBHE system at similar solar intensity conditions, reeled in better results than the system without cooling and the cooling system without UBHE. The average net power output and conversion efficiency for the panels without cooling system, with cooling system without UBHE, and cooling system with UBHE are 33W at 6.77%, 33.4W at 6.87%, and 35.8W at 7.38% respectively. These results prove that a cooling system is important for a PV system to improve its power and efficiency.

2.1.2 Nanofluid cooling

Nanofluids are fluids that contain nanoparticles inside of them. They are usually made of metals, oxides, carbon etc. They are generally used in heat transfer applications such as engine cooling and PC cooling due to their high heat capacity. This doesn’t stop researchers from using them in cooling solar panels.

This method was attempted by Ebaid et al. (2018). They used (TiO_2) nanofluid in water –polyethylene glycol mixture and (Al_2O_3) nanofluid in water cetyltrimethylammonium bromide mixture. They found that at any volume flow rate (mL/min), the maximum power output of the nanofluid in water mixture obtained a higher power output of PV cell at 37.9W compared to water and cooling. It was also found that the power output increases as the volume flow rate increases. This proves that the increase in concentration of nanoparticles and flow rate would reduce PV surface temperature. Power and efficiency of the cooled PV cell is also enhanced.

In the same year, Abdallah et al. (2018) attempted a performance analysis for a hybrid PV/T system using low concentration Multi Walls Carbon Nano Tubes (MWCNT)(water-based) nanofluid. They obtained a 12°C temperature reduction for the PV panel at 0.075% V of MWCNT and also at maximum incident radiation. This led to 83.26% overall system efficiency. Pure water and different concentrations of MWCNT mixed with water was used in obtaining the data. From this analysis, it was found that pure water performed weaker than MWCNT at any concentration. This proves that nanofluids can be used to as a substitute to water as coolants in PV systems though more research should be made.

Another attempt on using nanofluid was done by Rostami et al. (2018). They utilized ultrasound to atomize the working fluid available in the reservoir and transmit cold vapors to the back side of the PV module at different flow rates. By atomizing 0.8 (w/v) nanofluid, the module average surface temperature was found to decrease up to 57.25% while increasing the maximum power up to 51%. Through their research, it was found that atomized nanofluid was more efficient than atomized pure water. Other than that, increasing the nanofluid concentration would increase cooling efficiency as well as maximum power generated by the PV module.

2.2 Summary

The cooling for solar panels is very important as it could boost the power output of the system. Numerous methods such as water cooling, modifications of the existing water cooling systems, and also nanofluid cooling have been demonstrated in the past.

3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The work done was divided into basically two parts, software simulation to find the best design and construction. Software simulation was done in Solidworks using the Flow Simulation add-on and the construction of the PV system was eventually done on the rooftop above UTAR Sungai Long KB Block.

3.2 Simulation

At the start of the study, other solar power projects in the university were used as reference. A reference of 9 litre/min (0.00015 m^3/s) volumetric flow rate was used.

The piping dimensions for the input pipe is 15 mm in diameter. The reference project had 33 holes (each being 2mm diameter holes) for the water outlets. Due to the lack of resources, the solar panels used in this study will not be the same as the reference project, instead the Mitsubishi PV-MF120TE4N (a 120 W panel).

In the study, several factors which include the tilt angle of the water outlet, water outlet width, number of holes, and the height of the water outlet were considered. In order to study those, several cases were structured based on the factors above. The cases are listed below:

1. Increase water outlet width while maintaining the same number of water outlets
2. Increase water outlet width while maintaining the same total outlet area
3. Increase the number of water outlets
4. Increasing the water outlet height from the solar panel

Each of the cases will have their tilt angles adjusted from 0 degrees (horizontal) to 90 degrees downwards at 15 degree steps to find the optimum setup in terms of temperature reduction.

The several cases above were simulated in Solidworks Flow Simulation. The setup for the panel and the water outlets are shown as below.

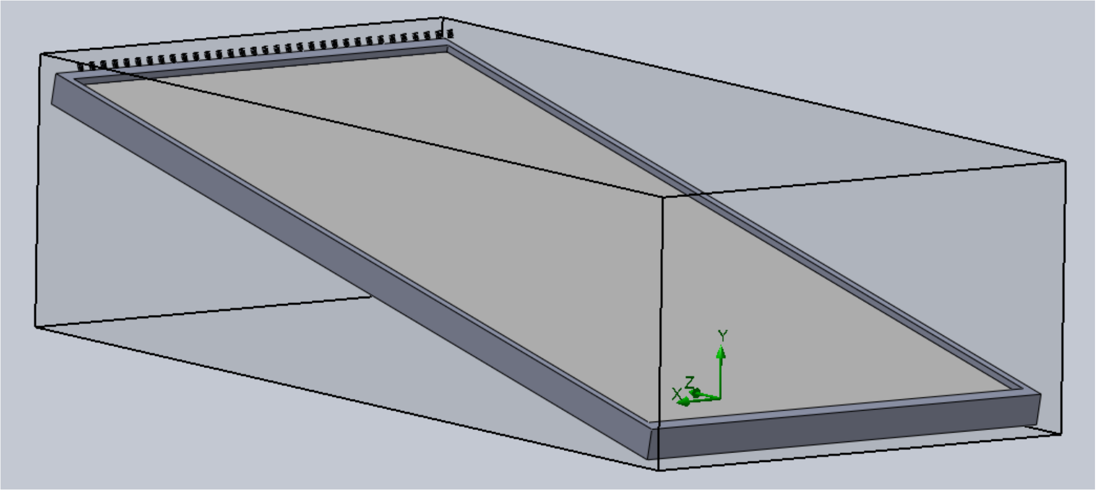


Figure 1: The layout of the water outlets and the PV panel.

Each hole (or slot) had to have their flow velocity defined based on the formula of

$$\dot{V} = vA$$

Where v = flow velocity and A = cross-sectional area at which the volume flows. For each case, the minimum, maximum, average temperatures for the panel and flow of the water over the panel were taken.

3.3 Construction

A solar PV system using the best design (best cooling effect) from the simulation is built on UTAR Sungai Long KB Block rooftop. The water outlet was connected to a water pump at a water tank via pipes. The water that flows down to the panel will be channelled to the water tank that is used to pump the water to form a cycle.

4

RESULTS AND DISCUSSIONS

4.1 Simulation results

The simulation was done in Solidworks Flow Simulation. A 1000 W/m^2 irradiance was assumed for simplification. To simulate the heat on the panel, the irradiance was multiplied with the area of the panel as shown below, then the resultant heat loss (in watt, W) will be defined on the surface of the panel.

$$\text{Area of PV panel} = 1.495 \text{ m} \times 0.674 \text{ m} = 1.00763 \text{ m}^2 \approx 1 \text{ m}^2$$

Assuming 1000 W/m^2 irradiance, power generated by the panel would be

$$P = 1000 \text{ W/m}^2 \times 1 \text{ m}^2 \times 12\% \text{ efficiency} = 120 \text{ W}$$

Assuming all losses are turned into heat, power loss

$$P_{loss} = 1000 \text{ W} - 120 \text{ W} = 880 \text{ W}$$

Thus, 880 W will be defined as a heat source on the panel surface. The simulated temperature of the panel surface without cooling was found to be 40.5064 °C. Since the experiment is conducted whereby the fluid (water) is flown from an outlet onto a surface, the study will be defined as an external flow. The setup for the water outlet and solar panel is shown below.

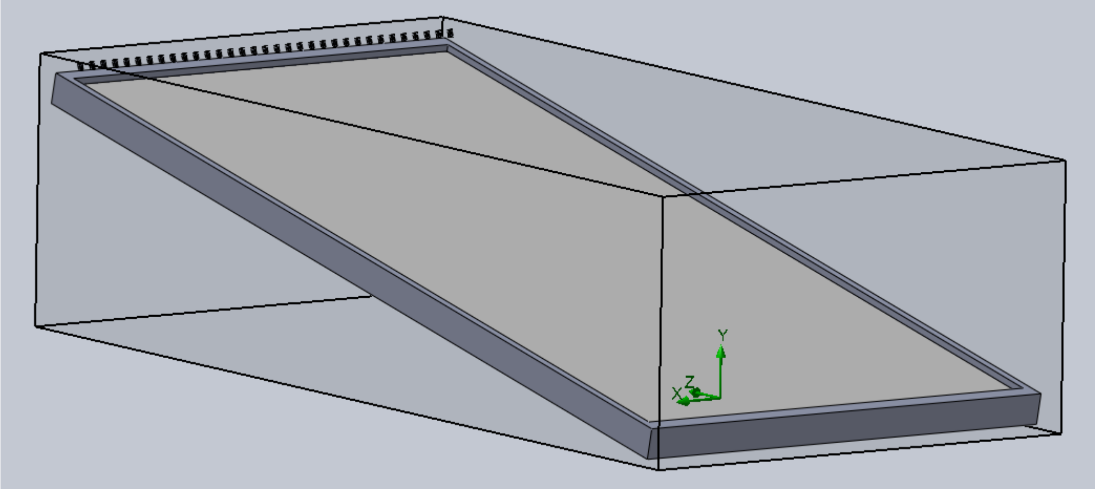


Figure 2: PV panel and water outlet setup for simulation in Solidworks.

Various parameters such as the water outlet width, area of the water outlet width in reference to the inlet area, number of water outlets and water outlet height from the top of the PV panel were taken into account in the simulation. The water outlets of the first three cases were all done at an elevation of 2 cm from the PV panel and at 0 to 90 degrees (starting at a horizontal position and aiming downwards till it hits 90 degrees).

4.1.1 Water outlet width while maintaining same number of water outlets

Based on the formula $\dot{V} = vA$, the following velocity values were determined for each outlet width and are shown below.

Hole width (m)	0.002m	0.003m	0.004m	0.005m	0.006m
Velocity (m/s)	1.446863119	0.884056	0.6364763	0.497228	0.407972

Table 1: Flow velocity calculated for each water outlet width.

The velocity values are then used for the simulation and the following temperature values are obtained from it.

	Average temperature for widths (Celsius, °C)				
Angle (degree, °)	2mm	3mm	4mm	5mm	6mm
0	31.5663	32.3982	33.5849	33.7844	33.7544
15	31.1344	33.2006	30.5597	32.5865	29.5309
30	31.6396	31.1078	34.1759	32.2484	33.3089
45	32.5133	31.0127	32.6927	32.6068	32.0044
60	32.7678	32.6669	33.327	33.5612	32.7199
75	33.3064	33.3188	33.6601	33.2563	27.2689
90	33.1025	32.6549	33.3084	32.9263	34.5785

Table 2: Average panel temperature readings of different water outlet widths at different water outlet tilt angles.

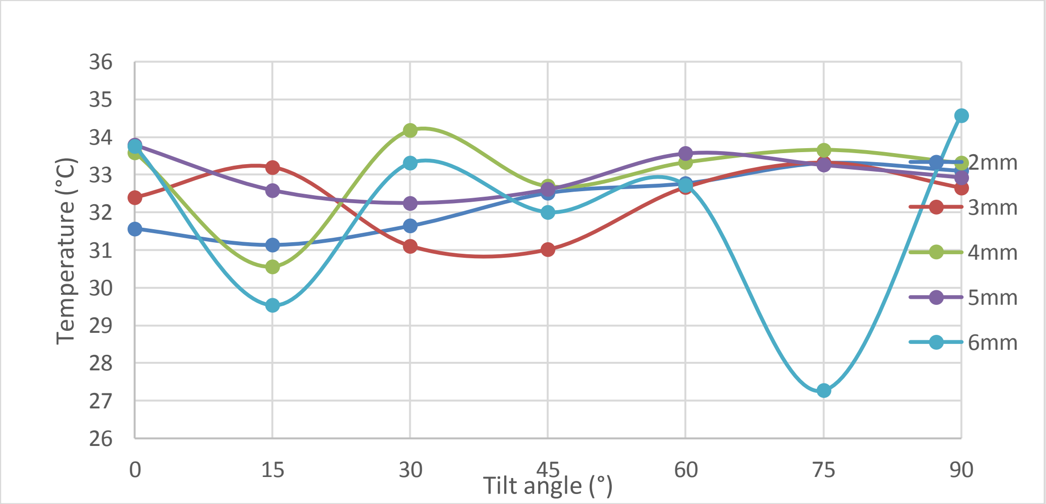


Figure 3: Graph of average panel temperature at different tilt angles while increasing outlet length

Based on the graph, it was found that the change of temperature readings at different tilt angles are not affected by the wideness of the water outlet. However, the best reading is found to be from the 6mm width at 75 degree tilt which brings in a 27.2689 °C (a 32.68% decrease in temperature).

4.1.2 Water outlet width while maintaining the same total outlet area

This part of the study intends to match the inlet (15mm diameter which results to 0.000176715 m^2) and outlet areas to maintain a steady flow. The number of holes for the different widths is determined using the following way:

e.g. for 2mm,

$$\text{Number of holes} = \frac{Total\ inlet\ area}{outlet\ area\ for\ one\ hole} = \frac{0.000176715}{\pi(\frac{2m}{2})^2} = 56.25 \approx 56$$

	Average temperature for widths (Celsius, °C)				
Angle (degree, °)	2mm (56 holes)	3mm (34 holes)	4mm (25 holes)	5mm (19 holes)	6mm (16 holes)
0	32.7607	32.3885	32.4594	33.4672	33.3221
15	32.1555	32.4867	32.2021	32.7431	32.5329
30	32.1842	32.3316	32.3857	32.8238	31.9905
45	32.8854	32.7078	32.2549	32.7052	32.1503
60	32.8925	32.681	32.527	32.6958	32.4136
75	32.9524	32.5477	32.4695	33.0302	32.7694
90	32.9589	33.1262	33.1172	33.096	33.1318

Table 3: Average panel temperature readings of different water outlet widths at different water outlet tilt angles while maintaining the same total outlet area as the inlet area.

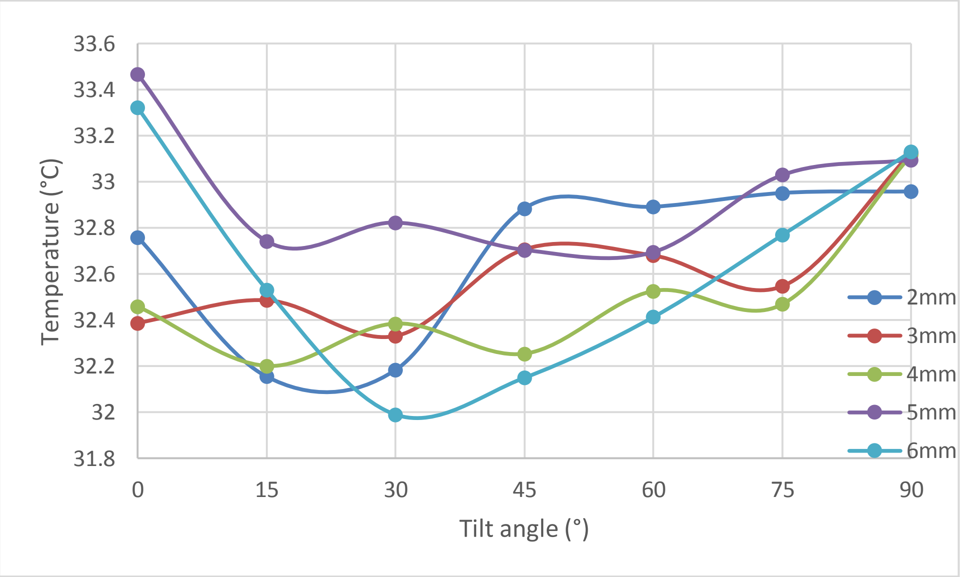


Figure 4: Graph of average panel temperature at different tilt angles while maintaining the same area as input

Increasing the width while maintaining the outlet area does not shift the graphs proportionally as seen in the figure above. However, the lowest temperature obtained was through the 6mm width of 16 holes at 30 degree tilt in which it brings in a 31.9905 °C (a 21.02% decrease in temperature).

4.1.3 Number of water outlets

This part of the study is to see the effect of increasing the number of holes. Since the best design for the previous two cases were of 6mm width, the hole widths here would also be the same.

	Number of water outlets						
Angle (degree)	16	20	24	28	33	37	41
0	33.3221	33.2395	33.1601	33.269	33.7544	33.2295	33.9671
15	32.5329	32.6919	32.901	33.0412	29.5309	32.8397	33.5565
30	31.9905	32.7594	32.5296	32.5611	33.3089	32.8375	33.3592
45	32.1503	32.5791	32.7003	32.6786	32.0044	32.5737	33.2793
60	32.4136	32.7031	32.6348	32.8672	32.7199	32.601	33.2947
75	32.7694	33.0013	32.9432	32.8737	27.2689	32.8155	33.4011
90	33.1318	33.1083	32.9754	32.9695	34.5785	32.7389	33.4478

Table 4: Average panel temperature readings of different number of water outlets at different water outlet tilt angles.

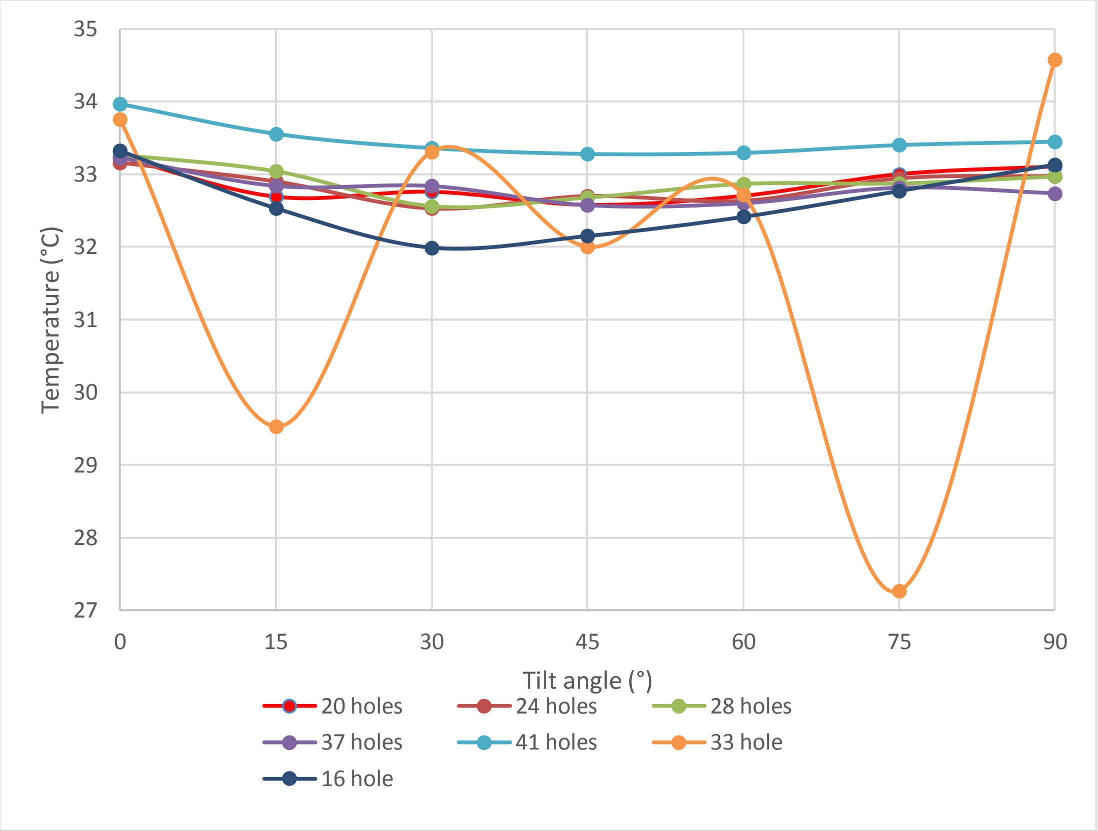


Figure 5: Graph of average panel temperature at different tilt angles with different number of holes

Based on the graph above, the best output was found to be by the 33 hole 6mm width tilted at 75 degrees which yielded a 27.2689 °C (a 32.68% decrease in temperature) which is the same as in the subsection 4.1.1.1.

4.1.4 Water outlet height from the solar panel

The water outlet was elevated at different heights (originally 2cm from the panel) to the values as shown in the table below.

Height (cm)	2cm	4cm	6cm	8cm	10cm
Temperature (Celsius, °C)	27.2689	33.8772	33.8335	32.8284	32.1287

Table 5: Average panel temperature readings at different water outlet heights.

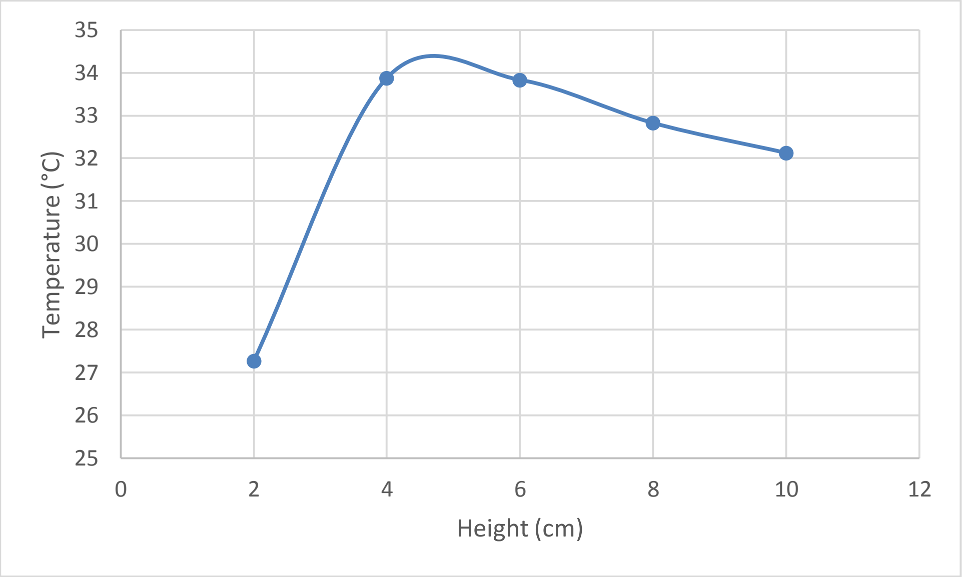


Figure 6: Graph of outlet height vs. average panel temperature

Based on the graph above, it was found that the 2 cm elevation yielded the best result. The graph formed shows a rise and then eventually a drop in temperature. However, more data should have been taken at different heights to better understand the effect of water outlet height on the cooling effect.

4.1.5 Choosing the setup for pipe fabrication

Based on the several subsections above, the lowest temperature yielded was 27.2689 ºC which was achieved by using the 33 hole 6mm width outlet tilted at 75 degrees. Thus, this design will be used in construction of the setup of the PV panel system. The following pictures show the temperature profile, and water flow profiles at different angles.

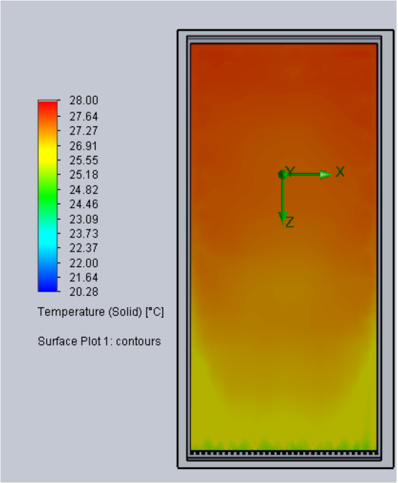


Figure 7: Temperature profile of the PV panel surface

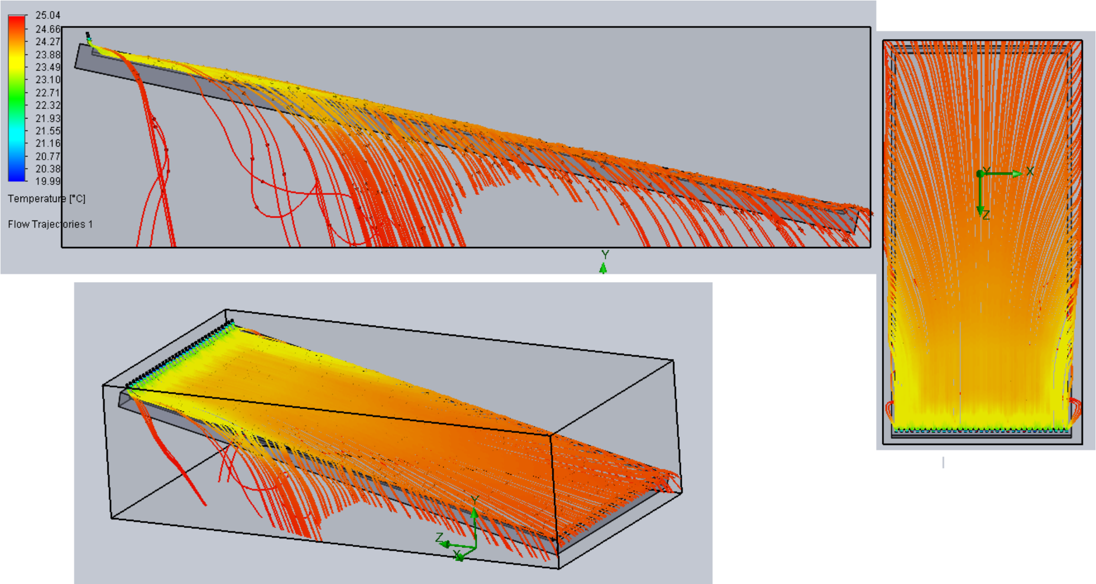
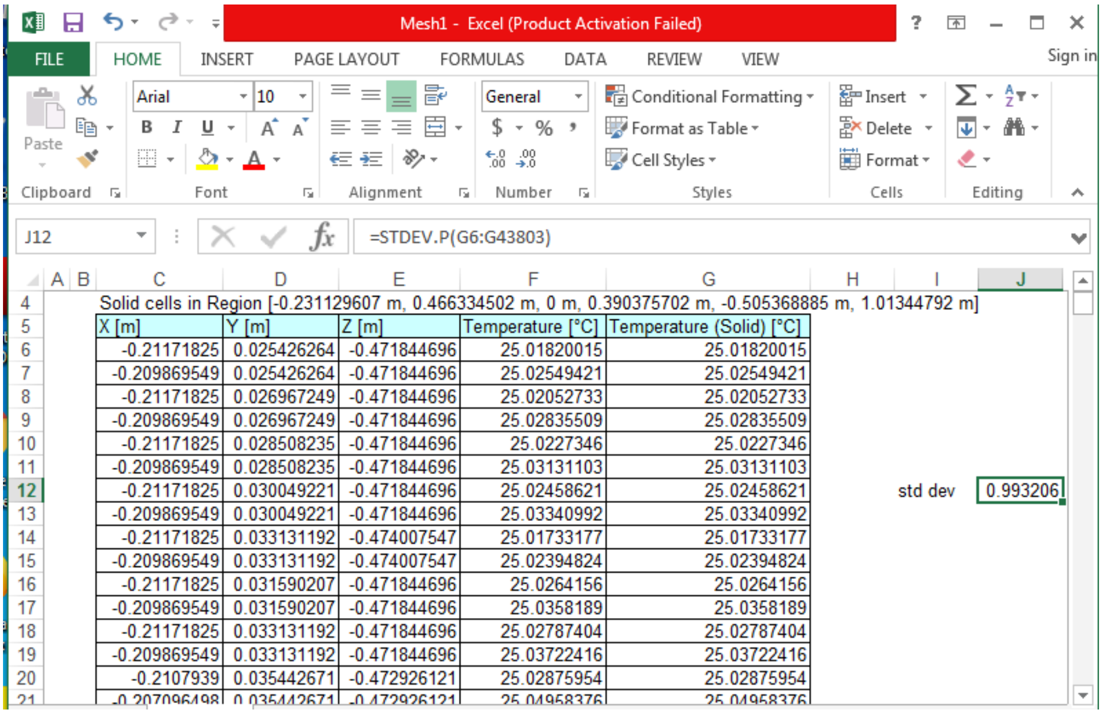


Figure 8: Water flow profile of the PV panel

A mesh study of the panel and water outlet was done to determine the temperatures at each part of the panel and the results were outputted to an Excel file as shown below. A standard deviation of 0.993206 was obtained from this.



J12 =STDEV.P(G6:G43803)

Solid cells in Region [-0.231129607 m, 0.466334502 m, 0 m, 0.390375702 m, -0.505368885 m, 1.01344792 m]

	X [m]	Y [m]	Z [m]	Temperature [°C]	Temperature (Solid) [°C]		
6	-0.21171825	0.025426264	-0.471844696	25.01820015	25.01820015		
7	-0.209869549	0.025426264	-0.471844696	25.02549421	25.02549421		
8	-0.21171825	0.026967249	-0.471844696	25.02052733	25.02052733		
9	-0.209869549	0.026967249	-0.471844696	25.02835509	25.02835509		
10	-0.21171825	0.028508235	-0.471844696	25.0227346	25.0227346		
11	-0.209869549	0.028508235	-0.471844696	25.03131103	25.03131103		
12	-0.21171825	0.030049221	-0.471844696	25.02458621	25.02458621	std dev	0.993206
13	-0.209869549	0.030049221	-0.471844696	25.03340992	25.03340992		
14	-0.21171825	0.033131192	-0.474007547	25.01733177	25.01733177		
15	-0.209869549	0.033131192	-0.474007547	25.02394824	25.02394824		
16	-0.21171825	0.031590207	-0.471844696	25.0264156	25.0264156		
17	-0.209869549	0.031590207	-0.471844696	25.0358189	25.0358189		
18	-0.21171825	0.033131192	-0.471844696	25.02787404	25.02787404		
19	-0.209869549	0.033131192	-0.471844696	25.03722416	25.03722416		
20	-0.2107939	0.035442671	-0.472926121	25.02875954	25.02875954		
21	-0.207096498	0.035442671	-0.472926121	25.04958376	25.04958376		

Figure 9: Mesh analysis output with the standard deviation

4.2 Construction of the PV system

The PV system was constructed at UTAR KB-block rooftop. For this study, two panels will be used, one as reference, another with the cooling mechanism. Two IV curve tracers (1 × Prova 210, 1 × PVPM 1040X) will be used to observe the performance of the panels simultaneously. The water outlet pipe is connected to a water pump and would pump at every 10 minutes. Ambient temperature of the surroundings was also taken at 10 minute intervals. An infrared thermal imager was also used to measure the panel temperature at 9 points for both panels.

Figure 10: Setup of the water outlet pipe above the PV panel.

Figure 11: The two panels being used, left: reference panel, right: panel with cooling (the 9 crosses represent the temperature collection points)

Figure 12: Setup of IV curve tracers for data collection

The data collection was done for several days (25 – 27 November 2019) and were computed using Microsoft Excel. Various graphs such as efficiency, power generated, temperature, irradiance, and comparisons between each other were plotted and shown below with regards to its collection day.

Day 1

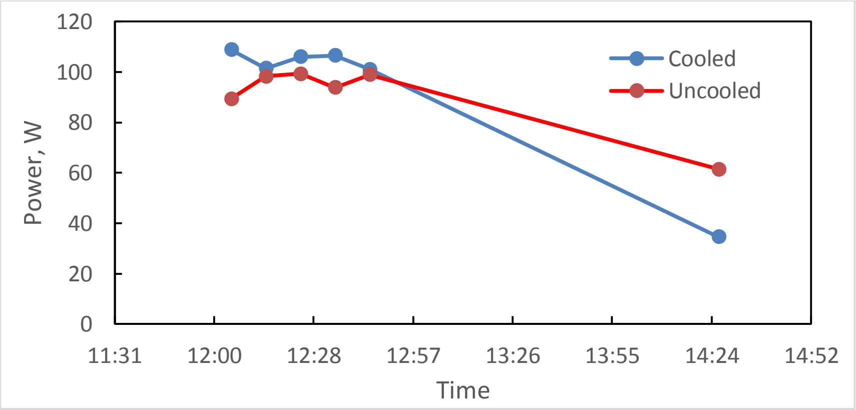


Figure 13: Graph of power over time (Day 1).

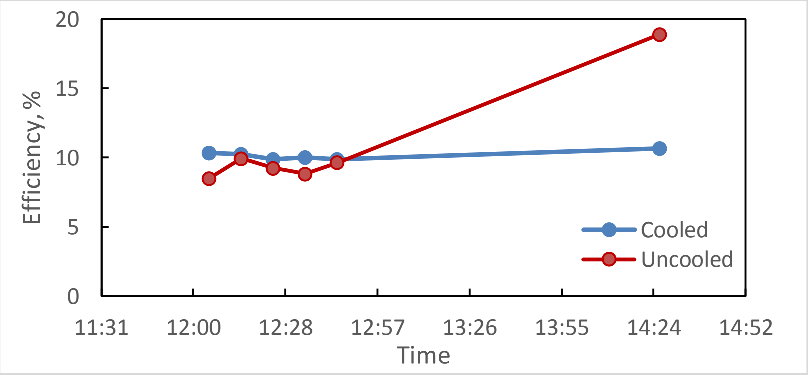


Figure 14: Graph of efficiency over time (Day 1).

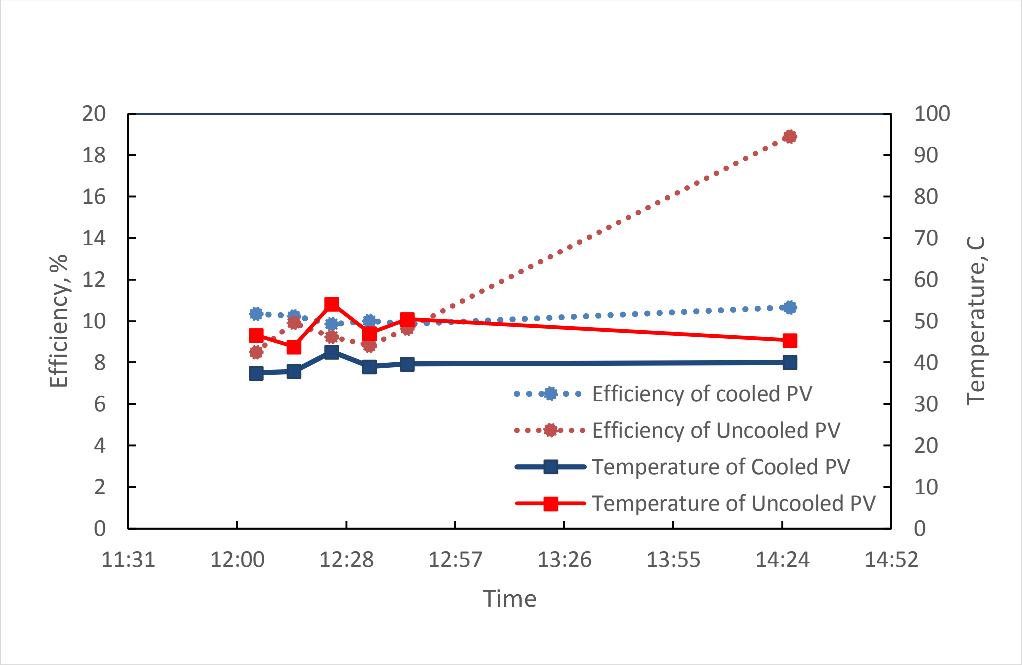


Figure 15: Graph of efficiency and temperature over time (Day 1).

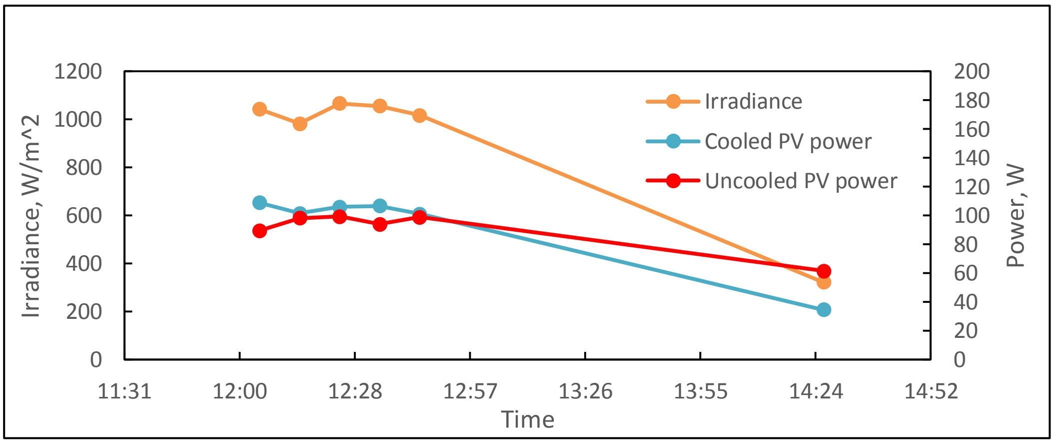


Figure 16: Graph of irradiance and power over time (Day 1).

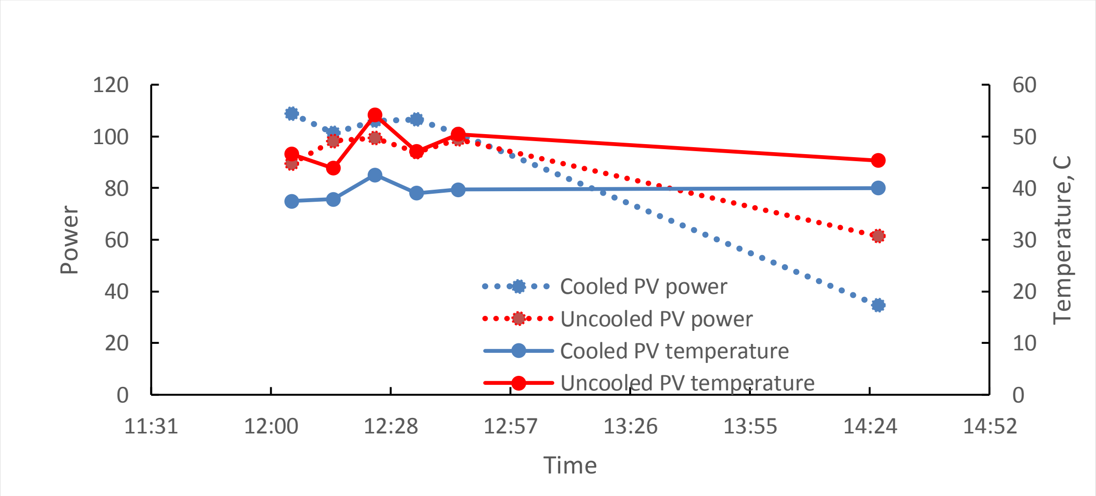


Figure 17: Graph of power and temperature over time (Day 1).

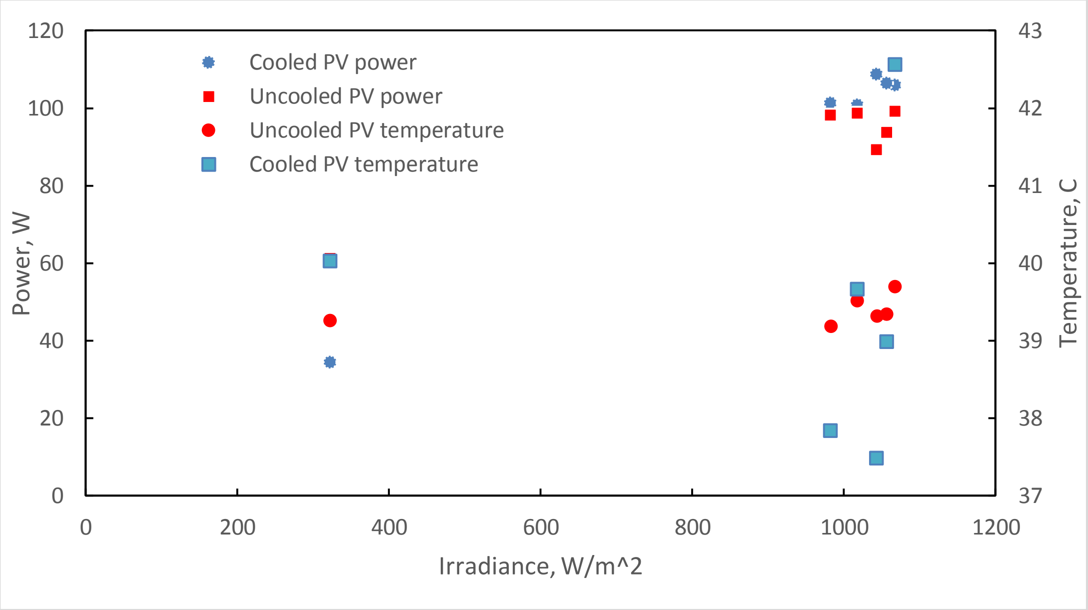


Figure 18: Graph of power and temperature over irradiance (Day 1).

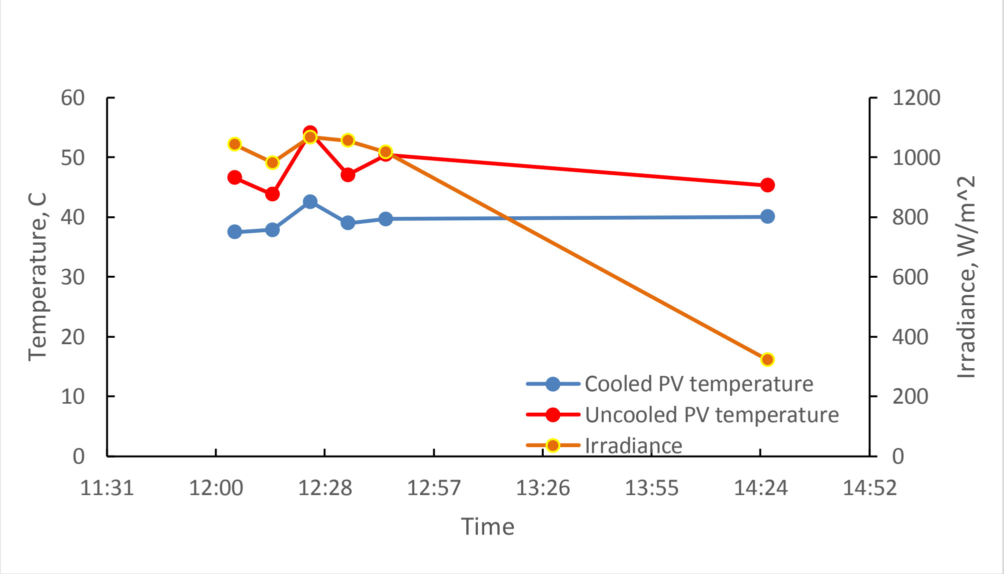


Figure 19: Graph of irradiance and temperature over time (Day 1).

The power collected on Day 1 sees a slight improvement of 90.16W on the uncooled PV panel and 93.05W on the cooled one. Average efficiency for the cooled and uncooled PV panel were found to be 10.165% and 8.4967% respectively. The graph of efficiency and temperature over time shows an agreement where the hot temperature (uncooled panel) lowers down the efficiency of the panel and vice versa. The graph of irradiance and temperature over time shows a relatively stable temperature even if the irradiance goes down over time. The graph of irradiance and power over time shows a proportional increase and decrease of power whenever the irradiance rises or falls. The graph of power and temperature over time shows a dramatic decrease in power during the afternoon due to high temperature. During this day, the cooled panel produces more power than the uncooled panel but is opposite in the afternoon which was due to bad weather.

Day 2

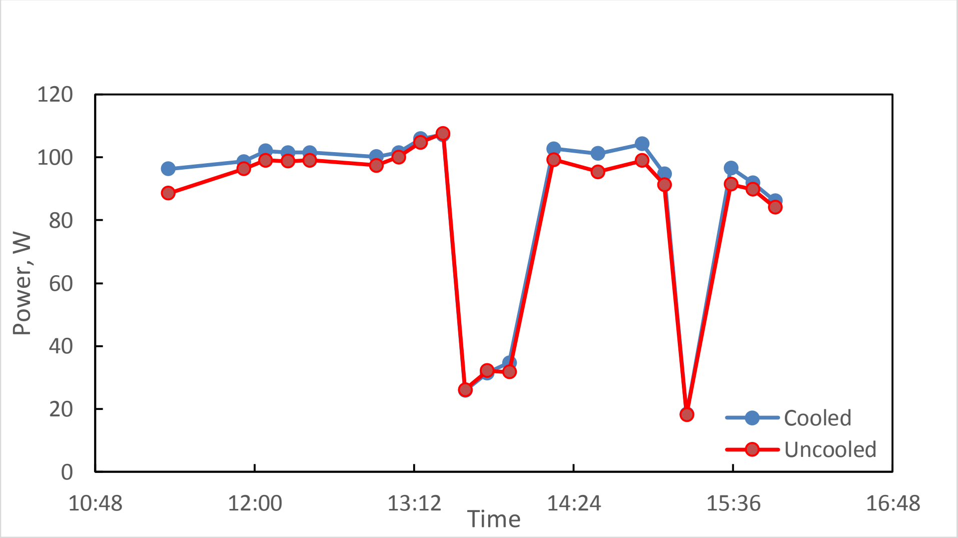


Figure 20: Graph of power over time (Day 2).

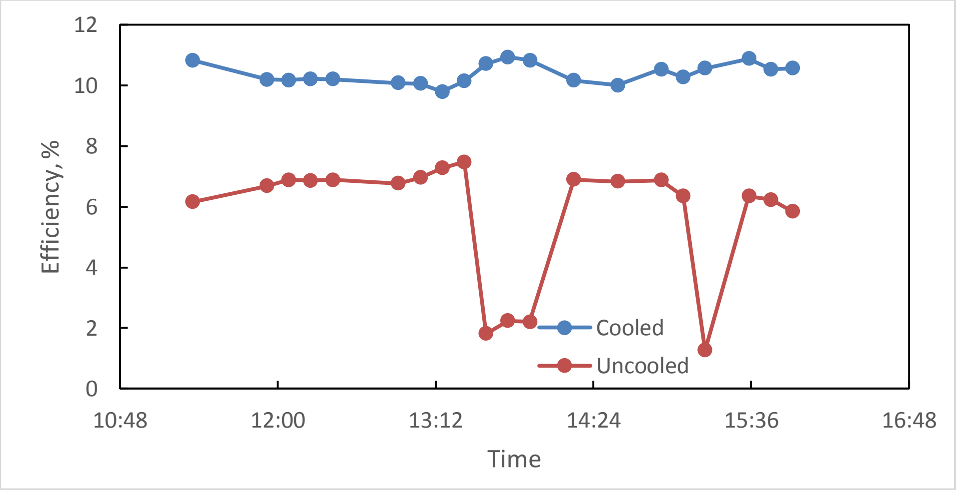


Figure 21: Graph of efficiency over time (Day 2).

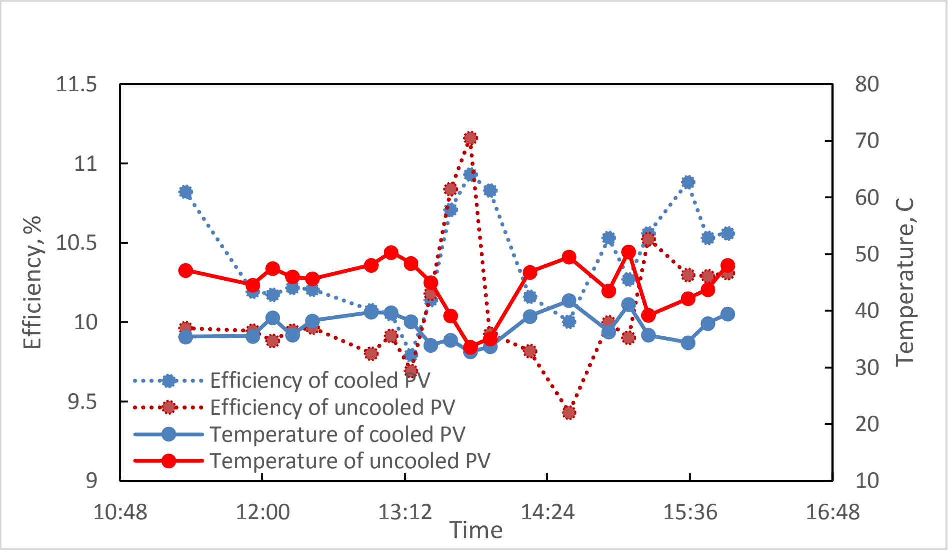


Figure 22: Graph of efficiency and temperature over time (Day 2).

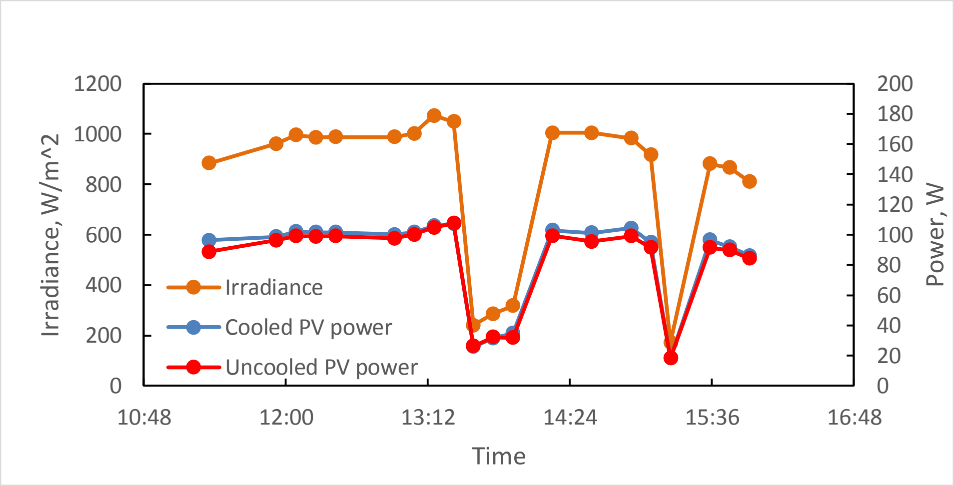


Figure 23: Graph of irradiance and power over time (Day 2).

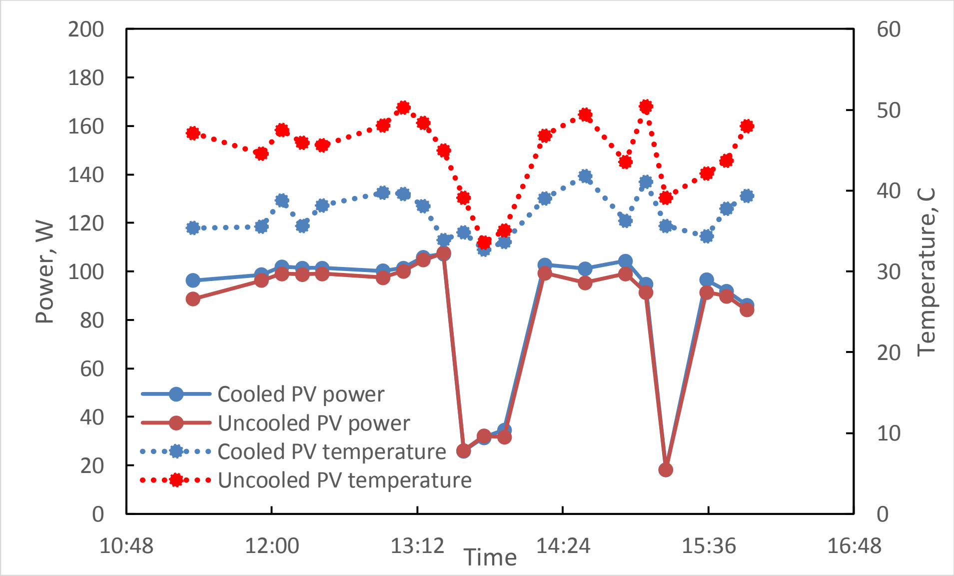


Figure 24: Graph of power and temperature over time (Day 2).

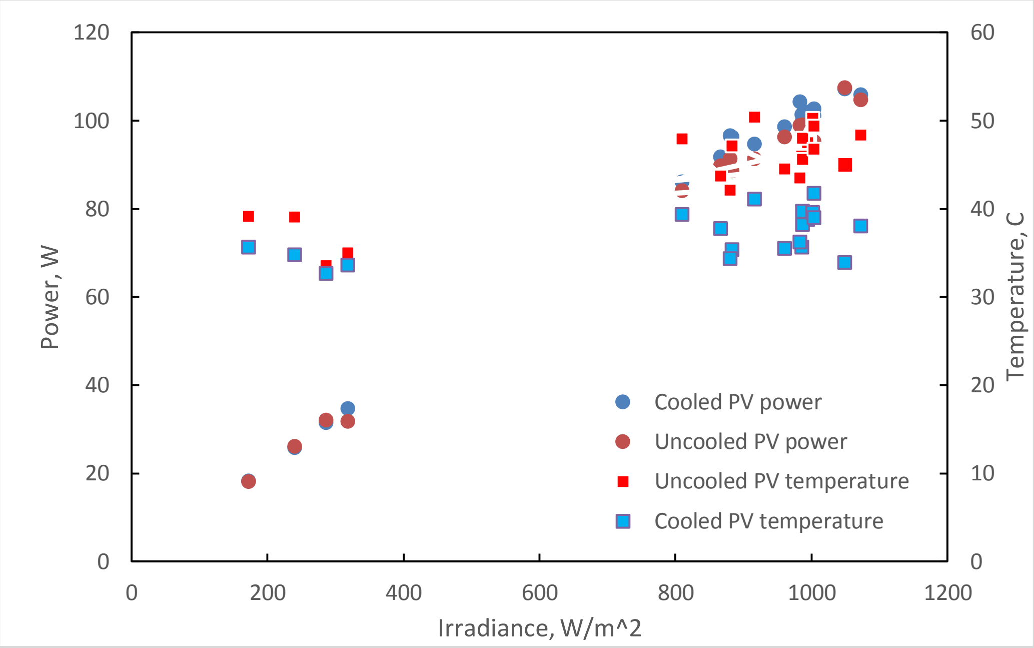


Figure 25: Graph of power and temperature over irradiance (Day 2).

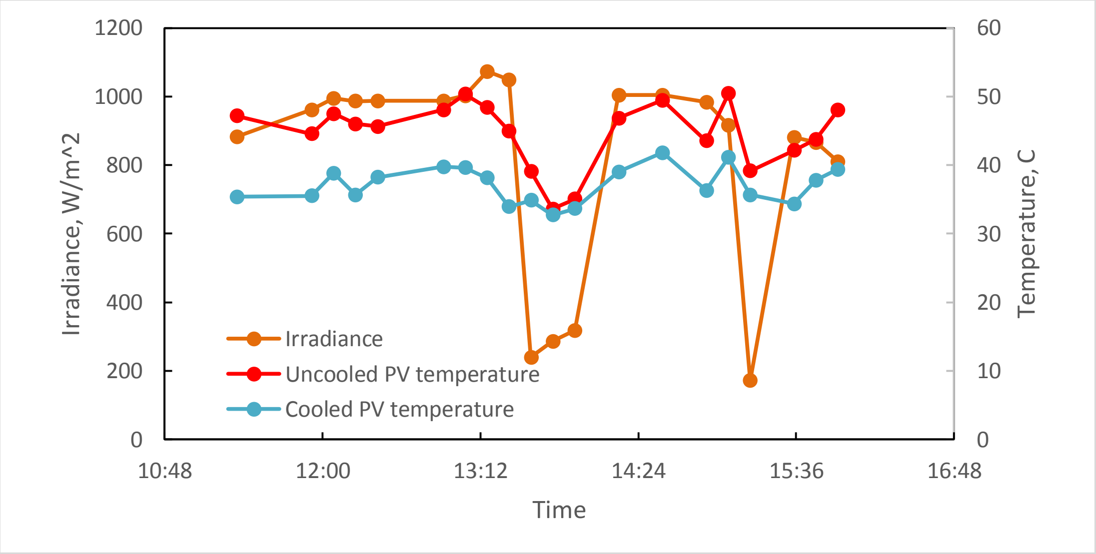


Figure 26: Graph of irradiance and temperature over time (Day 2).

During Day 2, the cooled and uncooled panels had an average of 85.15W and 82.542W respectively. The average efficiency was found to be 10.382% for cooled PV and 10.089% which is just short of around 0.3%. On the efficiency and temperature vs time graph, it is shown that the efficiency varies with the temperature where higher temperature would cause a dip in the efficiency. The spike in efficiency between 1pm and 2pm was caused by bad weather which lowered the temperature while increasing the efficiency. The graph of power and temperature over time shows that power is directly affected by the temperature where the cooled PV panel performs better than the uncooled PV panel even if it is just slightly. Based on the graph of power and temperature over irradiance, it was found that cooling had a better effect when the irradiance is higher, thus producing more power than the uncooled PV panel. When irradiance dips, this causes the ambient temperature to dip as well and thus raising the power generated.

Day 3

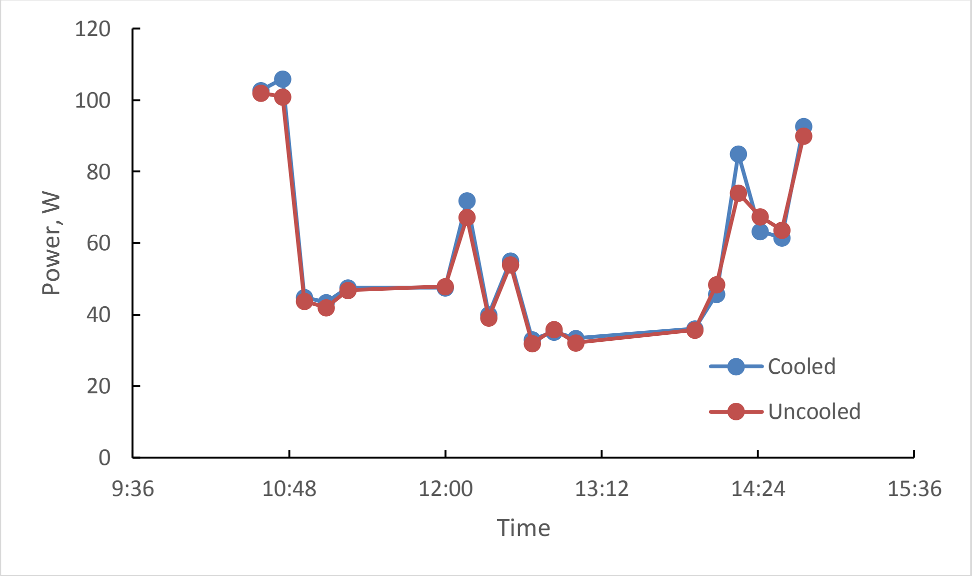


Figure 27: Graph of power over time (Day 3).

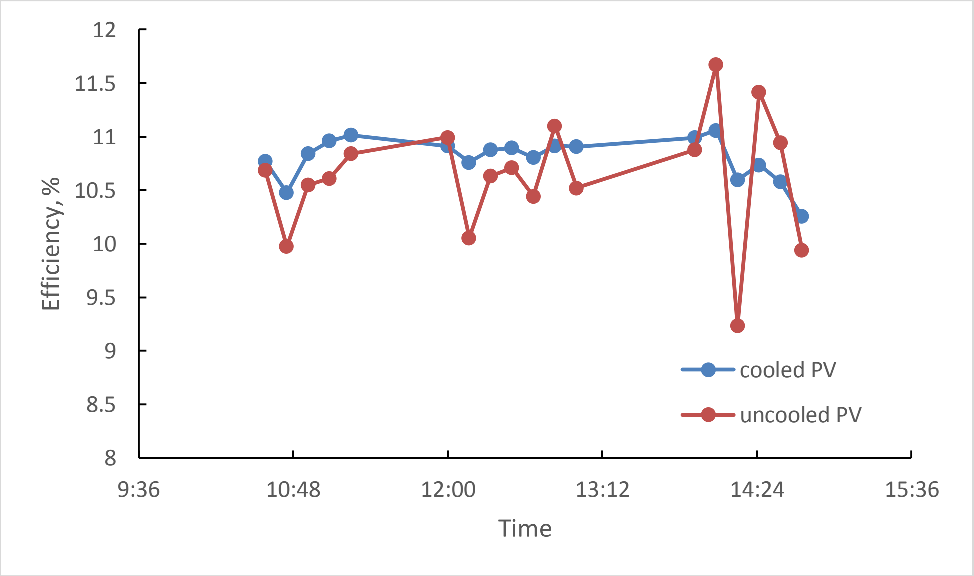


Figure 28: Graph of efficiency over time (Day 3).

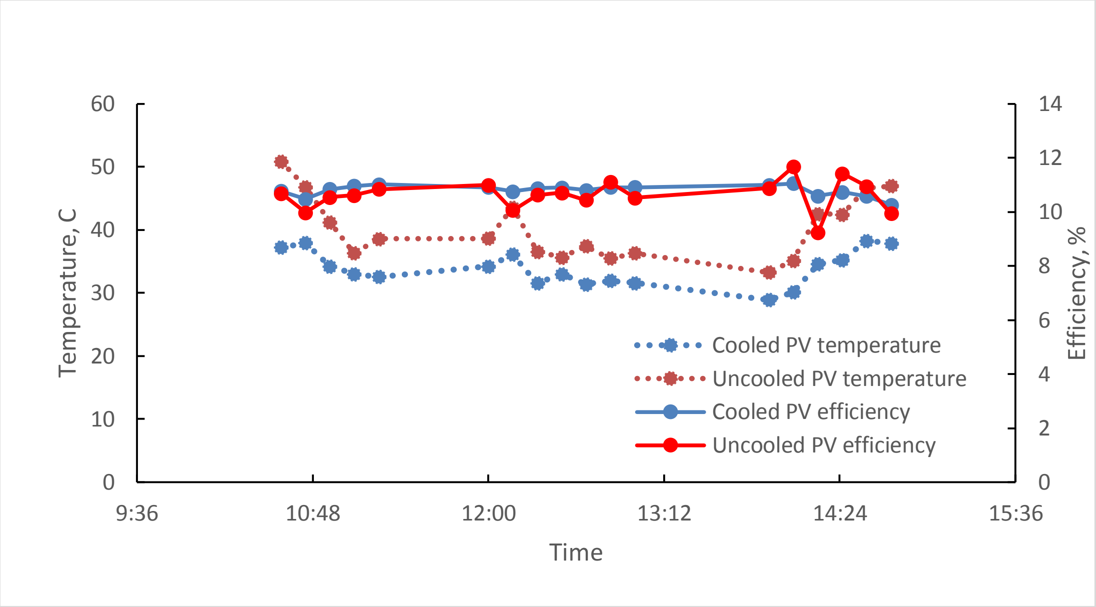


Figure 29: Graph of efficiency and temperature over time (Day 3).

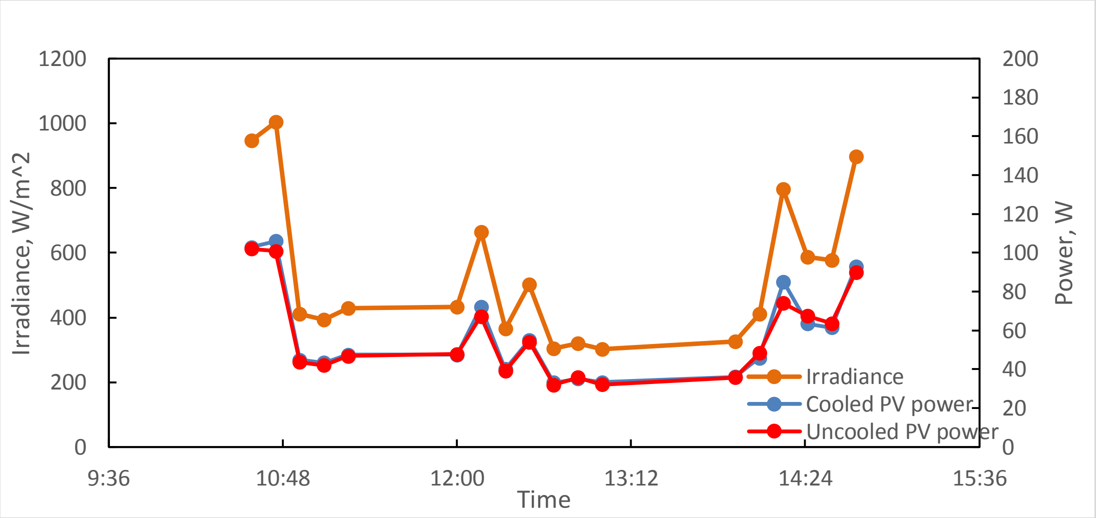


Figure 30: Graph of irradiance and power over time (Day 3).

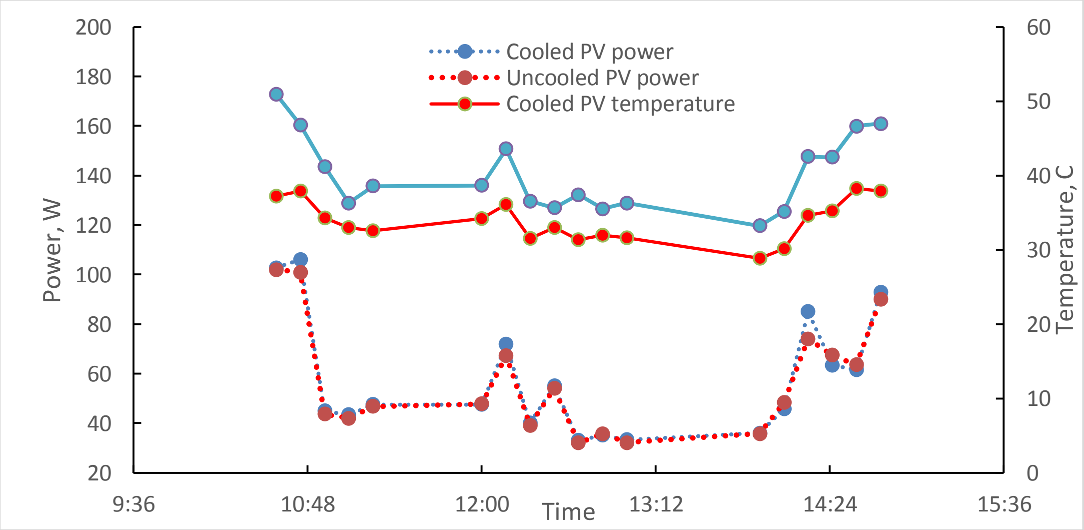


Figure 31: Graph of power and temperature over time (Day 3).

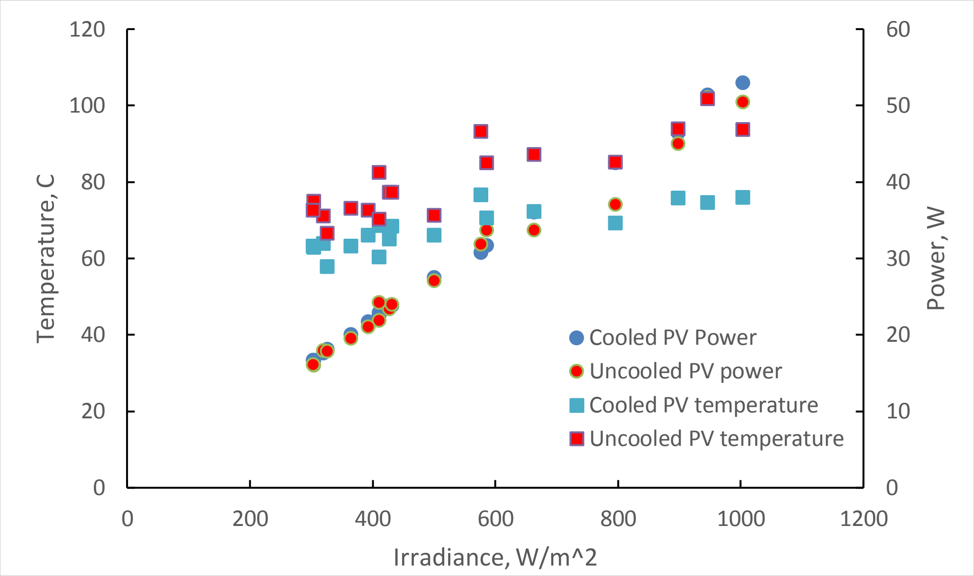


Figure 32: Graph of power and temperature over irradiance (Day 3).

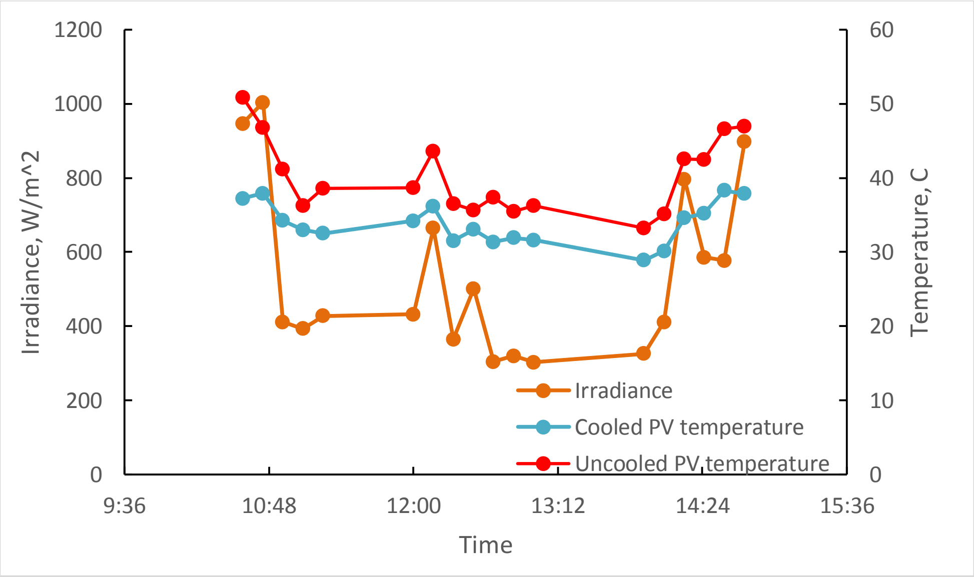


Figure 33: Graph of irradiance and temperature over time (Day 3).

During day 3, the cooled panel reached an average of 58.072W while the uncooled one reached a 56.818W. The average efficiency for both cooled and uncooled PV panels are 10.798% and 10.623% respectively. The graph of power over time shows only a slight increase in power on the cooled panel while the efficiency had about an average difference of 1%.The graph of efficiency and temperature over time shows that a lower temperature cooled PV panel reeled in a higher efficiency compared to the uncooled one. This would directly affect the output power as shown in the graph of power and temperature over time. The graph of power and temperature over irradiance shows that the cooled panel performs better than the uncooled panel when the irradiance is increasing. This would affect the temperature of the panels as well though the cooled one would generally have a lower temperature.

5.

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The average temperature for the cooled panel was found to be 36.0937ºC while the uncooled one was 43.213 ºC. The simulated values for the cooled and uncooled panels were 27.2689 ºC and 40.5064 °C respectively. The simulated recorded values of the cooled panel temperature saw a difference of 32.36%. This could be due to the assumption made that there was only heat loss and the simulated irradiance was at a constant 1000 W/m^2. The average power for both cooled panel and uncooled panel were 75.15W and 73.0575W respectively which leads to a 2.864% power increase. The cooled panel had an average efficiency of 10.545% while the uncooled one was 10.41%. The comparison can be seen below.

	Simulated temperature	Real temperature	Average power	Average efficiency
Cooled	27.2689 ºC	36.0937ºC	75.15W	10.545%
Uncooled	40.5064 ºC	43.213 ºC	73.0575W	10.41%

Table 6: Comparison of the cooled and uncooled PV panel values.

A reduction of 16.48% average in terms of temperature was obtained as well.

5.2 Recommendations for future work

For similar characteristic studies, a constant light source (solar simulator) like a lamp should be used to simulate the sun's irradiance at a constant level in an enclosed area. This is due the constant change in weather patterns and the sun's irradiance constantly changing due to clouds.

Furthermore, the flow of the water film should be studied as not the whole panel was covered by water which would cause a slight heating in that particular area as shown below.

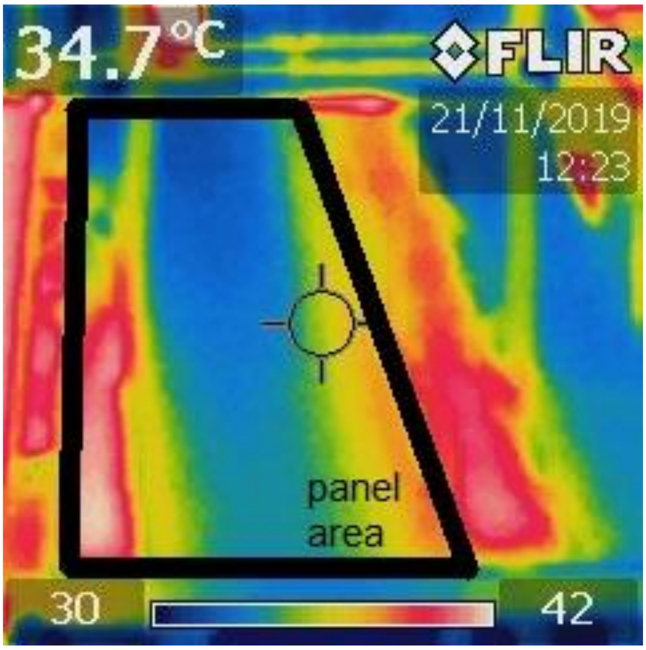


Figure 34: The irregular water flow that causes an irregular heat dissipation on the panel.

Complex cooling systems such as water cooling and wind cooling could be employed simultaneously though losses such as optical loss should be considered as well.

6.

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