PERFORMANCE OPTIMIZATION OF ROOFTOP POWER PLANT IN MALAYSIA CLIMATE BY LOWERING DOWN THE TEMPERATURE

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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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 **"PERFORMANCE OPTIMIZATION OF ROOFTOP POWER PLANT IN MALAYSIA CLIMATE BY LOWERING DOWN THE TEMPERATURE"** was prepared by **NGEI CHEE KIT** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic at Universiti Tunku Abdul Rahman.

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Supervisor : Dr. Lim Boon Han

Date : ____________________

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ABSTRACT

Malaysia is hot and humid all year round. This is because that Malaysia is located near the equator, thus its climate is equatorial. Since Malaysia is hot throughout the year, this discourages renewable energy such as solar energy. The higher the temperature, the lower the efficiency. Furthermore, Renewable Energy Act 2011 is an act to encourage implementation and establishment of a special tariff system. Besides that, it also promotes feed-in tariff (FiT) scheme. This whole act is to promote renewable energy by allowing electricity generate from renewable sources like solar energy be able to sold to power utilities. This project is to construct a hardware model experiment which consists of two photovoltaic modules and metal deck with various configurations and water systems. Water systems involved are water spraying and water dripping system. The project is carried out with a fixed inclination angle of 10^{o} and air gap of 10cm. Temperature sensors are placed below the solar panel. They are positioned at top, middle and bottom of the solar panel which are recorded using a data logger. Total of 4 experiments are conducted initially with 2 additional experiments. The initial 4 experiments are conducted with various configurations using both water spraying and water dripping system. This is to determine which configuration is the best for optimum result. After that, 2 more additional experiments are conducted to further improve the solar panel efficiency. The results are then collected to determine which water system is better. Comparison of temperature drop, increase in voltage, power and efficiency, voltage and power gained are taken into consideration to compare the cooling performance of the water systems. The initial 4 experiments yield exceptional cooling performance. However, the power gained of the additional experiments are similar to the initial 4 experiments. Recommendations are made to further improve the cooling performance and the efficiency of the solar panel.

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LIST OF SYMBOLS / ABBREVIATIONS

PV	Photovoltaic
P	Power, W
V	Voltage, V
I	Ampere, A
T	Temperature, K
I_{mpp}	Current at maximum power point, I
V_{mpp}	Voltage at maximum power point, V
I_{sc}	Short Circuit Current, I
V_{oc}	Open Circuit Voltage, V

mm	Millimetre
cm	Centimetre
m	Metre

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CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy is basically the energy that is obtained from resources which are naturally regenerated during a human timescale. There are many renewable energy such as wind, sunlight, waves, tides and geothermal heat. There are also many application for renewable energy. Some important applications are electricity generation, transportation, rural energy services and water and air heating/cooling. Based on REN21's 2014 report, renewable energy has started to improve as years pass by. Renewable energy contribute around 19% and 22% to the global energy consumption in 2012 and 2013 respectively. This is consider a great achievement. This is because renewable energy is a substitute for non-renewable resources such as fossil fuels. Fossil fuels is used to generate electricity. However, it will produce carbon dioxide emission which is bad. Furthermore, nowadays rich and well developed countries such as United States and China have started to invest heavily into biofuels, solar, wind and hydro. Besides that, carbon dioxide emission can lead to greenhouse gases (GHG). GHG is the gas in the atmosphere that will absorb the solar radiation from the sun. When this happens, the global temperature will continue to increase, thus causing global warming. Ice, ice bergs and glacier will start to melt due to global warming. Global warming not only affects the environment but it will affect but also the flora and fauna. Animals and plants habitat will also change due to the increase in temperature. Birds will start to migrate from country to country until the temperature of the environment is suitable for the species. Moreover, some species of animals and plants will start to extinct due to climate change. This is because the failure of the species to adapt with the global warming. GHG emission also will cause the depletion of the ozone layer. Therefore, this makes renewable energy very crucial to the environment. Renewable Energy Act 2011 is a policy or an act that encourage the implementation of renewable energy. This act specifically provides a special tariff system for a specific duration. This tariff system will give special premium price or rate for electricity produced from renewable sources. Most people will install solar panels to utilize this act. However, once the specific duration finishes, it will return back to the original rate. Solar panels are famous when this act is introduced. This is because solar panel can be install on almost anywhere from residential house, company rooftop and shop lot rooftop to a solar farm. Solar energy should be encourage in Malaysia. This is because Malaysia is summer throughout the year. This is due to it is close to the equator which makes Malaysia climate equatorial. Unlike some countries with have 4 seasons a year, Malaysia can produce solar energy throughout the year. The act along with the Malaysia climate encourages the installing of solar panel.

Malaysia has 2 monsoon wind seasons. Firstly is the Southwest Monsoon. Its duration is around late May to September. The second monsoon wind season is the Northeast Monsoon. It usually occurs around October to March. The second season usually brings more rainfall. This is because that monsoon originates in the north Pacific and also in China. The Southwest Monsoon originates from Australia. Although Malaysia have 2 monsoon wind seasons, wind energy is not popular in Malaysia. The strongest wind in Malaysia occurs in Cameron Highland or Genting Highland. Even the strongest wind in Malaysia does not produce enough energy require for the wind turbine. Therefore, Malaysia cannot harvest wind energy.

1.2 Aims and Objectives

The aim of this project is to investigate the temperature and the air gap distance of the photovoltaic module. Objectives of the project are

1. To set up a hardware model experiment which consists of two photovoltaic modules and metal deck roof with different configurations and water system

2. To construct water spraying and water dripping set up for solar photovoltaic system for panel cooling purpose

3. To analyse and compare the effect of water spraying and dripping system on the performance of the solar panel

1.3 Scope

This project is mainly focus on the relationship between the temperature and efficiency of the photovoltaic module with a fixed air gap and rooftop material. The rooftop material used is metal deck. The project is conducted using multicrystalline solar panels to evaluate its performance by lowering down its temperature. This project is carried out in Utar Sg. Long Campus rooftop with a height of a ten-storey building.

1.4 Project Progress Chart

Gantt chart is very crucial for any project as it shows the progress of the project. It also keeps the project on track. The progress chart also acts as a schedule.

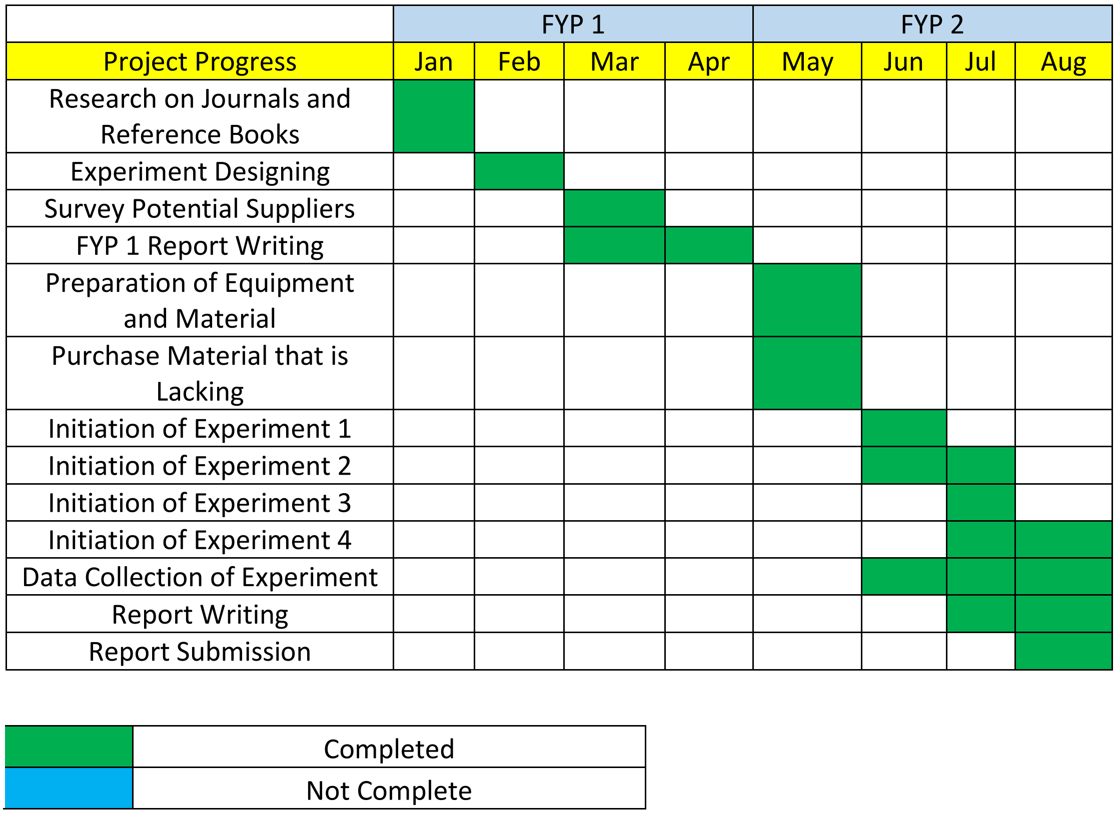


Figure 1.1: Project Overview

CHAPTER 2

LITERATURE REVIEW

2.1 Photovoltaic Cell

Photovoltaic (PV) cell is basically an electrical device that transforms light energy into electricity by photovoltaic effect. This is done by using a chemical and physical phenomenon. Furthermore, it also can be regard as a form of photoelectric cell. It also can have the electrical characteristics like resistance, current and voltage. These characteristics can vary when exposed to light. Photovoltaic modules or also known as solar panels require solar cells which are the fundamental building blocks. Light source can be obtained from many sources whether it is artificial light or sunlight. Light source will make solar cells photovoltaic. As long as there is a light source, the solar cells is photovoltaic. Photovoltaic cell is also known as solar cell. Solar cells can also be called as photodetector. This is because it can detect electromagnetic radiation that is near visible range, light or measuring light intensity. Photovoltaic cell requires 3 basic attributes which are the separation of charge carriers of opposite types, absorption of light, producing electron-hole or excitons and lastly separate extraction of those carriers to the external circuit.

2.2 Characteristics of Photovoltaic Cell

2.2.1 Current-Voltage Characteristics

One of the main factor that affect the current-voltage characteristic is the temperature. This is because it is one of the crucial factor that affects the maximum power output from the photovoltaic cell. The most significant is the temperature dependence of the voltage which decreases with increasing temperature (Markvart, T., 2000). Furthermore, silicon cell will have the voltage decrease is around 2.3 mV per ^{o}C. Usually the fill factor and the temperature differences of the current are very small amount, thus it is normally negligible in most of the photovoltaic system design. Another factor that affect the current-voltage characteristic is the solar irradiance as shown in Figure 2.1. However, solar irradiance does not affect as much as the temperature.

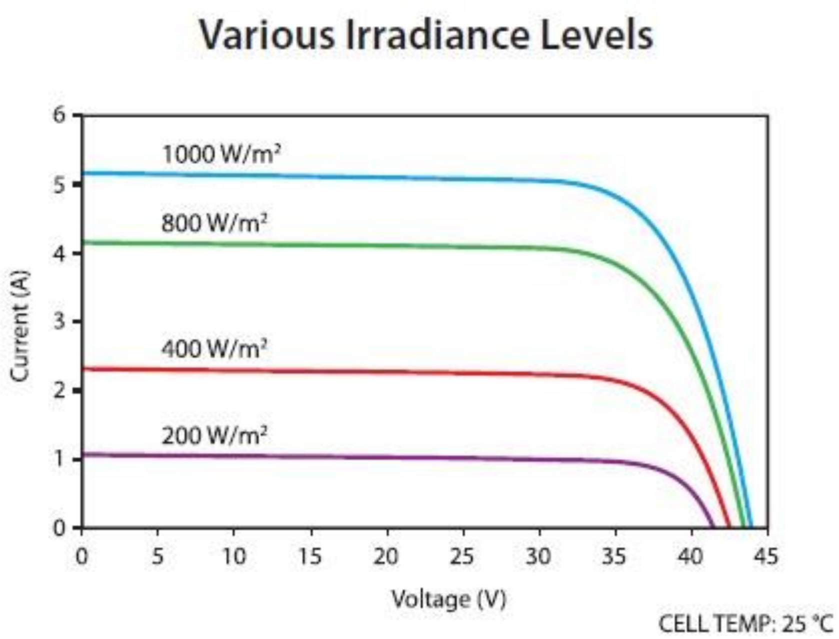


Figure 2.1: Irradiance Dependence of Current-Voltage Characteristic

(Enhance Photovoltaics, 2015)

2.2.2 Power characteristic

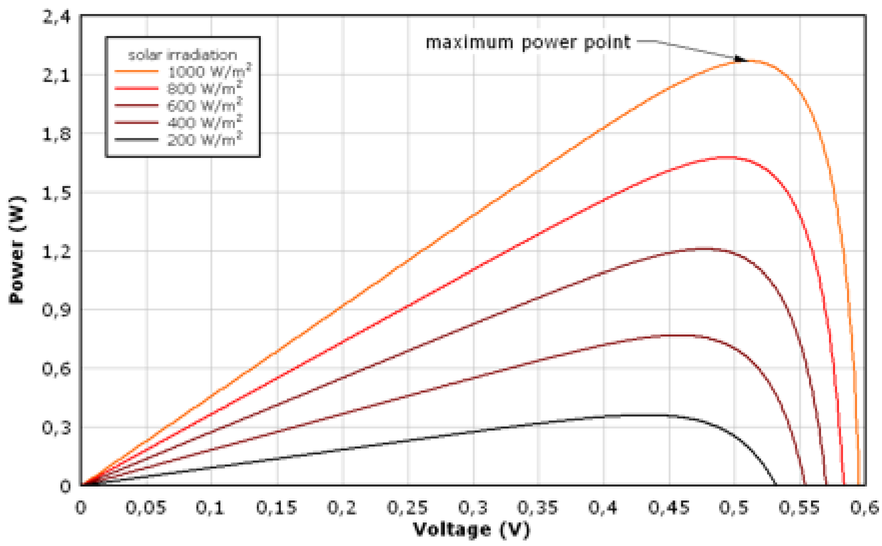


Figure 2.2: Power Produced as a Function of Voltage V at the Terminals

(Dennis L., 2016)

Irradiance must also be taken into consideration for the performance of the photovoltaic cell. Figure 2.2 shows the photovoltaic-cell characteristics with different levels of illumination. The flux of photons that is above the bandgap energy is proportional to the current generated by the solar cell. Based on the research above, the current generated by the photon flux increases as the irradiance increases. In other words, it can be said that the irradiance is directly proportional to the short-circuit current. In real application, usually the voltage variation is a small amount and it is usually negligible.

By using the formula P = VI, the solar cell produces the power as a function of voltage V at the cell terminals in Figure 2.2. Besides that, the Figure 2.2 also show elevated temperature and lower irradiance of the power characteristics. It is common sense that any solar cell should operate at its maximum power point. However, in real application it is not that easy. The most ideal way is to make the solar cell operate in such a way that it is operate at a constant voltage which is slightly below the maximum power point. However, this is less effective solution. Furthermore, if the voltage is operating at the linear part of the Current-Voltage characteristics, the temperature will hardly affect the power output produced by the photovoltaic cell. The short-circuit current and the irradiance will be directly proportional to the power delivered to the load.

2.3 Types of Photovoltaic Cell

Every solar cell consist of at least two or more thin layers of silicon or any semi-conducting material. When any silicon or semiconductor is exposed to light, electrical charges are produced. Once the charges are generated, it can be redirected by using metal contacts making it a direct current (DC). Usually single cell electrical output is too small, so many cells are connected together. Once they are connected together, a “string” will be formed. This will produce a direct current. Besides that, global company are also competing to research and develop renewable energy such as solar energy. Many type of solar cells are made. Some of the common type of solar cell are Multi-crystalline and Monocrystalline. They cover almost all the solar panels produced globally.

2.3.1 Amorphous Silicon Solar Cell

This solar cell is basically made up of silicon atoms in thin homogenous layer as shown in Figure 2.3. Furthermore, amorphous silicon tends to absorbs light more effectively compared to crystalline silicon (Kalogirou, S. A., 2009). This also tends to lead to thinner cells. This technology is also knows as thin film PV technology. In addition to this, amorphous silicon best advantage is it can be deposited on a wide range of substrates. It can be both flexible and rigid. On the other hand, the disadvantage of this solar cell is that it has low efficiency around the order of 6 %. In this modern generation, solar panels manufactured from amorphous silicon come in many different types of shapes. By using this advantage, amorphous silicon can even be made to the shape of roof tiles. By doing this, roof tiles on houses can replace normal brick tiles.

Figure 2.3: Amorphous Silicon Solar cell
(ModernEnviro, 2014)

2.3.2 Monocrystalline Silicon Cells (Mono-Si)

This solar cell are made from pure monocrystalline silicon. It has a single continuous crystal lattice structure based on Figure 2.4. This structure has almost no impurities or defects. This solar cell is common in solar panel manufacturing industry. The main reason is monocrystalline cells have high efficiency. The efficiency is relatively around 15%. However, the main disadvantage is this cell is that it has a complicated manufacturing process. Pure monocrystalline silicon requires high technology equipment which requires large investment scheme. By comparing this solar cell with other solar cell like amorphous silicon, it is relatively more expensive. In addition to that, crystalline silicon contribution towards photovoltaic solar cells is around 90% of which one third of them is monocrystalline silicon (Dobrzanski, L.A., et al., 2012).

Figure 2.4: Monocrystalline Silicon Cells

(The New York Times Company, 2016)

2.3.3 Multi-Crystalline Silicon (Multi-Si)

Multicrystalline cells are made from many grains of monocrystalline silicon. The manufacturing process of multi-crystalline silicon can be said to be easier than monocrystalline silicon cells. It is done by casting molten polycrystalline silicon into ingots. After that, it is subsequently cut into very thin wafers. It is then assembled together into complete cells which can be seen in Figure 2.5. Due to the simple manufacturing process, multicrystalline cells are cheaper to be produced. On the contrary, the efficiency is slightly less than monocrystalline silicon cells which is around 12%. Due to the low manufacturing cost, multicrystalline cells are more popular than monocrystalline cells. On the other hand, multicrystalline cells have bad electrical properties compared to monocrystalline silicon, thus intense research is being done to increase the conversion efficiency of the solar cells generated by the multicrystalline silicon (Dobrzanski, L.A. and Drygala, A., 2008). Besides that, it has been research that texturization can increase the short-circuit current.

In addition to this, another process in this modern generation is called fluidized bed reactor. The silicon produced is called metallurgical-grade silicon (UMG-Si). The name is come from using metallurgical process. Metallurgical process is used instead of the common manufactured way which is the chemical purification processes. Popular company from Japan, China, United States and many more such as Hemlock

Semiconductor, GCL-Poly and OCI produces around 230 000tonnes in 2013 (Bloomberg New Energy Finance, 2014). In addition to this, multicrystalline silicon has its own special characteristic. A “metal flake effect” can be seen on the top of the multicrystalline silicon solar cell. The efficiency of multicrystalline silicon is lower than monocrystalline cell but is higher than amorphous silicon solar cell. Due to this reason many company and firms choose to manufacture multicrystalline silicon. Furthermore, it also has a low start-up capital investment. Based on research, it takes about 5 tonnes of multicrystalline silicon to produce 1 MW of photovoltaic module (Mayur. S., 2015).

Figure 2.5: Multi-crystalline Silicon

(Solar Feeds, 2012)

2.3.4 Thermophotovoltaics

Thermophotovoltaic (TPV) is a photovoltaic device that uses infrared region of radiation instead of sunlight. It is an energy conversion from heat to electricity. It is done through photons. Thermophotovoltaic system is usually made up of a photovoltaic diode and a thermal emitter, it can be seen in Figure 2.6. In addition to this, modern TPV system includes burner, fuel, longwave photon recovery mechanism, PV cell, waste heat recuperation system and radiation (Kazmerski, 1994). The thermal emitter temperature is different for every system. It can range from 900 ^{o}C to 1300 ^{o}C.

Thermal emission is caused by thermal motion of the charges in the material. Furthermore, the continuous emission of photons also occurs in the thermal emission. Normal thermophotovoltaic temperatures will cause the radiation near the infrared frequencies. Moreover, radiated photons are absorbed by photovoltaic diodes. Once absorbed, they are then convert into free charge carriers. Free charge carriers are also known as electricity. The design of TPV system is done by matching the optical properties of the specific thermal emission with the conversion characteristics of the solar cell. Most researchers focus on gallium antimonide (GaSb). It is also found that Germanium (Ge) is also compatible (Jef. P. and Glovanni. F., 2003).

Besides that, there is a fine line between TPV and PV conversion. The main difference is the temperatures of the system geometries and the radiators. For solar cell, radiation is usually obtained from the sun which has the temperature around 6000K with the distance around 150 X 10^6km. However, TPV receives radiation in two forms which are narrow or broad band from a surface with lower temperature around 1300K to 1800K with distance of few centimeters. Moreover, the power density output of TPV converter is much greater compared to non-concentrator PV converter (Coutts, T. J., Allman C. S. & Benner, John. P., 1997).

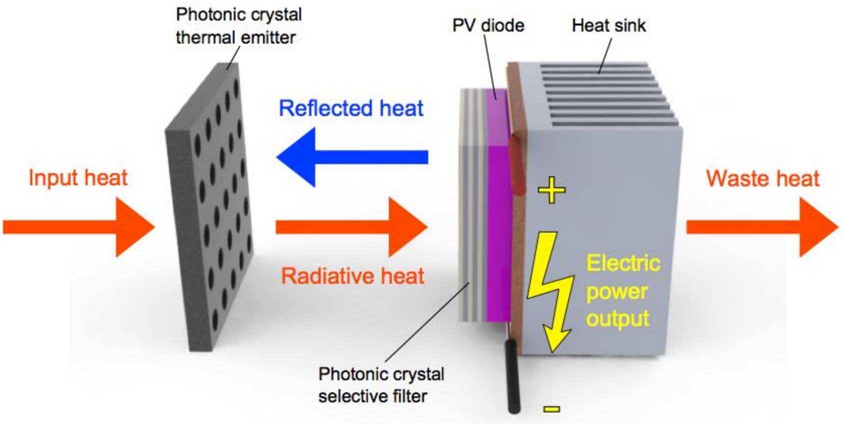


Figure 2.6: Thermophotovoltaic System

(New Energy and Fuel, 2016)

2.4 Factors Affecting the Efficiency of Photovoltaic Module

2.4.1 Temperature

Temperature is one of the major factor that affect the performance of the PV module. Increase in temperature of the PV module will decrease the voltage, thus lowering the maximum output power based on Figure 2.7. Any addition increases in temperature will result in degradation modes of any photovoltaic module. This is because increase in temperature will increase the stress on the thermal expansion. Furthermore, degradation rates increase by a factor of two for every increase 10^{o}C in temperature. The Nominal Operating Cell Temperature (NOCT) of most of the photovoltaic module is normally 25^{o}C. Furthermore, the current output has minimum changes and it is small enough to be consider negligible. Furthermore, it also known that solar irradiance increases when the cell temperature increase (Gail. A. M., 2013).

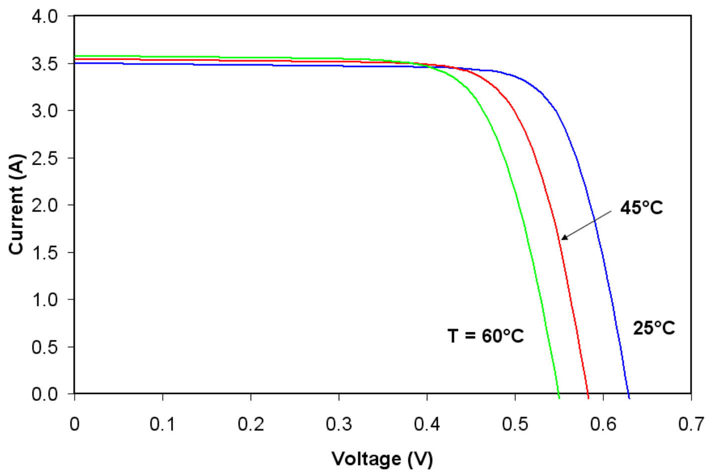


Figure 2.7: Temperature Effect on PV module

(OPVAP, 2011)

2.4.2 Solar Irradiance

Solar irradiance is a form electromagnetic radiation. It is the power per unit area which is W/m^2. It is also the measurement of solar energy that will affect the maximum power output of any PV cell. Solar irradiance will affect the output current of the PV module. On the other hand, temperature does not affect the output current. Furthermore, solar irradiance is a function with respect to the distance from the sun, cross-cycle changes and the solar cycle (Boxwell, M., 2012). In addition to this, the main factors that affects the solar irradiance is the sun's position and the weather conditions.

2.4.3 Cosine Effect

Cosine effect basically means tilting angle. It is the amount of solar energy from the sun is absorbed by the solar panel. This usually occurs when the sun is not directly perpendicular to the solar panel. In addition to this, solar irradiance is at its maximum when the angle between the sun and the surface of the solar panel is 0^o.

2.5 Air Gap Distance Effect against Temperature of Solar Panel

One of the important factor that affects the performance of the PV module is the air gap distance. The air gap can be classify into 2 types which are non-ventilated and ventilated. Air gap distance is one of the key factor that maintain the temperature of any solar panel. The gap between the solar panel and the rooftop can determine whether the heat is trap inside or it is able to escape. In most residential house, heat enters the house through the rooftop. This concept also applies to solar panel. The gap must be big enough to regulate the heat between the rooftop and the solar panel. However, it must not be too large as the pressure of the wind can be too strong and might blow the solar panel off the roof. If the air gap distance is too small, ventilation will not occur, thus internal heating of the solar panel will occur. Once internal heating occur, the temperature of the solar panel will increase, hence making the maximum output power decrease.

2.6 Heat Transfer

2.6.1 Thermal Conduction

Thermal conduction is the microscopic collisions of atoms and particles and the electrons movement within a body that transfers heat. Conduction can take place in any matter like plasmas, gases, liquids and solids. Thermal conduction can be also known as diffusion. The function of temperature difference between the properties of conductive medium and any two bodies is called temperature gradient. When the temperature of any body is high, the atoms inside the body move rapidly compared to the temperature of any body that is low. Furthermore, if any two bodies with different temperature are put in contact with one another, heat is transfer from the body with the higher temperature to the body with lower temperature. This is done by the vibration from the body with higher temperature. The body with higher temperature will continue to vibrate until it reaches equilibrium. Thermal conduction can also be applied to solar panel. As the protective glass starts to heat up, it will vibrate causing the solar cell to increase in temperature.

2.6.2 Radiation

Radiation uses electromagnetic waves to transfer heat. It comes from the word radiate. Radiate means to spread or send out from a fixed position. Furthermore, radiation transfer heat by carrying energy from a fixed position to the surrounding space around it. This energy is carried by electromagnetic waves. It does not involve any interaction or movement of matter. In addition to this, radiation can also occur through a region of space or matter such as vacuum. Heat obtained on Earth is from the sun. It is received by the electromagnetic waves that travels through vacuum between the sun and the Earth. Solar panel will tend to heat up through the electromagnetic waves from the sun. Only a partial of the wavelength is able to be convert to electricity by the photovoltaic cell.

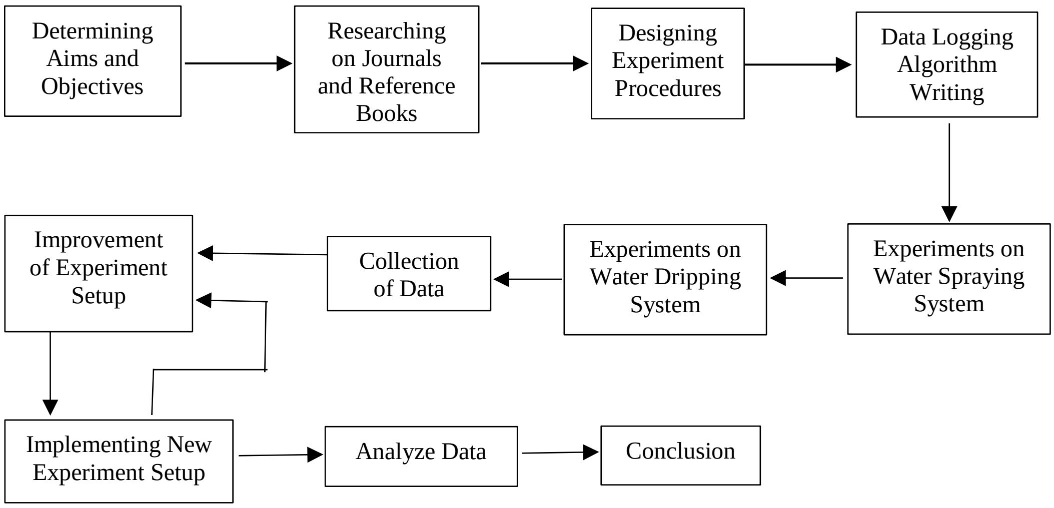
2.6.3 Convection

Convection is the movement of fluids that transfer heat from one location to another location. Gases and liquids are fluids. These fluids will move around the bulk of the sample of matter. The fluids will carry energy. The movement of the fluid will be from the high temperature towards the low temperature. Furthermore, convection also shows how an electric heater in any room warms up the room. The coils of the heater will warm up the air near it. Heated air will become less dense and start to rise. After that cold air will tend to move to the bottom of the room as the hot air risen. Once the cold air reaches the bottom of the room, the coils of the heater will heat it up, making the air to rise. Convection currents will start to form slowly. These air also carry energy that is obtained from the electric heater. The same application also applies to the solar panel. The hot air absorbed by the metal deck will rise and heat up the solar panel, thus forcing the cold air to fall onto the metal deck. After a while, the sun will then heat up the cold air forcing it to rise once again to heat up the solar panel. Convection will stop once it reaches equilibrium. Based on research, equilibrium usually takes around fifteen minutes (Armstrong, S. and Hurley, W.G., 2010).

CHAPTER 3

METHODOLOGY

3.1 Flow Chart Procedure



3.2 Equipment and Apparatus

There are several equipment and apparatus used in this project. They are as follows:

1. Pyranometer
2. Multimeter
3. Electrical Wiring
4. CF-260 Photovoltaic Module

5. Supporting Beams
6. Water Hose
7. Polyvinyl Chloride (PVC) Pipe
8. Data Logger
9. DS18B20 and DHT22 Temperature Sensors

3.2.1 Pyranometer

Pyranometer is basically to measure the solar irradiance. It is usually done on a planar surface. Pyranometer is a type of actinometer. It can measure solar radiation flux density. The wavelength range must be within 0.3 μm to 3 μm. Furthermore, based on research, solar radiation spectrum that radiates to earth usually have wavelength around 300 to 2800 nm. There are a few types of pyranometer. First is the thermopile pyranometer. It covers large flat spectral sensitivity. Next type is photodiode-based pyranometer. This pyranometer covers a specific portion of wavelength which is around 400 nm to 1000 nm.

Pyranometer is needed for this project. It is crucial to determine the solar irradiance as this project is to determine the performance efficiency of the solar panel. However, pyranometer is very costly. Due to its high cost, UTAR is only able to afford one unit. By using pyranometer, the power of the solar panel can be measured. The Figure 3.1 shows how a pyranometer looks like.

Figure 3.1: Pyranometer

(The Eppley Laboratory, INC., 2016)

3.2.2 Multimeter

Multimeter is an electronic device that can measure several measurement functions. It is also known as VOM (Volt-Ohm meter). As the name implies it is multi, it is very convienient as it can measure most electrical measurement such as current, resistance and voltage. There are two type of multimeter. First multimeter is the analog multimeter. It uses a microammeter along with a moving mechanical pointer to display the readings. The second type is the digital multimeter. Since it is digital, it has a numeric display. The display not only shows numeric display but can also display graphical bar to represent the measured value. Due to its digital display, it is more famous than the analog multimeter. Besdies that, multimeter is a convienient device as it is portable. Multimeter is well known for many application. It can be use to for field service work and also fault finding. In addition to this, high degree of accuracy can also be obtained by using a bench instrument of multimeter. However, it is costly.

This project is conducted on the roof of UTAR building, hence convienient devices are needed. Several hand-held multimeters are used to measure the voltage and current of the solar panel. In one experiment, several solar panels will be conducted simultaneously. These multimeters will be used to measure the voltage and current to determine the performance efficiency of the solar panel. It is important that a few multimeters are required. This is because in one experiment around three solar panels are conducted paralelly. It is important that the solar panels are conducted at the same time. This is because the solar irradiance is not the same during morning and afternoon. It is not the same even for the next day having the same time. Therefore, multimeters play an important role for this project. Figure 3.2 shows a multimeter.

Figure 3.2: Multimeter

(Thomas Publishing Company, 2016)

3.2.3 Electrical Wiring

Electrical wiring is also an important process in this project. Electronic devices such as computer, pyranometer and solar panel have wires and they are connected together. Once they are connected together, they are simulated to produce a result. The result is then analyze to produce the performance of the solar panel.

3.2.4 Solar Panel

Solar panel is the main component for this project. As the study and research revolves around the solar panel. The model of solar panel used is CF-260 Photovoltaic Module from the company Malaysian Solar Resources Sdn Bhd. Solar panels are studied in this project to increase its efficiency.

3.2.5 Supporting Beams

Supporting Beams are the based structure of the solar panel. It is used to hold the solar panel in position. Furthermore, supporting beams are also used to hold the rooftop material below the solar panel such as metal deck and roof tile. In addition to this, supporting beams can also be used for the study of tilting angle. Inclination of the solar panel can be done by adjusting the supporting beams in such a way that it is incline in a specific angle such as 0^o, 10^o and 20^o.

3.2.6 Water Hose

The study of temperature against the performance efficiency of the solar panel are studied. Water hoses are used to spray the solar panel to lower down its temperature to increase its effciency. Figure 3.3 shows how a water hose looks like.

Figure 3.3: Water Hose

(Harbor Freight Tools, 2016)

3.2.7 Polyvinyl Chloride (PVC) Pipe

PVC pipe is used to connect the water from the water source as shown in Figure 3.4. It is also use as a dual function as a dripping system for the solar panel. A water sprinkler cost roughly RM80 per unit and a dripping system would cost around RM100 per system. By using PVC pipes and a electrical drilling machine, a self-make dripping system can be created. This dripping system is used in this project to evaluate the efficiency of the solar panel.

Figure 3.4: PVC Pipe

(Avion Tech Sdn Bhd, 2016)

3.2.8 Data Logger

Data logger is basically a device that records specific data over time. It usually has a built in sensor or instrument. In this modern generation, most of the data logger are based on a computer or a digital processor. Data logger is usually portable, small and battery powered based on Figure 3.5. Most of the data logger interface with a computer. There are specific software to use the data logger to analyse and view the collected data. Expensive data logger can be also buy as a whole stand-alone device. It has its own monitor and keypad. The main function of a data logger is that it has the ability to collect data on a 24-hour basis. No operator or any human personnel is needed to operate the data logger. It can be left unattended to record the measured value based on the duration of the time set. This is very convenient for any final year project student as research can be done while the data is being recorded. Furthermore, student can even attend lecture class and come back a few hours to view the data collected in the data logger.

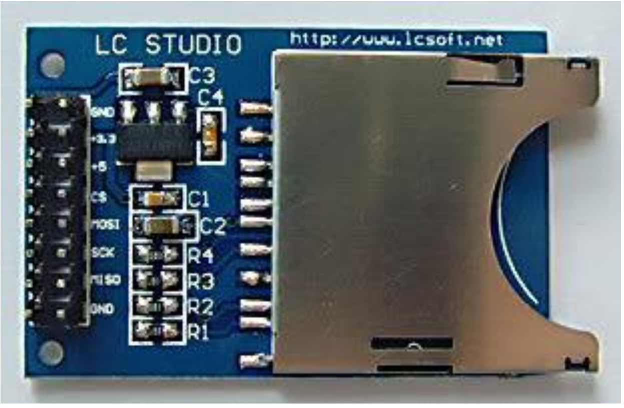


Figure 3.5: Data Logger

(Autodesk, Inc, 2016)

3.2.9 DS18B20 and DHT22 Temperature Sensors

Temperature sensors are used in the project to determine the temperature of the solar panel. Temperature sensors such as DHT22 and DS18B20 are used. These sensors are relatively cheap. DS18B20 is also a transistor that can measure temperature. Based on studies, it can be more accurate than a thermistor. Its circuit is sealed which means that it is not subject to oxidation. DS18B20 also produces a higher output voltage compare to thermocouples and that output voltage is not required to be amplified. Furthermore, the output voltage is also directly proportional to the temperature. Scale factor is around 0.01V/^{o}C. The conversion of the sensor produces small amount of voltage, thus output voltage of 10mV is produce for every 1^{o}C differences. Besides that, DHT22 is a sensor that is very sensitive and is stable for measuring ambient temperature. Both temperature sensors DHT22 and DS18B20 are connected to the Arduino board for data logging of temperature and humidity.

3.3 Experiment Setup

Experiments are set up to in order to study the efficiency of the solar panel. Supporting beams are used as the foundation of the solar panel. It is set up with an inclination angle of 10^o and an air gap of 10cm. This project is mainly focus on the temperature of the solar panel. Furthermore, the project is used to stimulate real life condition and situation. Metal deck is used as most factory uses metal deck. This is to test the performance of the solar panel using metal deck as the rooftop material. The experiment is set up by setting up the supporting beams as the base. Total of 2 solar panels are set up. Each piece of solar panel is supported by 2 vertical supporting beams on both ends. The supporting beams are locked with brackets and bolts with nuts. The metal deck is mount below the solar panel. The inclination angle of 10^o is used because this can improve the results obtained. Furthermore due to its inclination, raindrops or any water source will roll down the solar panel absorbing the heat. It will also wash off any dirt, thus increasing its efficiency. Air gap of 10cm is used to make the ventilation of the solar panel bad. By doing this, the temperature of the solar panel will increase, thus making it easier to see the comparison between both solar panel. By having air gap of 10cm it can also increase the internal heating of the solar panel. Since one of the solar panel is a reference and the other is the variable, various method of cooling the solar panel is used. This is to study the various cooling performance on the efficiency of the solar panel. Furthermore, by having such a large air gap, strong wind can blow off the solar panel easily, thus air gap of 10cm will not be a problem when strong wind occurs.

Both structure of the solar panels are identical, it can be seen in Figure 3.6. Front part of the structure has a height of 67cm and a length of 130cm. Rear part of the structure has a height of 135cm and also a length of 130cm while the side length is 240cm. There are several types of supporting beams. One of it is the L metal bar. L metal bar is one of the important supporting beam. This is because it is the “backbone” of the solar panel structure. The L metal bar will hold the metal deck and the solar panel together. In order to form a base for the solar panel, four L metal bars are used. They are placed at every corner of the solar panel to make the foundation stable. In addition to this, the supporting beams height is 67cm for the front structure and a height of 135cm for the back structure. The height of the supporting beams are consider short.

By doing this it will lower the center of gravity of the solar panel, increasing its stability. Rainy days will have a very strong wind pressure that can blow off the solar panel. Therefore, it is important to have a solid foundation. Metal deck is installed below the solar panel.

Installation of the metal deck must be properly install. The metal deck must be placed at the center of the solar panel. The distance between every corner and edge must be identical. Sunlight will produce two type of energies which are heat energy and light energy. The heat energy will be absorbed by the metal deck, thus it is important that the metal deck is at the middle of the solar panel when it is placed below the solar panel. The heat energy absorbed from the sun will be evenly distributed by the metal deck and some of the heat is absorbed by the solar panel. The evenly distributed heat to the solar panel is important because this project is mainly focus on the effects of external water source to increase the efficiency of the solar panel.

Figure 3.6: Structure of the Solar Panels

Figure 3.6 shows the structure of 2 solar panels used throughout all the experiments. Both solar panels are MYS-60P CF-260 multi-crystalline photovoltaic modules. They are manufactured from MSR Sdn Bhd. Each module has 60 individual cells in an array of 10 vertical and 6 horizontal. The dimensions are 1666mm in length and 997mm in width. Total rated maximum power at STC, P_{max} at 260W.

Rated Maximum Power at STC (W) P_{max}	260
Maximum Power Voltage (V_{mp}/V)	30.67
Maximum Power Current (I_{mp}/A)	8.48
Open Circuit Voltage (V_{oc}/V)	37.96
Short Circuit Current (I_{sc}/A)	9.01
Temperature Coefficient of P_{max} (γP_{mp})	-0.4112% / °C
Temperature Coefficient of V_{oc} (βV_{oc})	-0.3137% / °C
Temperature Coefficient of I_{sc} (αI_{sc})	+0.0427% / °C

3.3.1 Water Spraying and Dripping System Setup

Water hose and 2 PVC pipes are bought in order to make the water spraying and dripping system. The water hose is then cut into 2 parts. The first part is 20m while the other is 10m. Since the structure of both solar panels are near to 1 of the water source at UTAR rooftop, 1 of the water hose length does not require to be long. However, the next water source at UTAR rooftop is around 15m away, thus 20m water hose is required. A nozzle is then installed onto the "head" of both water hose in order for the water hose to spray. After that, the water hose is then attached onto the structure of the solar panel. Figure 3.7 shows the setup of the experiment.

Figure 3.7: Water Hose Attached onto the Solar Panel

The simple piping system is created by using PVC pipes. PVC pipes are bought from local hardware store. They are then cut into 84cm in length and another 70cm in length. Both PVC pipes are then drilled several holes to let the water drip out of the PVC pipe. A “head” of 4mm drilled is used to drilled the hole of the PVC pipe. The hole of the PVC pipe cannot be too big as the water will not drip anymore but flow. Besides that, the hole cannot be too small either as any smaller than 4mm, the water will not drip constantly, thus 4mm is the best size. Both PVC pipes are then drilled with an interval of 7cm per hole. 2 adapters are bought to connect the PVC pipe and the water hose. PVC pipe having the length of 84cm will then have 12 holes including the other end of the PVC pipe is then installed on top of the solar panel. PVC pipe having the length of 70cm will then have 10 holes including the other end of the PVC pipe is then installed on top of the metal deck.

3.3.2 Data Collection Setup

Data collection setup has two main parts. They are automated collection and manual collection. Manual collection involves reading on multimeters. Multimeters are connected to the solar panels in order to measure the current and voltage. Pyranometer is used to measure the power of the solar irradiance. Automated collection is done by using Arduino as shown in Figure 3.9. They are total of 10 temperature sensors in this experiment to measure the temperature. However only 7 temperature sensors are used while the other 3 served as a backup temperature sensor. 1 DHT22 and 6 DS18B20 are used to measure the temperature. DHT22 is used to measure the ambient temperature and the humidity. The DHT 22 is placed between both of the solar panels based on Figure 3.10. By doing this, the ambient temperature and the humidity is more accurate and not bias. DS18B20 is used to measure the temperature of the solar panels. They are install underneath the solar panel. 3 DS18B20 is installed for each solar panel. They are position top, middle and bottom of the solar panel as shown in Figure 3.11. The sensors are connected to a plug board that is specially design for the sensors. The special advantage of the plug board is that it is very convenient as it is very portable. It can be remove and install easily. This plug board is then connected to the Arduino. The Arduino then convert and stores the data onto the data logger that was installed on the Arduino. Besides that, all 10 temperature sensors are placed onto the same material to test consistency. The material used is a book. It can be seen that the temperature sensors have an error of ± 0.5^{o}C which is quite consistent based on Figure 3.8.

```
Initializing SD card...card initialized.
Logging to: LOGGER36.CSV
Millis,  Stamp,       Date          Time,  Humidity,DHT22, Temp 1,Temp 2,Temp 3,Temp 4,Temp 5,Temp 6,Temp 7,Temp 8,Temp 9
1999, 2212184785, "2165/165/165 165:165:85", 98.60, 32.80, 31.37, 31.19, 31.19, 31.19, 31.19, 31.25, 31.19, 31.06, 31.12
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209999, 2212184785, "2165/165/165 165:165:85", 98.60, 32.90, 31.37, 31.19, 31.19, 31.19, 31.19, 31.25, 31.19, 31.06, 31.12
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241999, 2212184785, "2165/165/165 165:165:85"
```

Figure 3.8: 10 Temperature Sensors Tested For Consistency

Figure 3.9: Arduino Mega 2560

(Electro Schematics, 2016)

Figure 3.10: DHT22 Position between Both Solar Panels

Figure 3.11: 3 DS18B20 Position Top, Middle and Bottom of the Solar Panel

3.3.3 Experiment Layout

Figure 3.12 shows the experiment layout. It shows how the experiment is setup and how the results are recorded. Furthermore, the experiment layout also shows the position of the temperature sensors are placed.

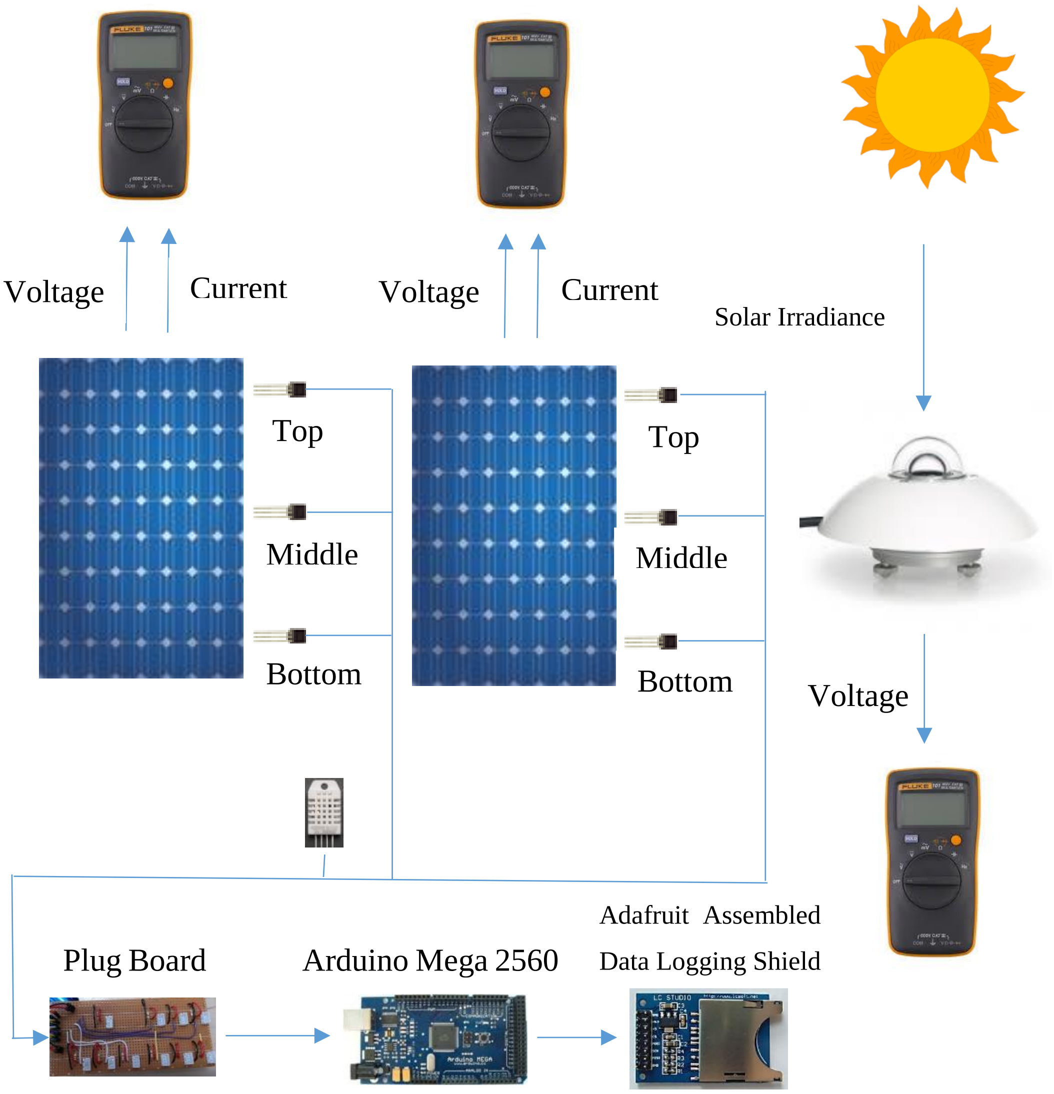


Figure 3.12: Experiment Layout

3.3.4 Experiment 1: Water Spraying System (Spray Solar Panel)

The first experiment is about using water hose to lower down the temperature of the solar panel. This experiment is conducted because research shows that the output power of the solar cells can be increase by almost 50% when it is cooled by water (Moharram, K.A., et al., 2013).

2 solar panels are set up identically having the same structure. 1 of the solar panel acts as a reference and the other as a variable. An external cooling factor is used to lower down the temperature of the solar panel to test the performance. The external

cooling factor used is a water hose. The water hose is then attached on top of the solar panel. It is then used to spray water onto the solar panel. The sides of the solar panels are not covered allowing natural wind to flow through. Figure 3.13 shows the setup of experiment 1.

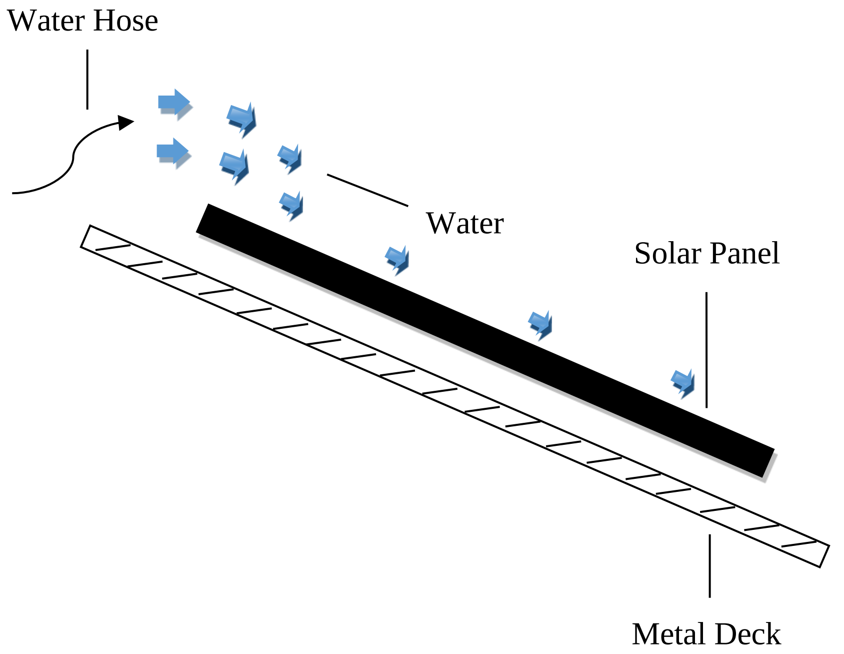


Figure 3.13: Cross Section View of Water Hose Spray onto the Solar Panel

3.3.5 Experiment 2: Water Spraying System (Spray Metal Deck)

This experiment is similar to the previous experiment. The only thing that is different is that the water hose is spray onto the metal deck as shown in Figure 3.14. This is to test the cooling performance when sprayed onto the metal deck instead of the solar panel.

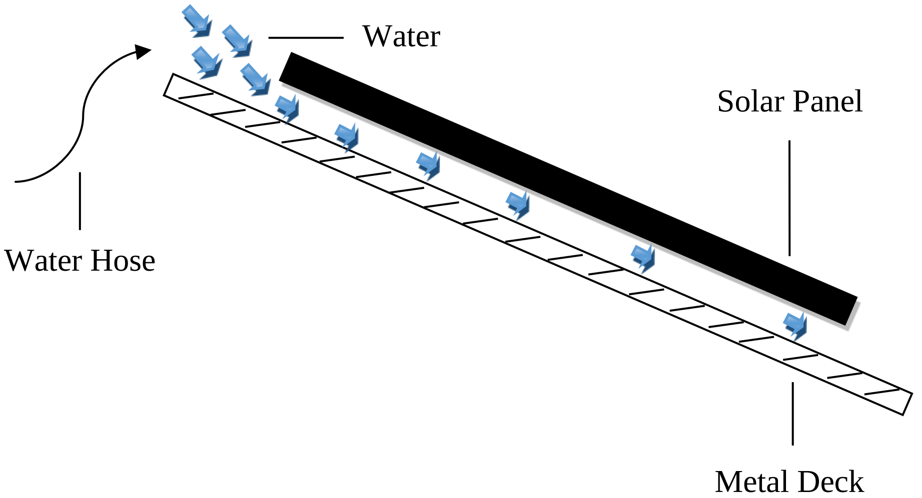


Figure 3.14: Cross Section View of Water Hose Spray onto the Metal Deck

3.3.6 Experiment 3: Dripping System (Drip Solar Panel)

This experiment is done by using polyvinyl chloride (PVC) pipe as a dripping system. Once again this experiment has 2 solar panels. An electrical drilling machine is used to drill several holes on the PVC pipe. The water hose is then connected to the PVC pipe via a PVC adapter. Once the water source is turn on, water droplets will drop out of the holes that are drilled. For this experiment, a PVC pipe with a length of 84cm with an interval of 7cm for each hole is attached onto the solar panel. The size of the hole is 4mm to allow water droplets to drip out. Figure 3.15 shows the setup of experiment 3.

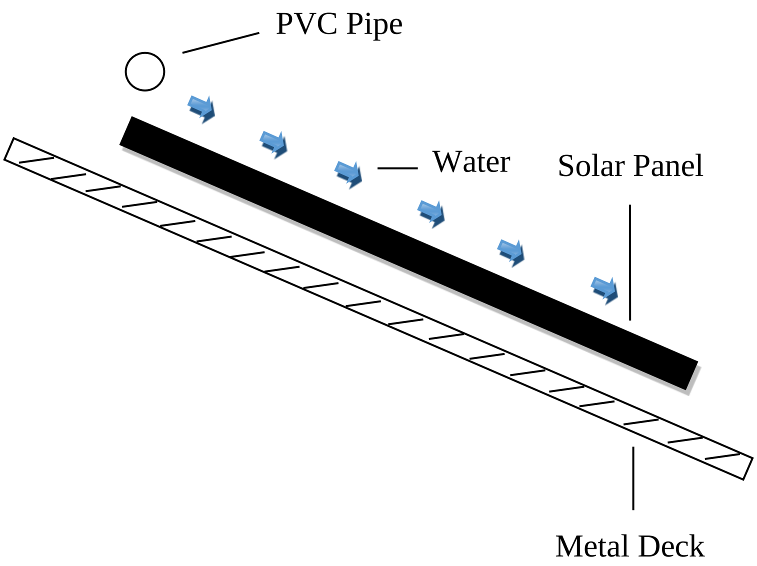


Figure 3.15: Cross Section View of PVC Pipe Drip onto the Solar Panel

3.3.7 Experiment 4: Dripping System (Drip Metal Deck)

This experiment is similar to experiment 3. In this experiment, the PVC pipe is attached onto the metal deck instead of the solar panel as shown in Figure 3.16. This is to test the cooling performance of the PVC pipe when drip onto the metal deck.

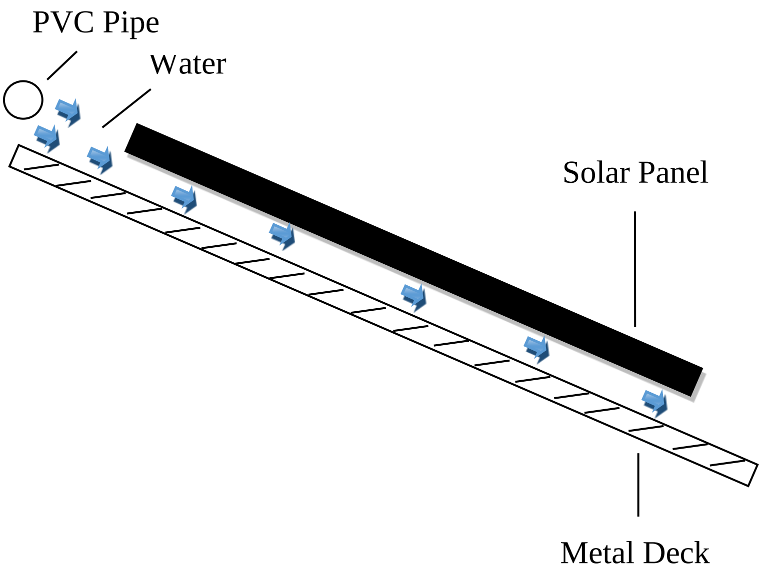


Figure 3.16: Cross Section View of PVC Pipe Drip onto the Solar Panel

3.4 Additional Experiments

Another 2 more extra experiments are conducted to further improve the performance of the solar panel. There is a potential to increase the efficiency of the solar panel by using the spraying system and the dripping system to lower down the temperature of both solar panel and metal deck at the same time.

3.4.1 Experiment 5: Water Spraying System (Spray Solar Panel and Metal Deck)

This experiment is the combination of experiment 1 and 2. Instead of just spraying either solar panel or metal deck individually, in this experiment the water spraying system is used to spray both solar panel and metal deck as shown in Figure 3.17. The efficiency of the solar panel is tested when both solar panel and metal deck is cooled down.

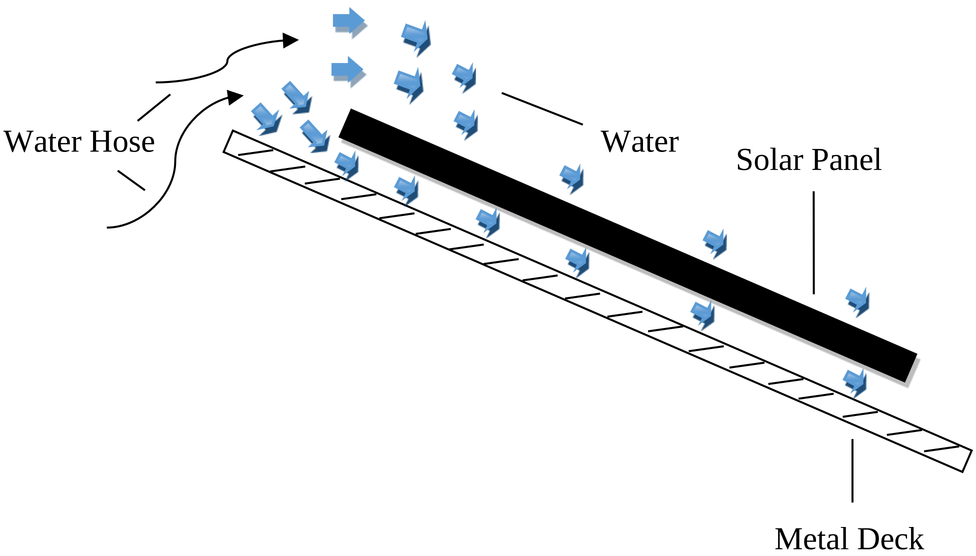


Figure 3.17: Cross Section View of Water Hoses Spray onto the Solar Panel and Metal Deck

3.4.2 Experiment 6: Dripping System (Drip Solar Panel and Metal Deck)

This experiment is the combination of experiment 3 and experiment 4. 2 PVC pipes are installed above the solar panel and the metal deck as shown in Figure 3.18. Once the water source is turned on, water droplets will then drip out of the PVC pipe and onto the solar panel and metal deck. This is to test whether the performance of the solar panel will increase when both solar panel and metal deck temperature is lower.

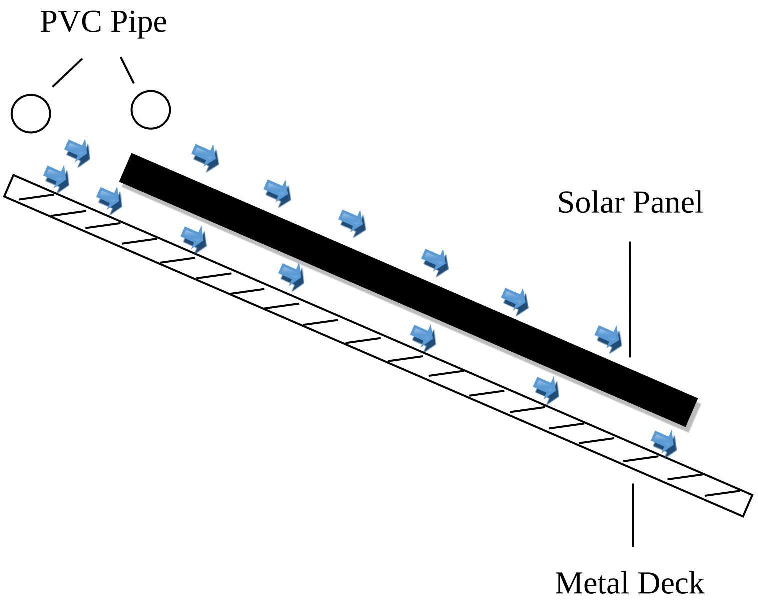


Figure 3.18: Cross Section View of PVC Pipe Drip onto the Solar Panel

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Pre-Analysis

4.1.1 Water Speed Analysis

Bucket method is used to determine the water speed. A 6 litres container is brought to UTAR rooftop and the time taken to fill it up is measured. Once the time taken is measured, the volumetric flow rate (Q) can be determined based on Table 4.1 and Table 4.2.

Water Spraying System:

Table 4.1: Bucket Method Data for Flow of Water Spraying System

Trial Number	Time (seconds)	Bucket Volume (Litres)
1	118	6
2	124	6
3	131	6
4	123	6
5	124	6

$t = \frac{118+124+131+123+124}{5}$ = 124 seconds

$Q = \frac{V}{t} = \frac{6\ litres}{124\ seconds}$ = 0.048 $\frac{litres}{second}$

Flow rate is 0.048 $\frac{litres}{second}$ or Q = 0.048 $\frac{litres}{second}$ X 60 $\frac{second}{minute}$ = 2.903 $\frac{litres}{minute}$. Therefore, the flowrate (Q) is 2.903 LPM.

Dripping System:

Table 4.2: Bucket Method Data for Flow of Dripping System

Trial Number	Time (seconds)	Bucket Volume (Litres)
1	190	6
2	186	6
3	188	6
4	179	6
5	182	6

$t = \frac{190+186+188+179+182}{5}$ = 185 seconds

$Q = \frac{V}{t} = \frac{6\ litres}{185\ seconds}$ = 0.032 $\frac{litres}{second}$

Flow rate is 0.032 $\frac{litres}{second}$ or Q = 0.032 $\frac{litre}{second}$ X 60 $\frac{second}{minute}$ = 1.946 $\frac{litres}{minute}$. Therefore, the flowrate (Q) is 1.946 LPM.

Comparing Water Spraying System and Dripping System:
Difference in flowrate:

Q = 0.048 – 0.032 = 0.016 $\frac{litres}{second}$

= 0.96 LPM

By using the dripping system, approximately 0.016 litres per second can be saved. Dripping system is much more efficient than water spraying system as dripping system can cover almost the whole solar panel. Water spraying system does not cover the edges of the solar panel and the water being sprayed is not evenly spread out like the dripping system. Another factor that can affect the water spraying system is also the wind. When strong wind occurs, it will also change the direction of the water being sprayed onto the solar panel, making the water sprayed off the solar panel. On the other hand, dripping system is not affected by the strong wind as the water droplets are already on the solar panel the moment it drip out of the PVC pipe.

4.1.2 Reference System Analysis

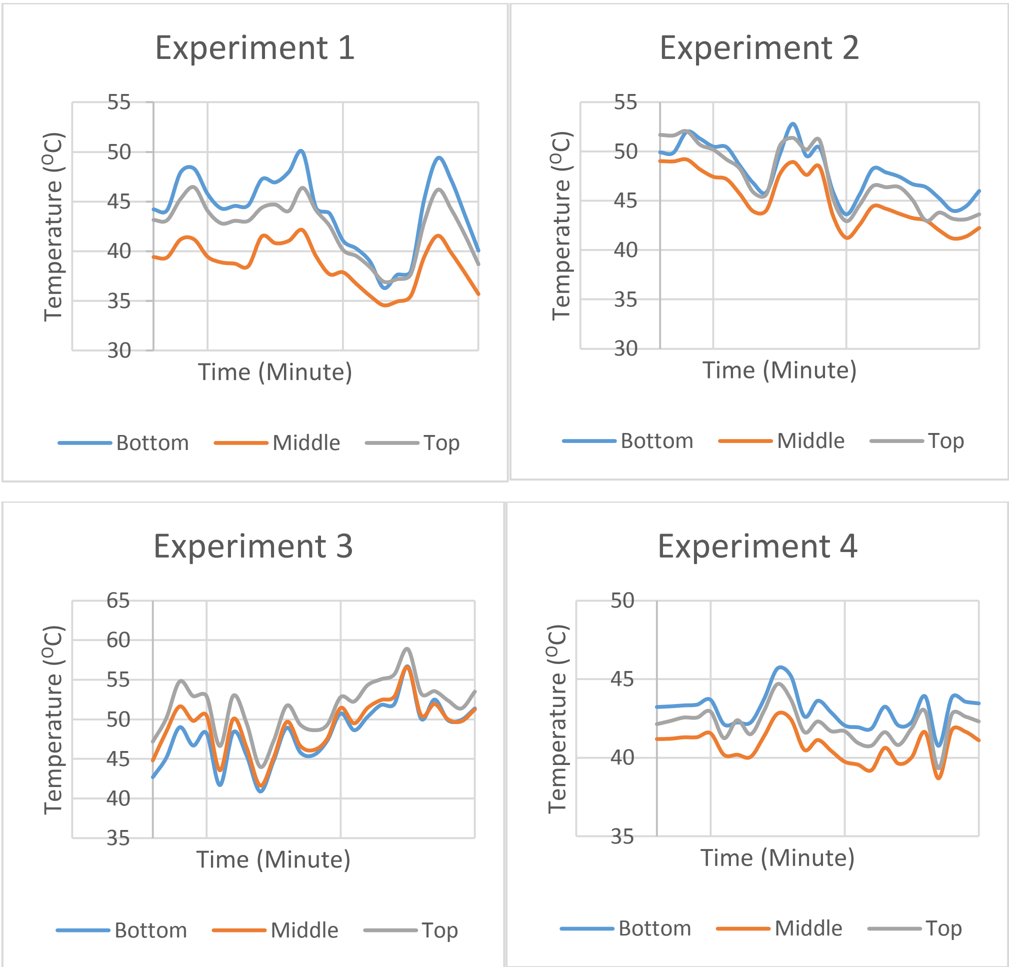
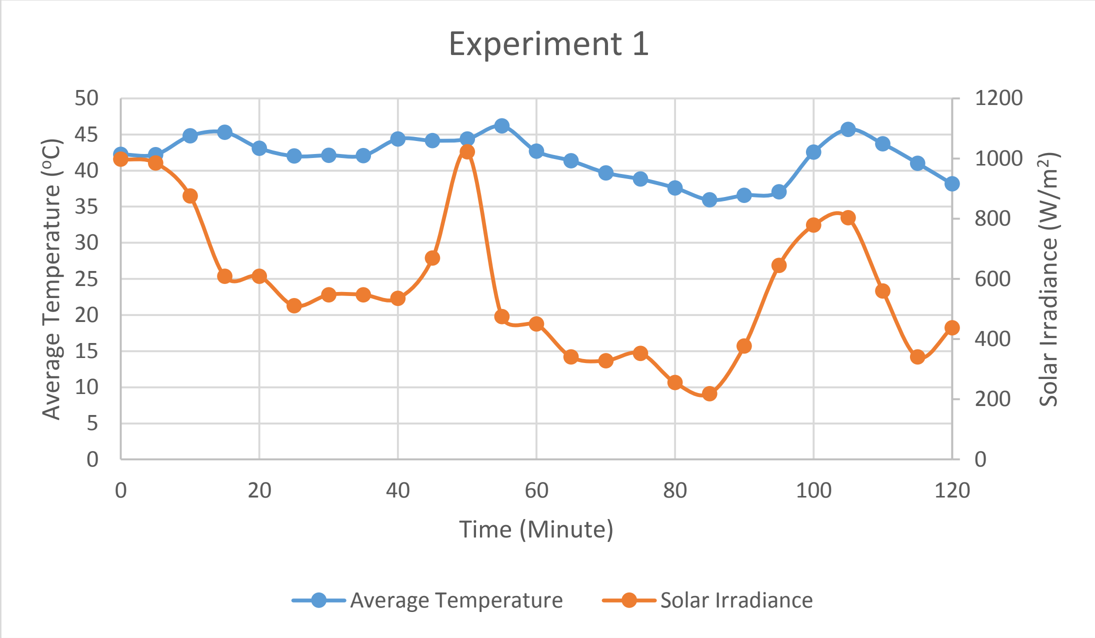
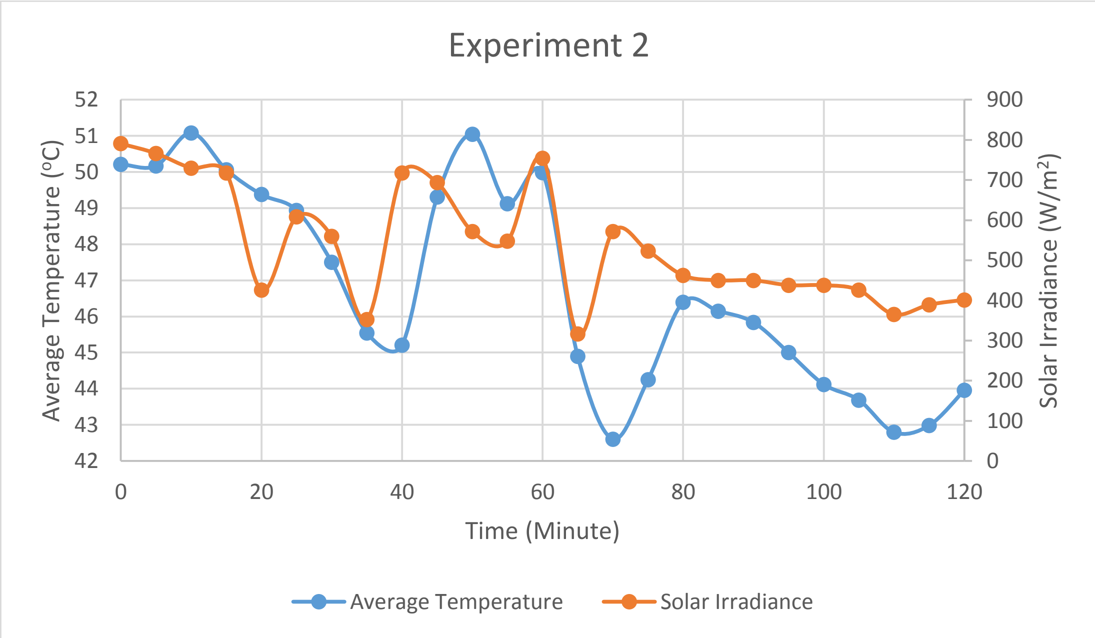


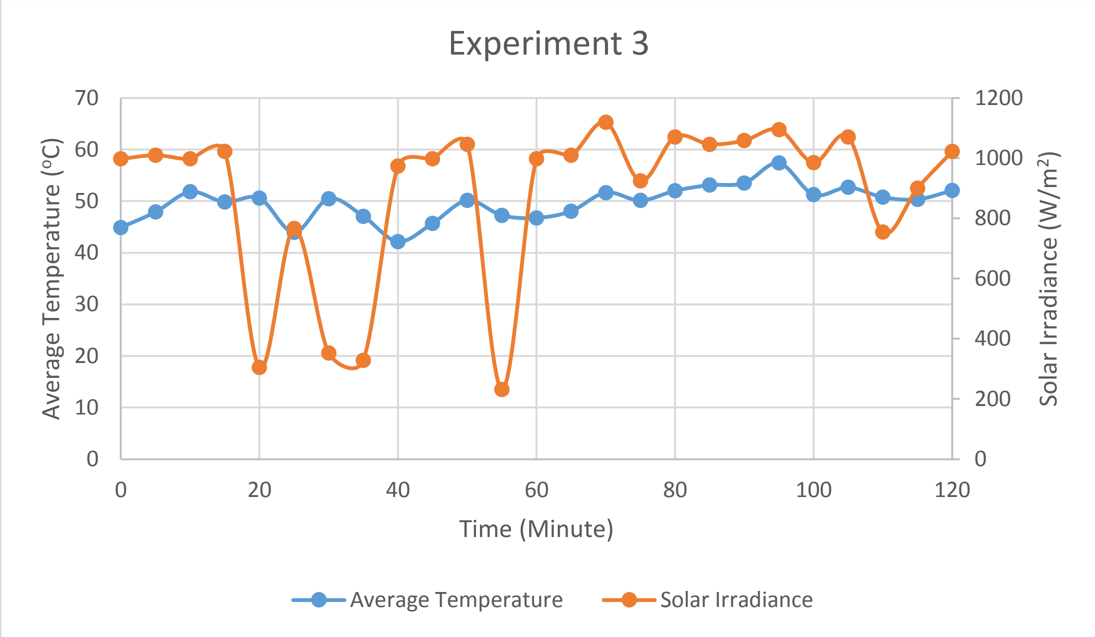
Figure 4.1: Reference System Temperature

Based on the Figure 4.1, it can be seen that bottom of the solar panel has the highest temperature for most of the time than the middle and top of the solar panel. There are times when top of the solar panel has the highest temperature. The temperature of the reference system is affected by the natural convection.

4.1.3 Irradiance Analysis







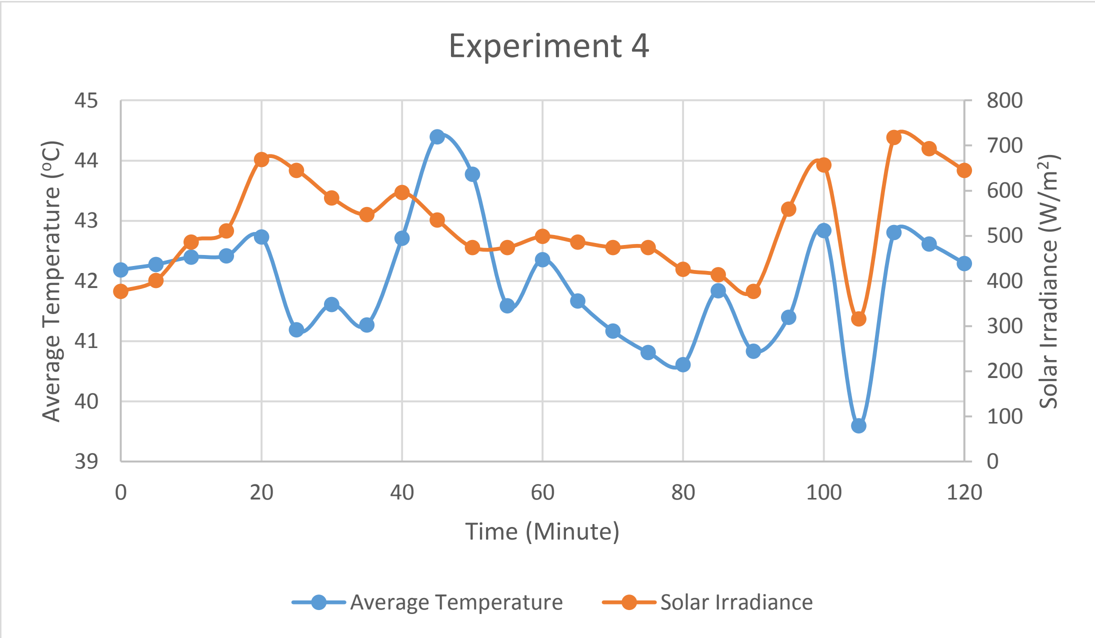


Figure 4.2: (a) (b) (c) (d) Comparison of Solar Irradiance and Average Temperature of Reference System

Based on Figure 4.2, all 4 experiments can be observed that when the solar irradiance increases, the average temperature also increases. The average temperature is the average of the bottom, middle and top temperature of the solar panel. Furthermore, the solar irradiance fluctuates as the passing clouds block out the sunlight from reaching the solar panel. There is a slight delay for the temperature to increase or decrease when the solar irradiance increases or decreases. This is because heat energy is absorbed by the solar panel for it to increase by 1°C. Besides that, when a big cloud pass by fast enough, it will not affect the temperature.

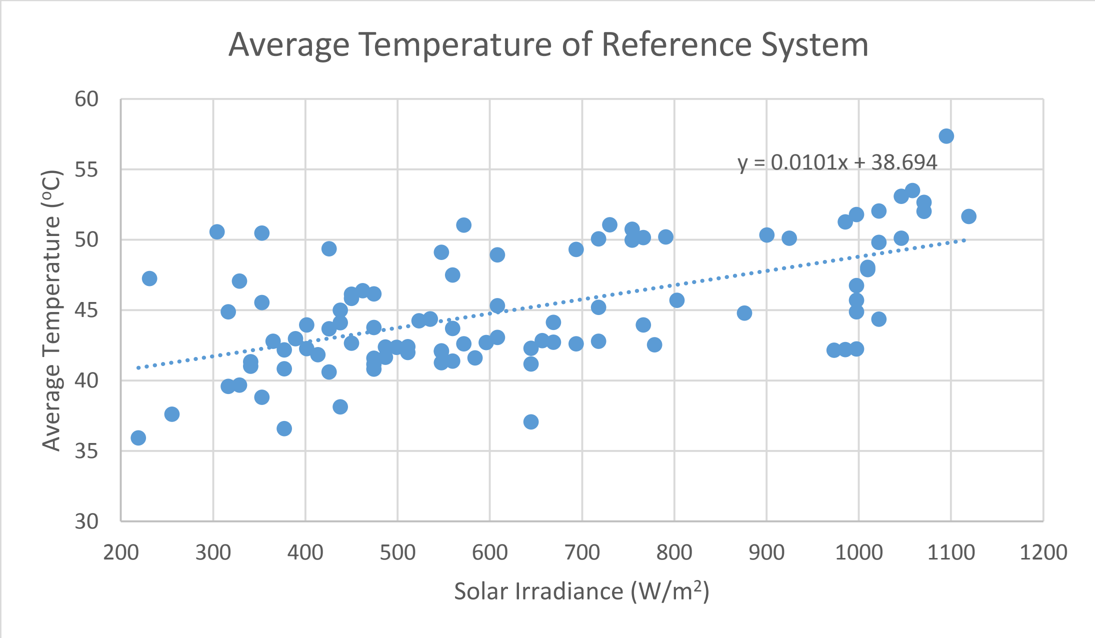


Figure 4.3: Total Average Temperature against Solar Irradiance

Figure 4.3 also shows that the higher the solar irradiance, the higher the average temperature. There are times where the solar irradiance is high while the average temperature is low and vice versa. This is because of the weather. When big clouds block out the sunlight from the sun, the solar irradiance decrease drastically. Thus, causing the system having a high temperature state with low solar irradiance.

4.2 Experiment Analysis

4.2.1 Experiment 1: Water Spraying System (Spray Solar Panel)

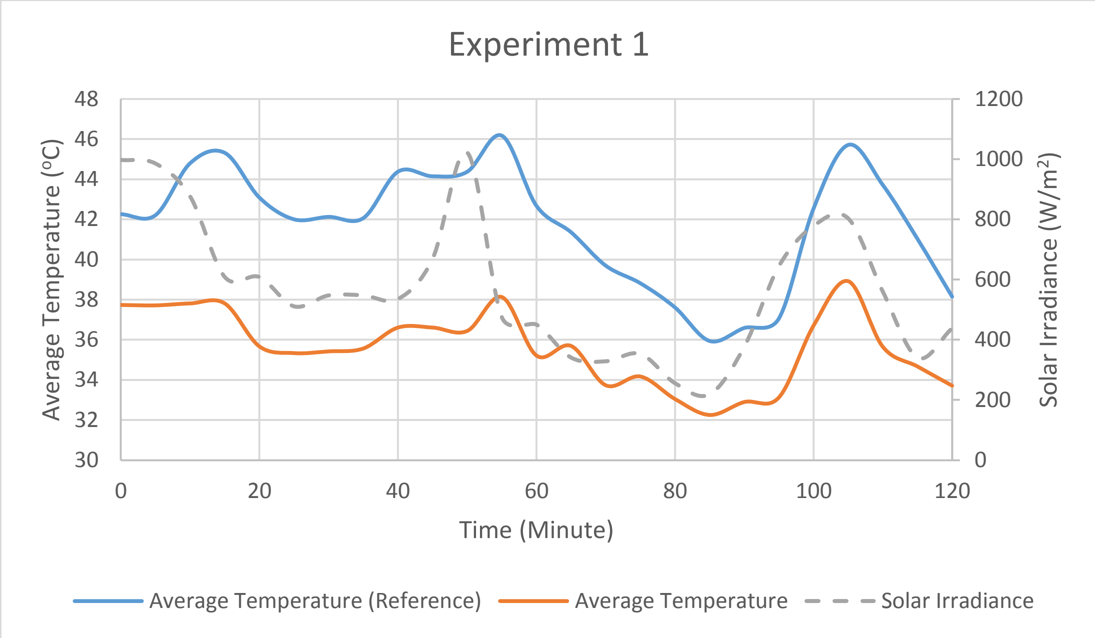


Figure 4.4: Average Temperature against Time

Figure 4.4 shows that the average temperature decreases when the solar panel is sprayed. Water does have effect on the temperature of the solar panel. On a normal sunny day, the average temperature decreases around 5°C. Furthermore, when on a scorching sun, the average temperature can reduce up to 8°C. On the duration of 2 hours, it can be seen that the temperature of the solar panel being sprayed has lower temperature compared to the reference.

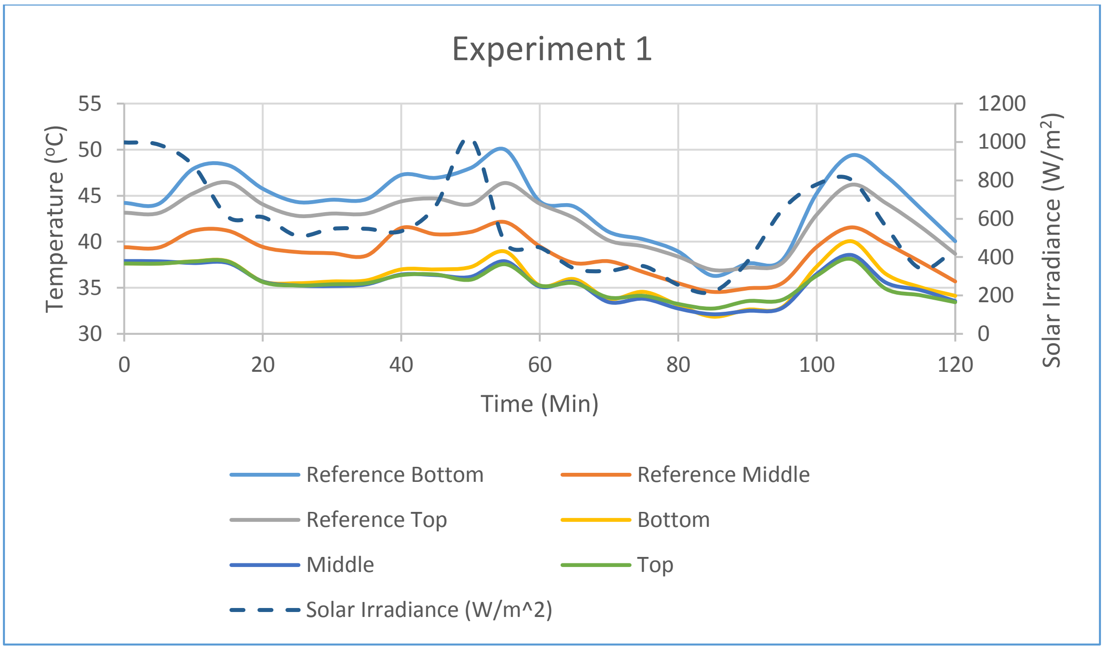


Figure 4.5: Bottom, Middle and Top Temperature with Reference against Time

Based on Figure 4.5, all of the temperature sensors that are under the sprayed solar panel have lower temperature than the reference. It can been observed that the bottom of both reference and sprayed solar panel has the highest temperature. For the sprayed solar panel, the uneven water spraying on the solar panel causes the bottom part of the solar panel to be hotter than both middle and top part of the solar panel. Based on observation during the experiment, the edges of the solar panel are hardly sprayed, hence making the edges hotter. Therefore, spraying the solar panel can reduce the temperature of the solar panel but can be improved.

4.2.2 Experiment 2: Water Spraying System (Spray Metal Deck)

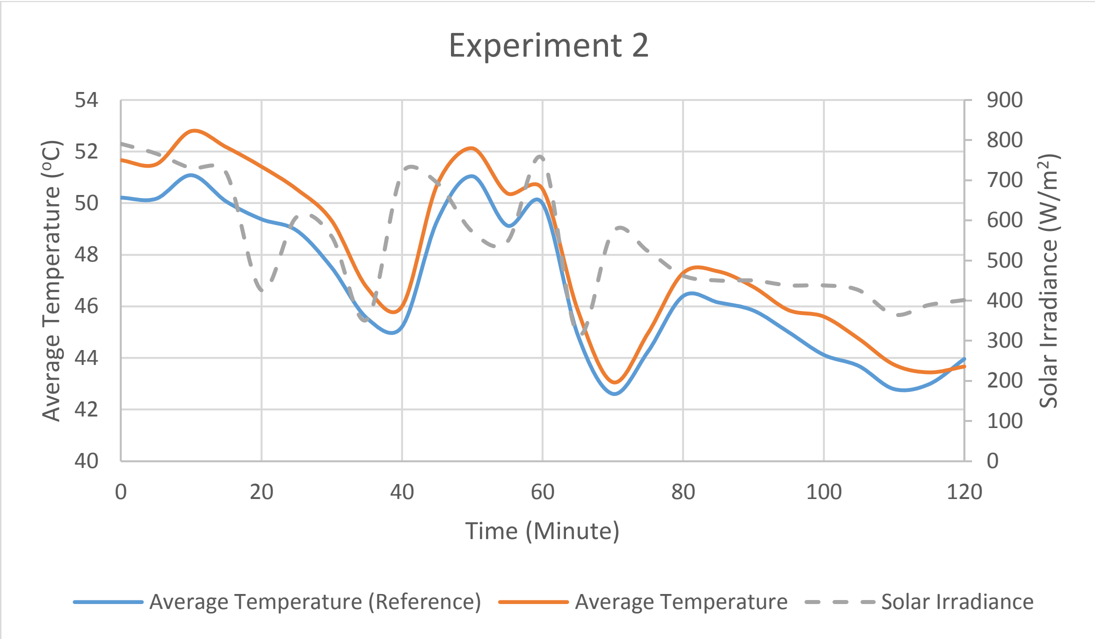


Figure 4.6: Average Temperature against Time

Figure 4.6 shows that the average temperature of the sprayed metal deck is higher temperature than the reference for most of the time. The temperature difference is not that high which is about 1°C and up to 2°C. This is because of the water on the metal deck can evaporate and heat up the solar panel. There are times where the reference system is higher temperature than the sprayed metal deck. This depends on the natural convection. Nevertheless, the water spraying system has no effect when sprayed onto the metal deck.

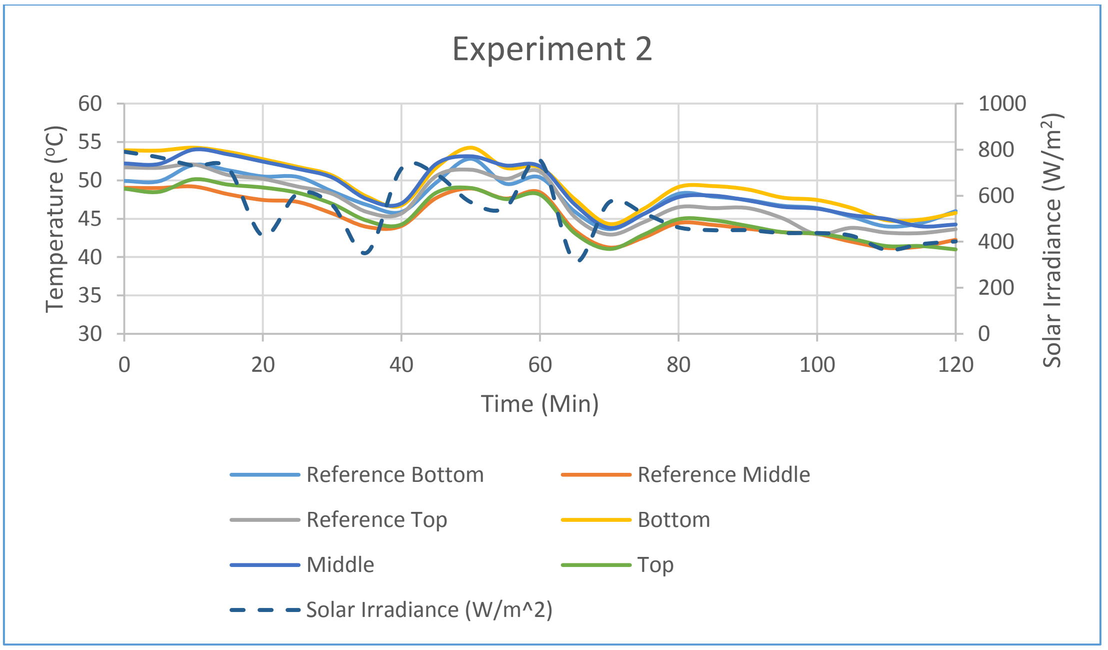


Figure 4.7: Bottom, Middle and Top Temperature with Reference against Time

Referring figure 4.7, the bottom part of the solar panel of the sprayed metal deck is the highest temperature for most of the time compared to the other 5 temperature sensors. For the duration of 2 hours, it can be observed that the temperature of the sprayed metal deck is higher for most of the time compared to the reference. Evaporation of the of the hot water causes water vapour to heat up the solar panel. Thus, it is not encourage to spray the metal deck.

4.2.3 Experiment 3: Dripping System (Drip Solar Panel)

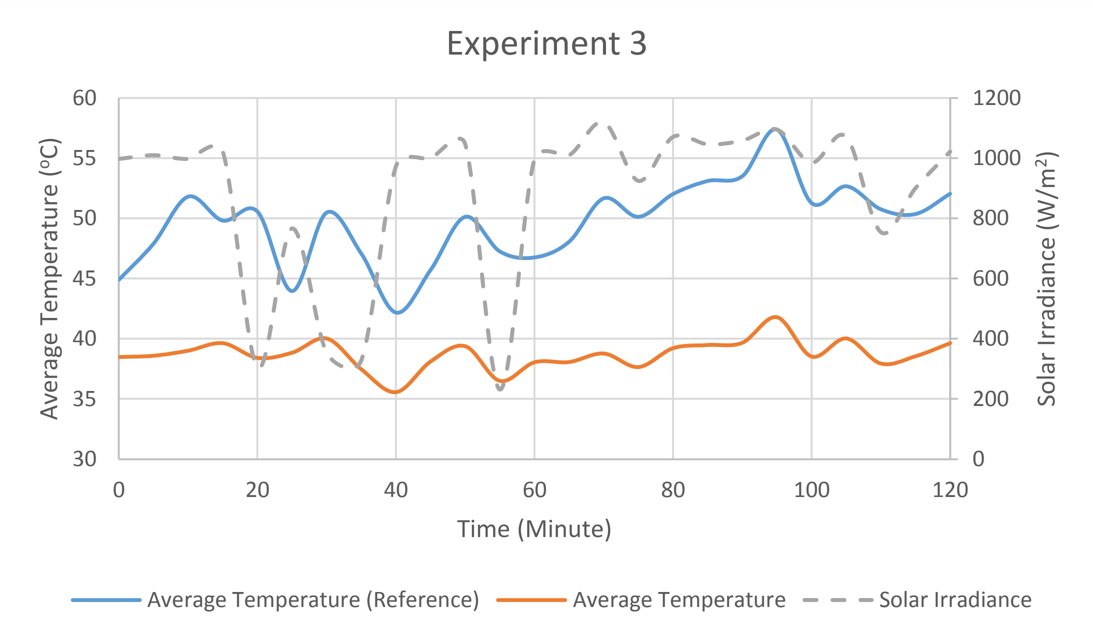


Figure 4.8: Average Temperature against Time

Based on Figure 4.8, the average temperature of the dripped solar panel is lower than the reference. The average temperature decreases around 10°C on a normal average day but as high as 16°C on a blazing sun. The solar irradiance for this experiment is the highest among the 4 experiments carried out which is 1119.2214 W/m^2. When the experiment is conducted, it can be observed that the water is evenly distributed across the solar panel. The edges of the solar panel is also dripped. Furthermore, solar cells that made up the solar panel is connected in series. Hence, if the water does not flow on the edges of the solar panel, it will lower the output of the solar panel. For this experiment, the dripping system will drip the water evenly throughout the solar panel. Thus, making the solar cells throughout the solar panel to generate high output power.

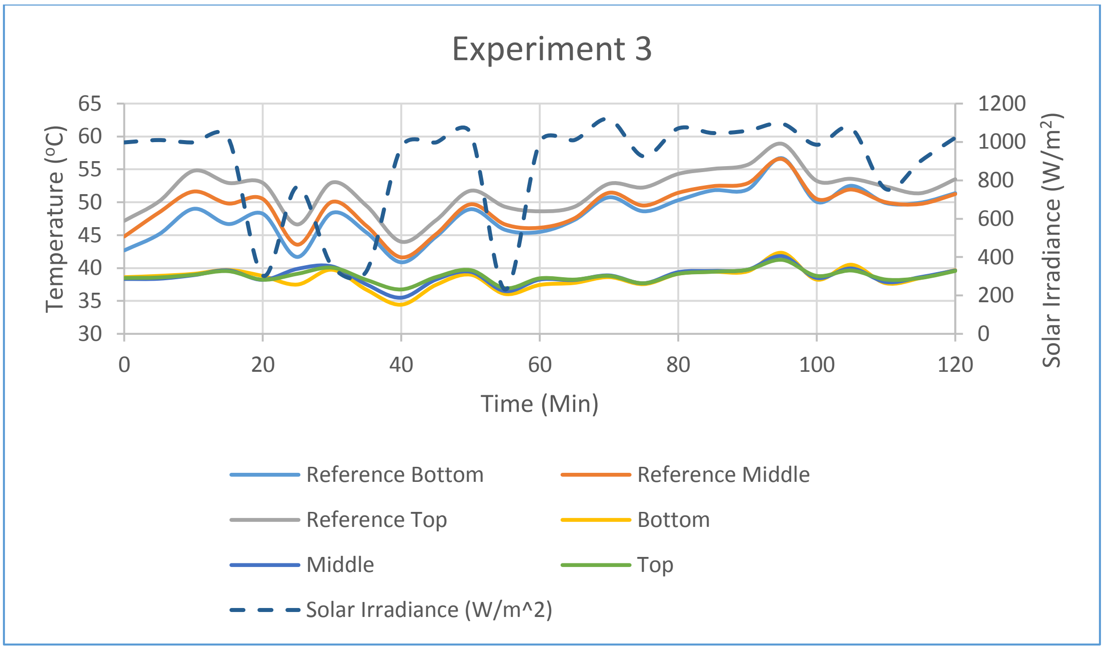


Figure 4.9: Bottom, Middle and Top Temperature with Reference against Time

Based on Figure 4.9, it can be seen that all of the dripped solar panel temperature sensors are constant or almost similar. This is because of the evenly distributed water by the dripping system. By doing this, a higher output of power can be achieved generating higher efficiency. The top part of both reference and dripped solar panel temperature sensors are the highest temperature throughout the experiment. The natural convection tends to cool down the temperature of the middle and bottom part of the solar panel of that particular day. The highest temperature for this experiment is 58.88ºC for the reference solar panel while the dripped solar panel temperature sensor is 41.25ºC. Therefore, temperature reduced on a sunny day is around 10ºC while on a blazing sun the temperature reduced is as high as 17.63ºC.

4.2.4 Experiment 4: Dripping System (Drip Metal Deck)

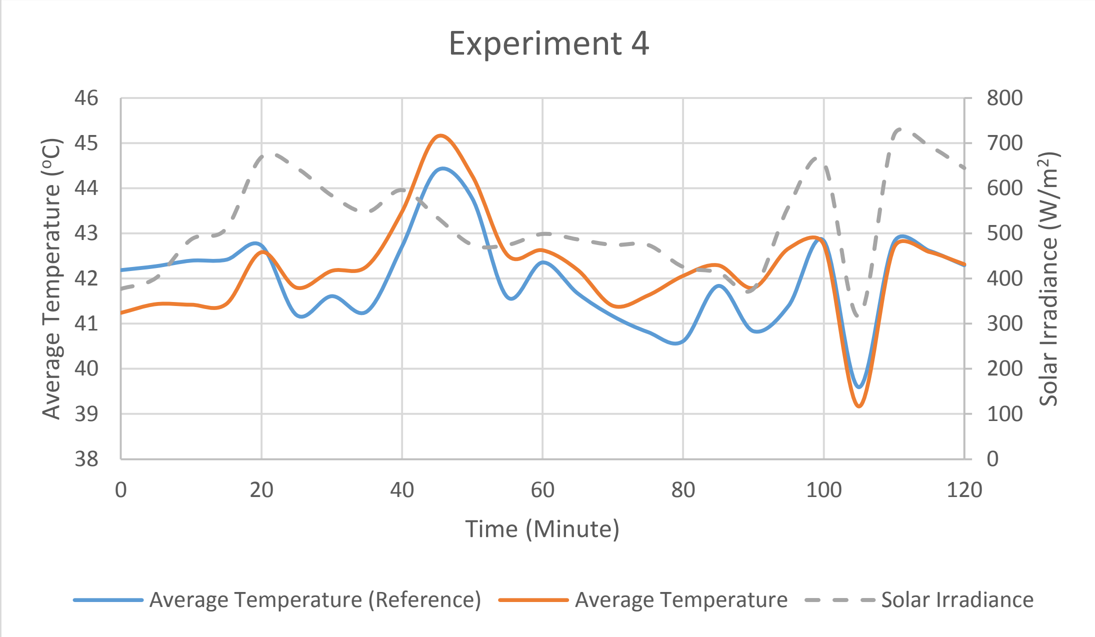


Figure 4.10: Average Temperature against Time

Based on Figure 4.10, it can be observed that the average temperature of the dripped metal deck is higher than the reference for most of the time. There are times where the reference has higher average temperature compared to the dripped metal deck. The outcome is the same as experiment 2. Therefore, water has no effect on the metal deck.

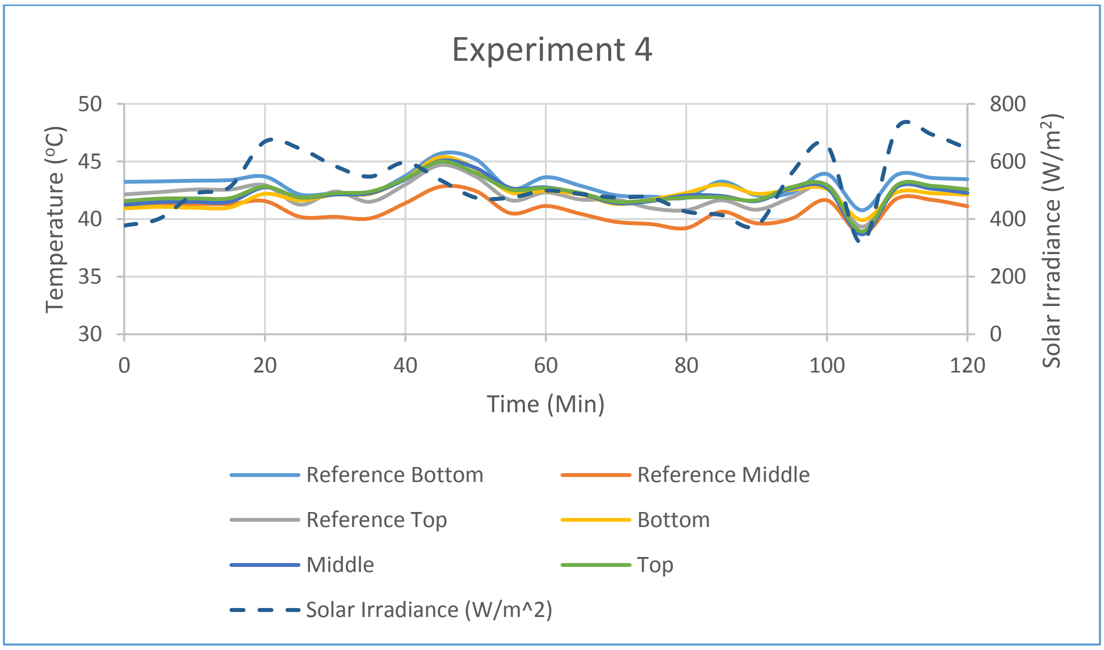


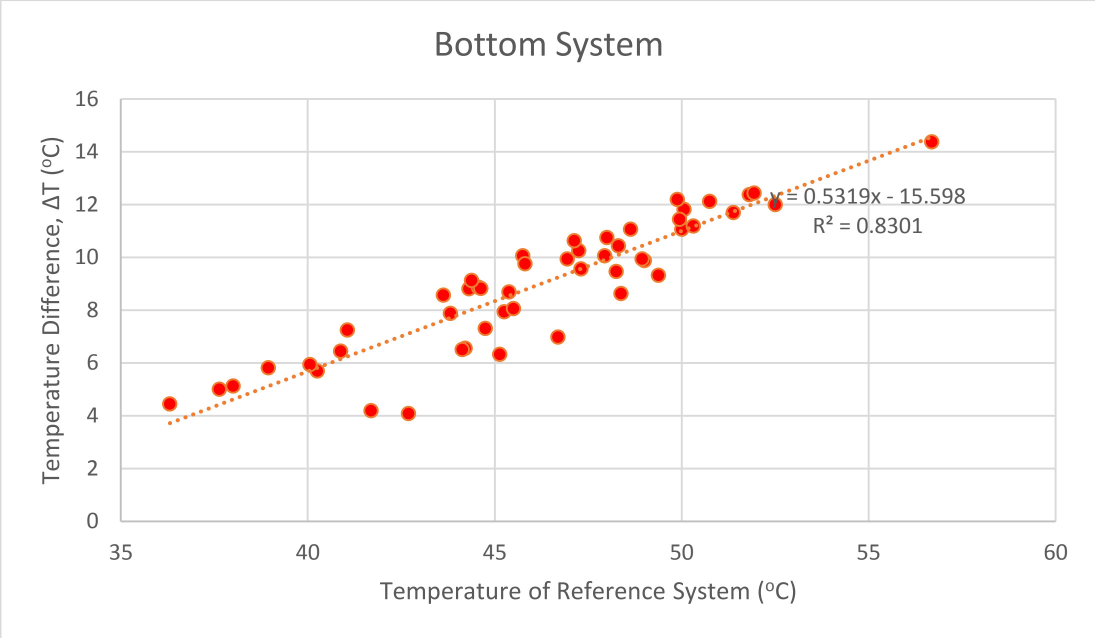
Figure 4.11: Bottom, Middle and Top Temperature with Reference against Time

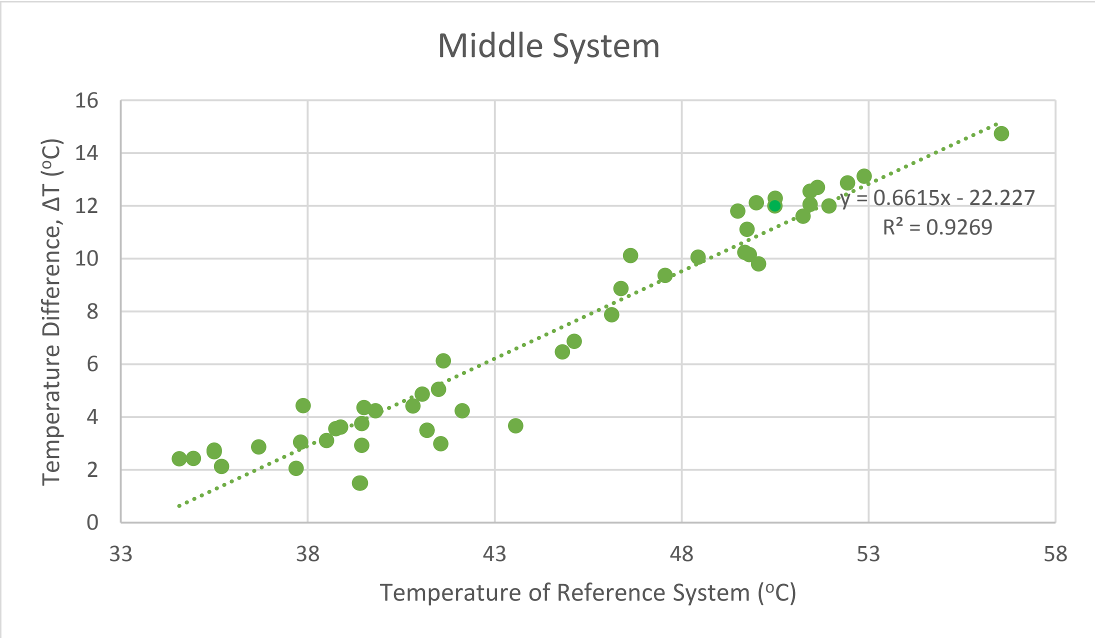
The temperature sensors of the dripped metal deck is almost the same as the reference throughout experiment 4. The temperature fluctuates between 40^{o}C to 43^{o}C for both solar panel as shown in Figure 4.11. Once again, it can be observed that water has no effect on the metal deck.

4.3 Performance Analysis

4.3.1 Cooling Performance of Water Spraying and Dripping System

A cooling performance comparison is done to see the water spraying and dripping system efficiency. The temperature difference, ΔT of a specific part of the solar panel and the reference system is taken to see the cooling performance. Only experiment 1 and 3 is used for the cooling performance as experiment 2 and 4 have no cooling performance. The graphs below are 3 systems which are bottom, middle and top system. The temperature difference is plotted against the temperature of reference system.


Bottom System
Temperature Difference, ΔT (°C)
Temperature of Reference System (°C)
y = 0.5319x - 15.598
R² = 0.8301
16
14
12
10
8
6
4
2
0
35
40
45
50
55
60


Middle System
Temperature Difference, ΔT (°C)
Temperature of Reference System (°C)
y = 0.6615x - 22.227
R² = 0.9269
16
14
12
10
8
6
4
2
0
33
38
43
48
53
58

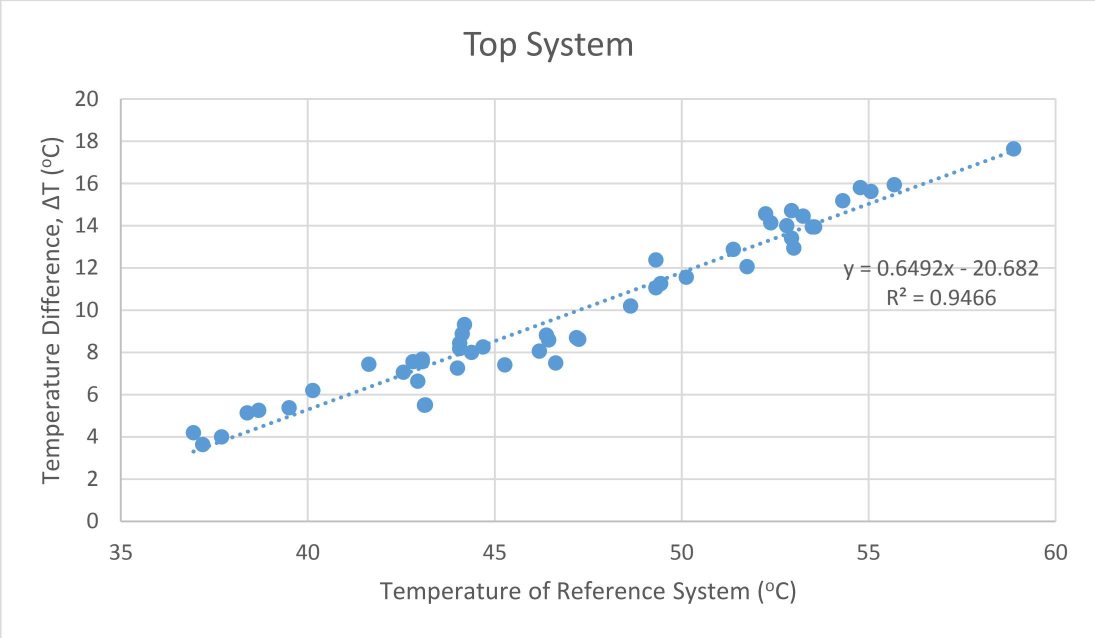


Figure 4.12: Graph of Bottom, Middle and Top System of Temperature Difference, ΔT Against Temperature of Reference System

Experiment 1 and 3 show an increase in cooling performance based on Figure 4.12. The higher the temperature of the reference system, the higher the temperature difference. Based on the middle system above, the middle system has the steepest increase in performance. Either the top or the bottom system will have high temperature and the other will have low temperature. If the temperature is high, the cooling performance will be high and vice versa. The middle system temperature is always in between the top and bottom system. Thus, giving it more room to cool down. If the temperature is high, the thermal energy exchange is also high, thus increasing the cooling performance. Therefore, the middle system has the best cooling performance.

4.3.2 Power Analysis of Water Spraying and Dripping System

Below is the formula to calculate the fill factor and power of the solar panel:

Fill Factor = Rated P_{max} / (V_{oc} x I_{sc})

= 260 / (37.96 x 9.01)

= 0.7602

Power = Fill Factor x V_{oc} (measured) x I_{sc} (measured)

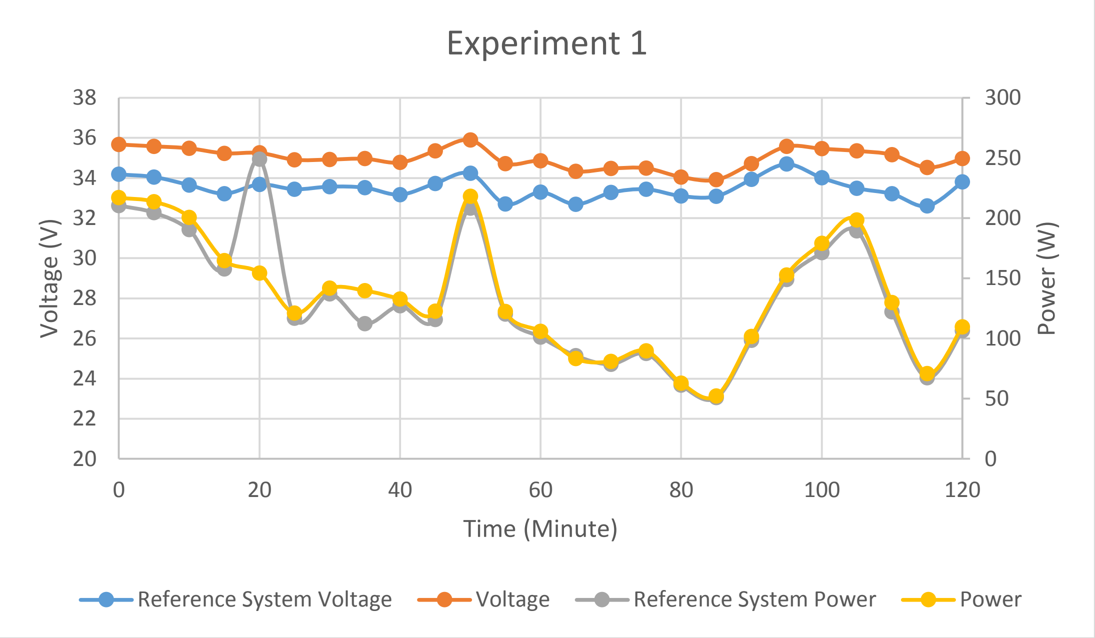


Figure 4.13: Comparison of Voltage and Power with Their Respective Reference (Spray Solar Panel)

By observing Figure 4.13, it can clearly be seen that there is an increase in voltage and power compared to their respective reference. The average increase in voltage in this experiment is 1.49V. This gives an increase in efficiency of 4.36%. The highest increase in voltage in this experiment is 1.92V which gives 5.89% increase in efficiency based on the voltage. Based on theory, the lower the temperature, the higher the efficiency of the solar panel. This shows that the theory is true. The highest increase in power is 7.71W which gives efficiency of 6.31%. The increase in voltage and power also depends on how high the solar irradiance. High solar irradiance tends to make the solar panel even hotter. Once the solar panel is hot, the performance will drop. This is where the water spraying system comes in. Water is sprayed onto the hot solar panel to cool it down, thus increasing its performance. The cooling performance increases as the solar panel gets hotter, thus giving higher efficiency. In Figure 4.13, it can be observed that there is 1 point the reference power is higher than the sprayed solar panel power. This is because of the frequent fluctuation of the current that changes very fast.

At that moment the current of the reference system is taken, the solar irradiance is very strong and so happen at that time, a big cloud passed by at the moment the current of the sprayed solar panel is taken. Thus, this gives a low current resulting in low power.

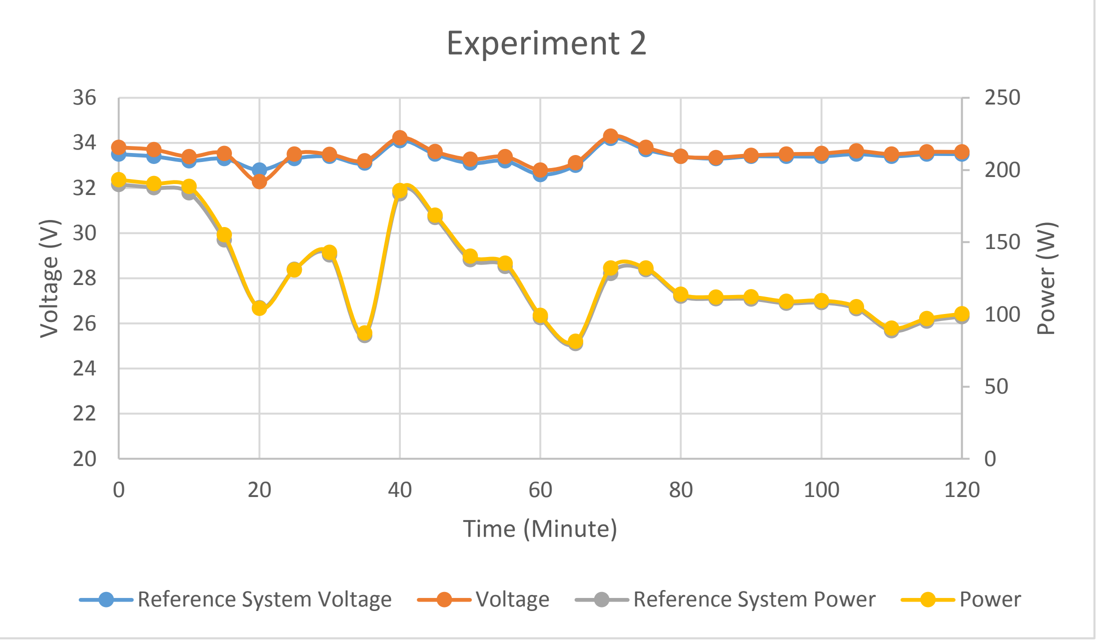


Figure 4.14: Comparison of Voltage and Power with Their Respective Reference (Spray Metal Deck)

Since water has no effect on the metal deck, the voltage of the sprayed metal deck is almost the same as the reference. The voltage difference is less than 1V based on Figure 4.14. The power obtained is also similar to the reference which has the difference of less than 4W. The power difference is slightly higher than the voltage due to the fluctuation of the current during data collection. The error is minimise by taking the reading of current first, followed by voltage.

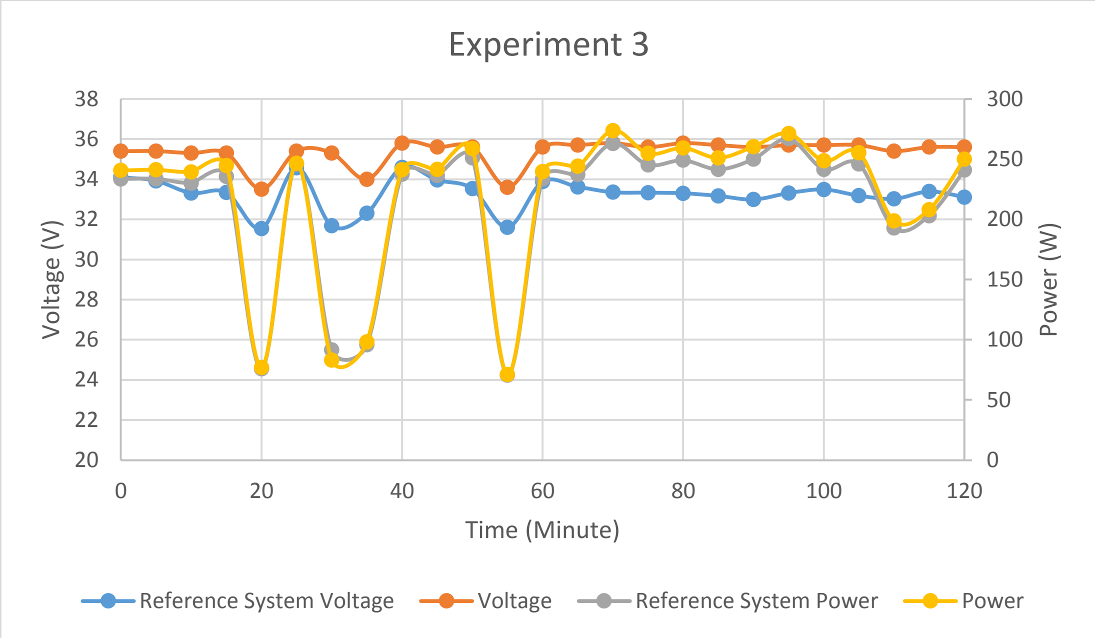


Figure 4.15: Comparison of Voltage and Power with Their Respective Reference (Drip Solar Panel)

In experiment 3, the solar irradiance is the highest among the 4 experiments which is 1119.2214 W/m^2. The average rise in voltage is 1.72V giving the efficiency of 5.08%. The highest rise in voltage is 2.61V giving the efficiency of 7.91%. Besides that, the highest rise in power is 10.62W. The voltage, efficiency and power for this experiment is the highest based on Figure 4.15. The major factor that affects the efficiency is the high solar irradiance and the evenly water distribution. High solar irradiance is needed to generate more voltage. However, high solar irradiance also tends to make the solar panel hotter. The dripping system is more efficient than the water spraying system. This is because it uses less water and also cover a wider range. Furthermore, the water is also evenly distributed as the hole size of the PVC pipe is constant which is 4mm. Since the whole solar panel is dripped by the PVC pipe, the solar cells of the solar panel which are connected in series will generate higher voltage. Water spraying system is not as efficient as dripping system because the water sprayed onto the solar panel is not even and does not cover the whole solar panel. As the solar cells are connected in series, parts that are not sprayed will affect the overall voltage generated. For instance, solar cells that are low temperature will generate high voltage but the voltage also will have to go through the solar cells that are high temperature. When this happens, the high voltage generated will be reduced. Therefore, it is important that the whole solar panel has a constant temperature. There are sudden spikes in the power. This is due to big clouds blocking the solar irradiance from the sun. The current is most affected by the clouds as the value will drop a lot, thus causing the spikes in the power.

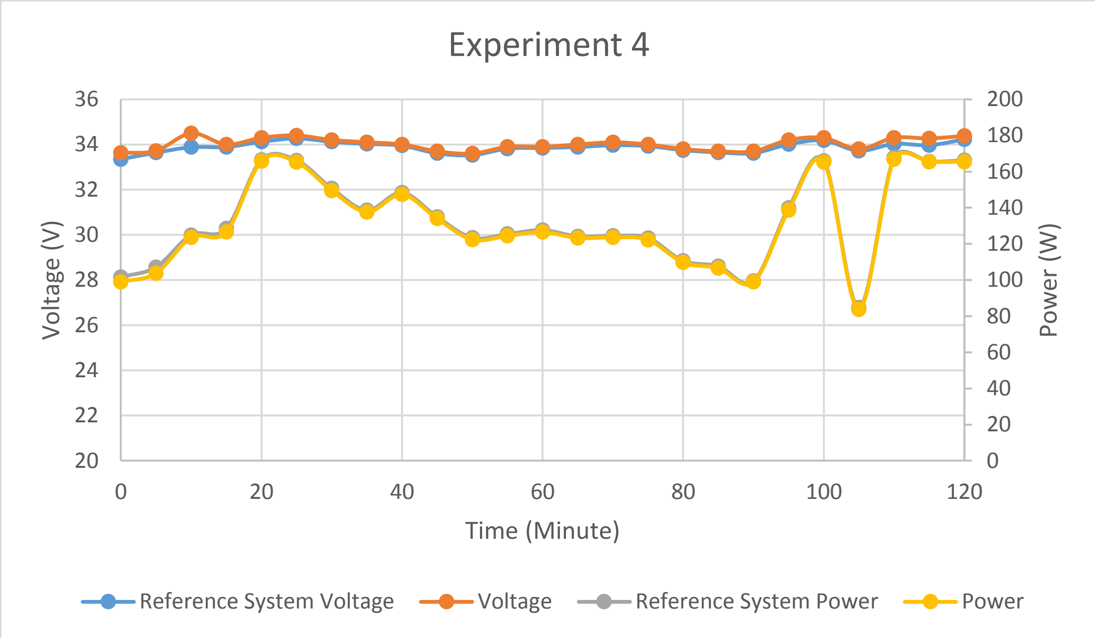


Figure 4.16: Comparison of Voltage and Power with Their Respective Reference (Drip Metal Deck)

Dripping system is implemented onto the metal deck in experiment 4. There is hardly any increase in voltage or power. The result is almost the same as experiment 2. Thus, dripping water onto the metal deck has no effect based on Figure 4.16.

4.3.3 Performance of Water Spraying and Dripping System

The performance of the water spraying and dripping system is evaluated. This is to compare which system is more efficient and can be implemented in real life situation. The power and voltage gained are determine to see the performance of both systems. Experiment 1 and experiment 3 are used as a representative to see the performance of the water spraying system and dripping system respectively. Since water has almost no effect on the metal deck, experiment 2 and experiment 4 are not used.

Power and voltage gained are calculated using the formula below:

Power Gained = Rated P_{max} [1 + (γ x ΔT)] – Rated P_{max}

Voltage Gained = Rated V_{oc} [1 + (β x ΔT)] – Rated V_{oc}

ΔT = Temperature difference between reference system and the solar panel

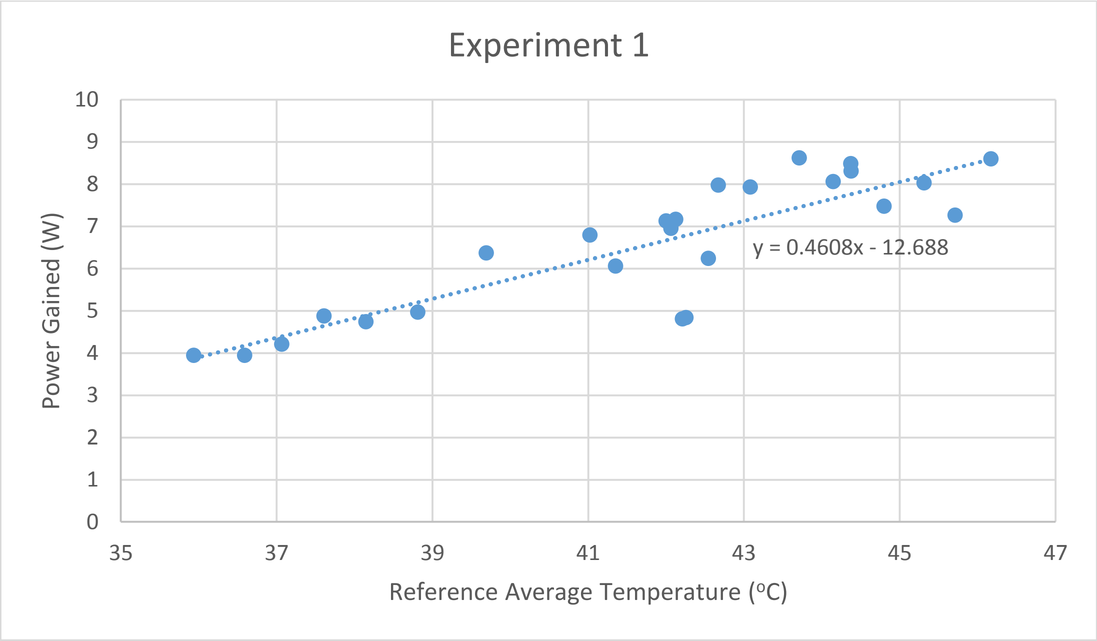


Figure 4.17: Power Gained against Reference Average Temperature (Spray Solar Panel)

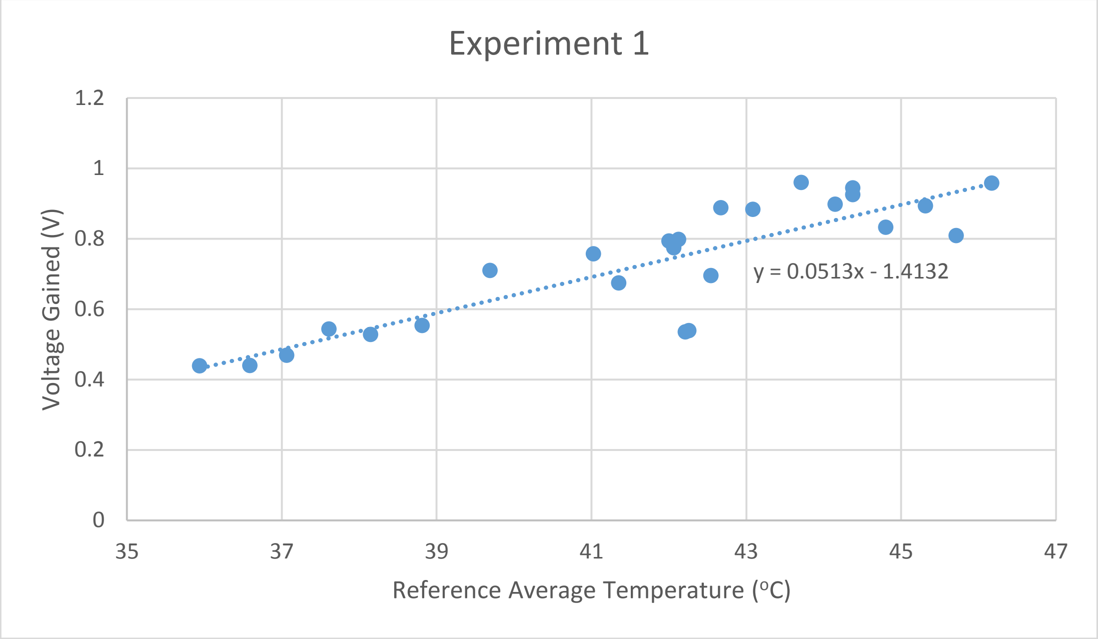


Figure 4.18: Voltage Gained against Reference Average Temperature (Spray Solar Panel)

Based on the formula used, both power and voltage gained are dependent on the temperature. The larger the temperature difference, the higher the power and voltage gained based on Figure 4.17 and Figure 4.18. Therefore, it can be mention that the power and voltage gained are linear with the reference average temperature. The highest power and voltage gained are 8.62W and 0.96V respectively. Lower average temperature shows that the power and voltage gained are lower and vice versa.

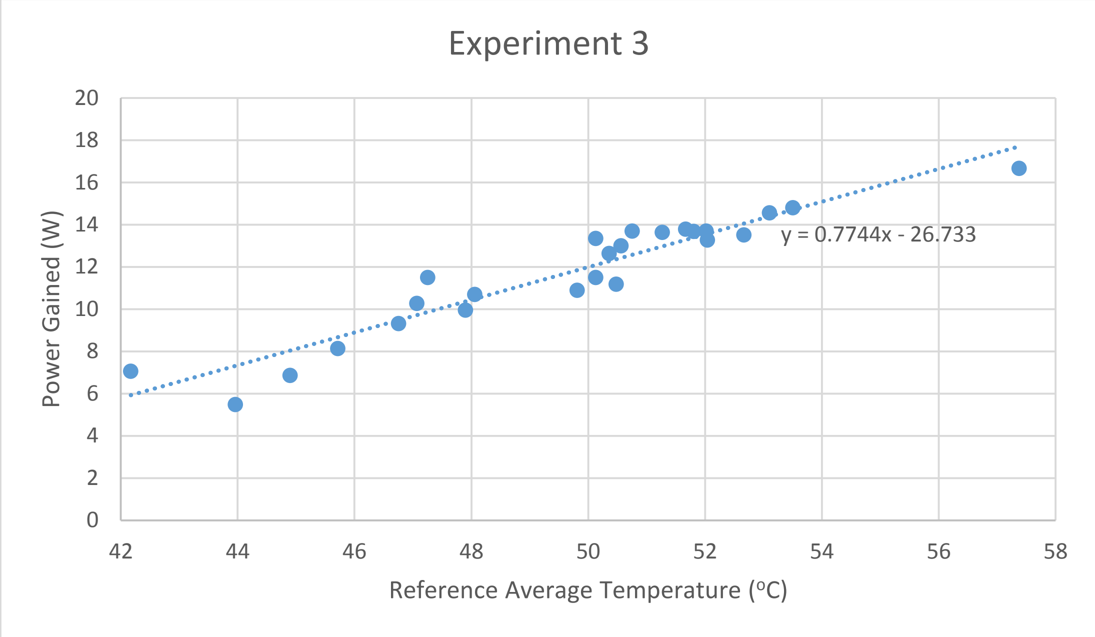


Figure 4.19: Power Gained against Reference Average Temperature (Drip Solar Panel)

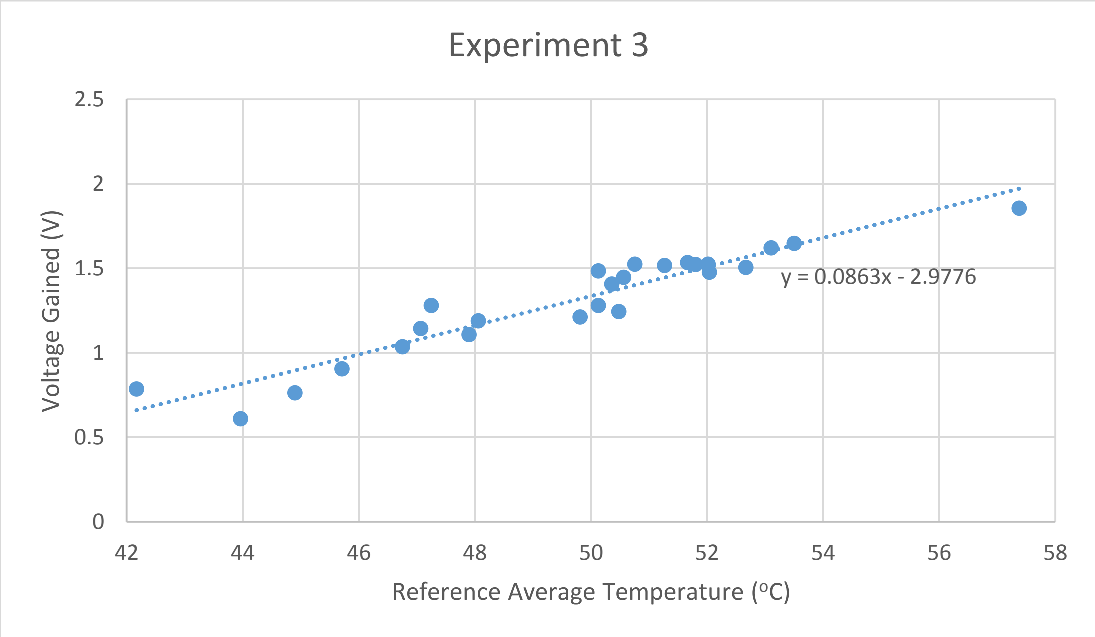


Figure 4.20: Voltage Gained against Reference Average Temperature (Drip Solar Panel)

Experiment 3 shows a better result compared to experiment 1. The highest power and voltage gained are 16.66W and 1.86V which are almost double the gained in experiment 1 based on Figure 4.19 and Figure 4.20. Once again, the solar irradiance has the most effect on the power and voltage gained. Since the solar irradiance is the highest, in this experiment, the solar panel is the hottest among the 4 experiments. This cause both dripped solar panel and the reference to have high temperature. Since dripped solar panel and the reference have high temperature, this experiment can actually test the performance of the dripping system to see the effectiveness. As mention before, the dripped solar panel temperature reduced by 17.63^{o}C which is significant. Due to the big drop in temperature compared to the reference, the power and voltage gained increase drastically. The evenly distributed water by the dripping system also make the whole solar panel cool down. Since the solar cells are connected in series, every cell is important to produce high power and voltage gained. High current and voltage will flow through every cell, thus it is important to keep the temperature of the whole solar panel low. If a portion of the solar panel has high temperature, it will affect the overall current and voltage flow. This dripping system has evenly water distribution, thus this problem does not occur, giving high performance.

4.4 Additional Experiments Analysis

4.4.1 Experiment 5: Water Spraying System (Spray Solar Panel and Metal Deck)

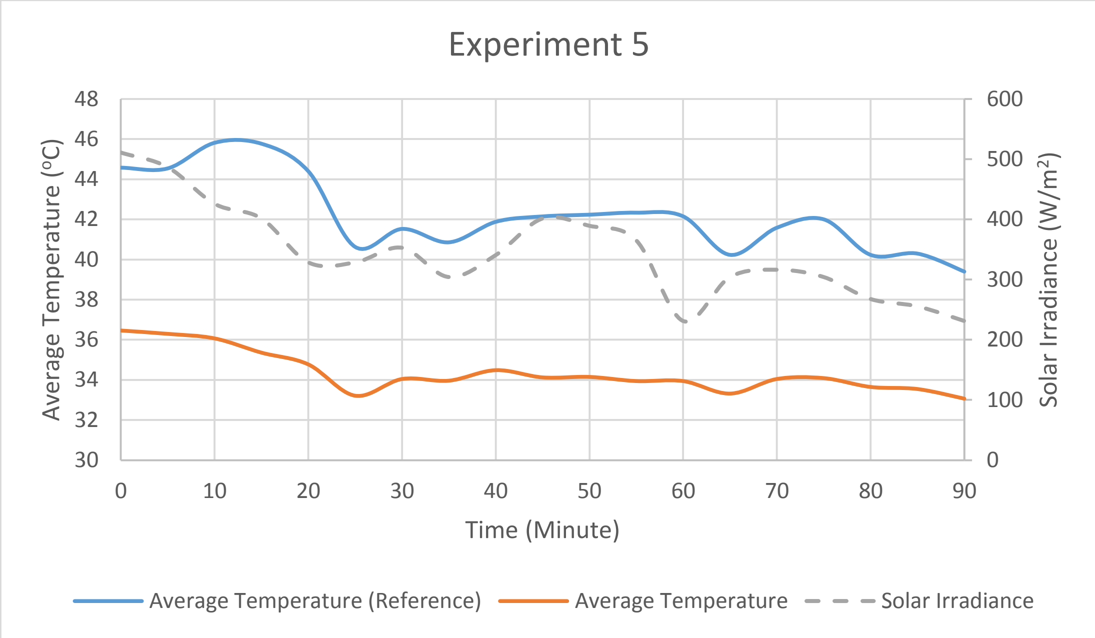


Figure 4.21: Average Temperature against Time

Experiment 5 is conducted to see whether the performance of the solar panel can be further improved. In experiment 1 and 2, water spraying system is used to spray the solar panel and the metal deck individually. However, in experiment 5 both solar panel and metal deck is sprayed. Experiment 1 shows that the average temperature can be lowered if water is sprayed onto the solar panel while experiment 2 shows that the average temperature is not affected when sprayed onto the metal deck. Due to mild solar irradiance on the day of the experiment, the solar panel is not that hot. The average temperature reduced by the sprayed solar panel is 7°C while the highest is 9°C based on Figure 4.21. The outcome is almost the same as in experiment 1. It can be observed that the average temperature dropped due to the water sprayed onto the solar panel but not the metal deck.

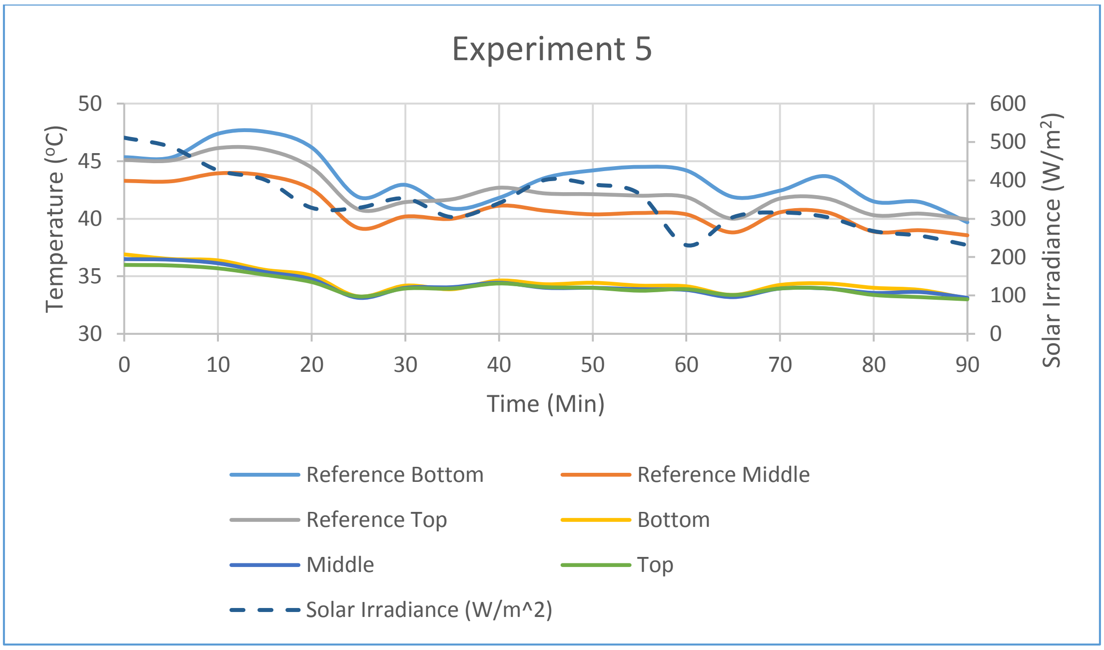


Figure 4.22: Bottom, Middle and Top Temperature with Reference against Time

Based on Figure 4.22, it can be seen that all of the temperature sensors of the sprayed solar panel and metal deck are almost the same which is good. If all the whole solar panel has the same temperature, the overall performance will increase. The average temperature difference between the sprayed solar panel and metal deck against the reference is 9.25°C while the highest temperature difference is 12°C. This result is similar as to experiment 1. Given that the sprayed solar panel and metal deck temperature sensors are almost the same, it should increase the performance of the solar panel. However, it can be seen that even with increase performance, the outcome is more or less the same as experiment 1. Therefore, spraying both solar panel and the metal deck at the same time does not increase the performance of the solar panel.

4.4.2 Experiment 6: Dripping System (Drip Solar Panel and Metal Deck)

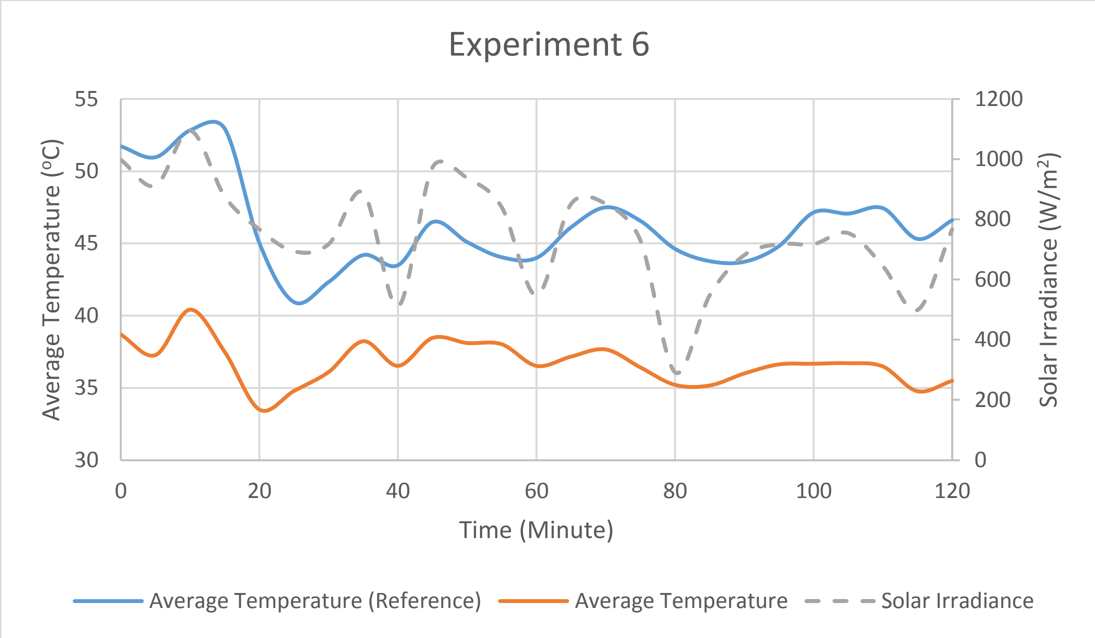


Figure 4.23: Average Temperature against Time

Based on Figure 4.23, the dripped solar panel and metal deck average temperature is lower than the reference. Average temperature drop is 10.47°C while the highest temperature drop is 15.45°C. Once again the dripping system shows a higher drop in temperature compared against the water spraying system. Comparing the result against experiment 3, it is slightly lower. By using dripping system to drip both solar panel and metal deck, the performance should increase slightly, however it did not. Therefore, the average temperature of the dripped solar panel and the metal deck decreased due to the water dripped onto the solar panel but not the metal deck.

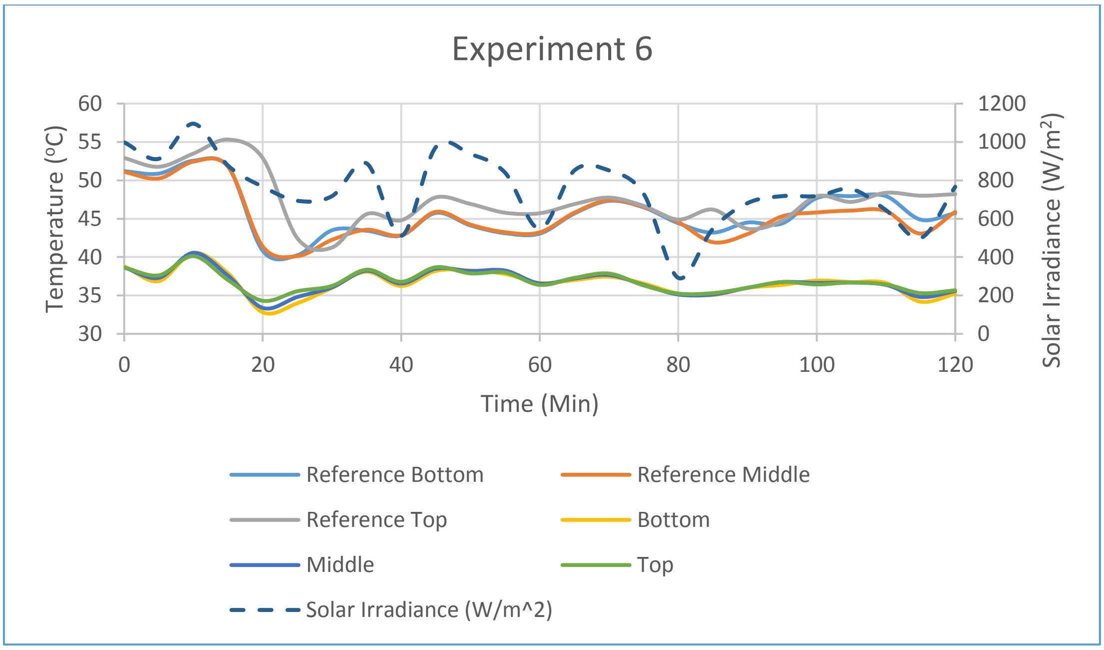
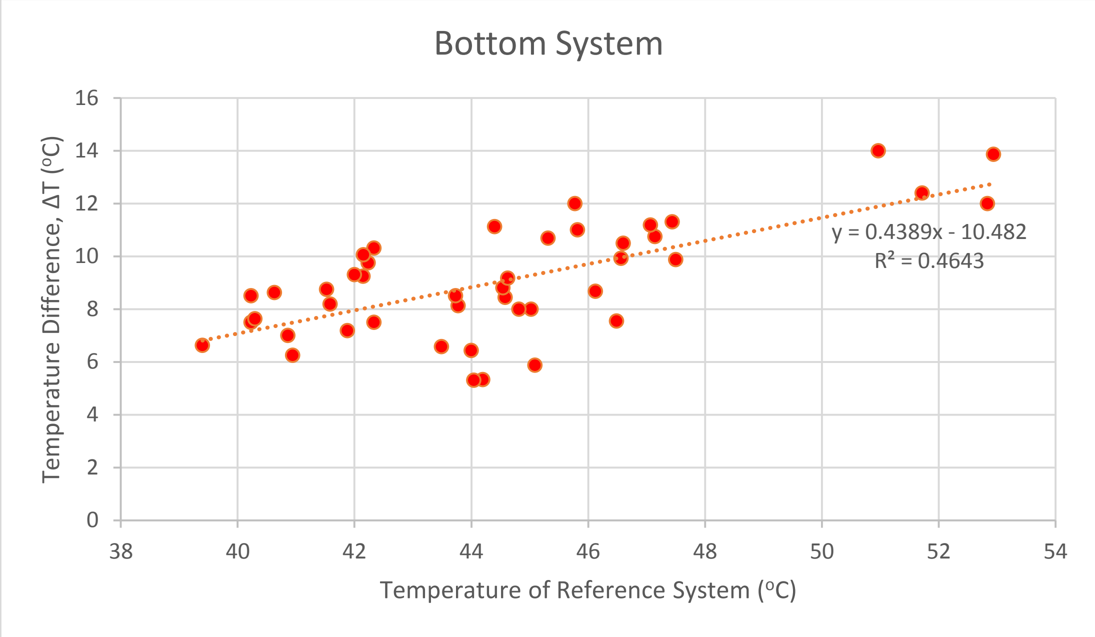
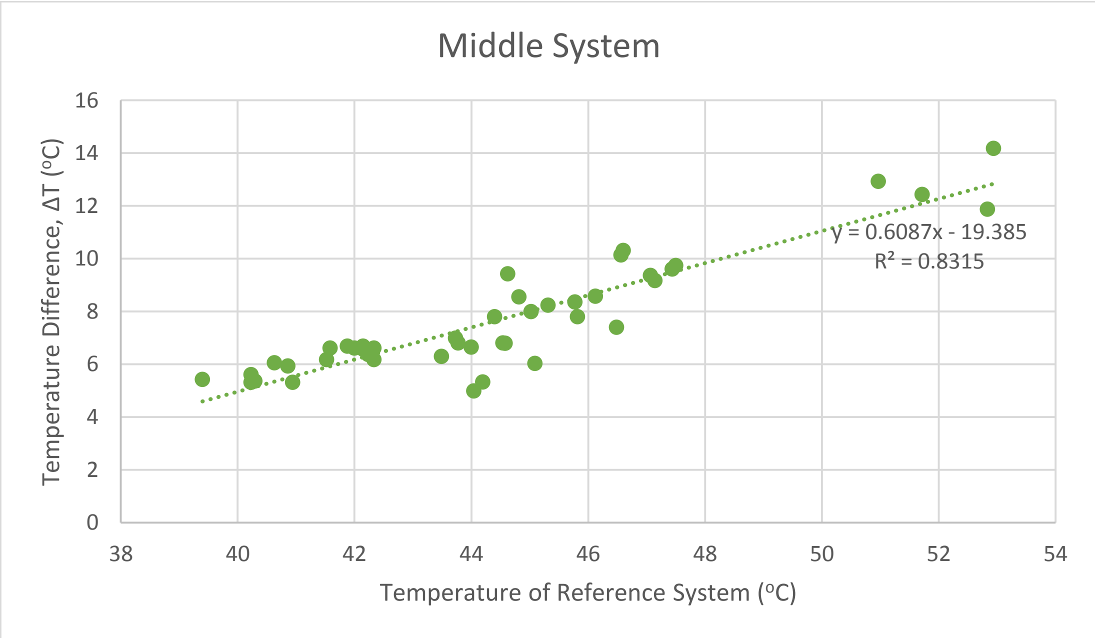


Figure 4.24: Bottom, Middle and Top Temperature with Reference against Time

Based on Figure 4.24, it can be observed that the temperature sensors of the dripped solar panel and metal deck are lower than the reference and are also almost the same. The average temperature drop is around 11.49°C while the highest temperature drop is 18.31°C. Since the temperature sensors of the dripped solar panel and metal deck are almost the same, the overall performance of the solar panel should increase. Comparing the result with experiment 3, it can be seen that experiment 6 has the highest temperature drop among the 6 experiments. However, based on experiment 1,2,3,4 and 5, it can be clearly observed that water has no effect on the performance of the solar panel when sprayed or dripped onto the metal deck. Therefore, experiment 6 reached a high temperature drop of 18.31°C by dripping water onto the solar panel alone. It can be conclude that water has no effect on the metal deck whether using water spraying or dripping system.


Bottom System
y = 0.4389x - 10.482
R² = 0.4643
Temperature Difference, ΔT (°C)
Temperature of Reference System (°C)
0
2
4
6
8
10
12
14
16
38
40
42
44
46
48
50
52
54


Middle System
y = 0.6087x - 19.385
R² = 0.8315
Temperature Difference, ΔT (°C)
Temperature of Reference System (°C)
0
2
4
6
8
10
12
14
16
38
40
42
44
46
48
50
52
54

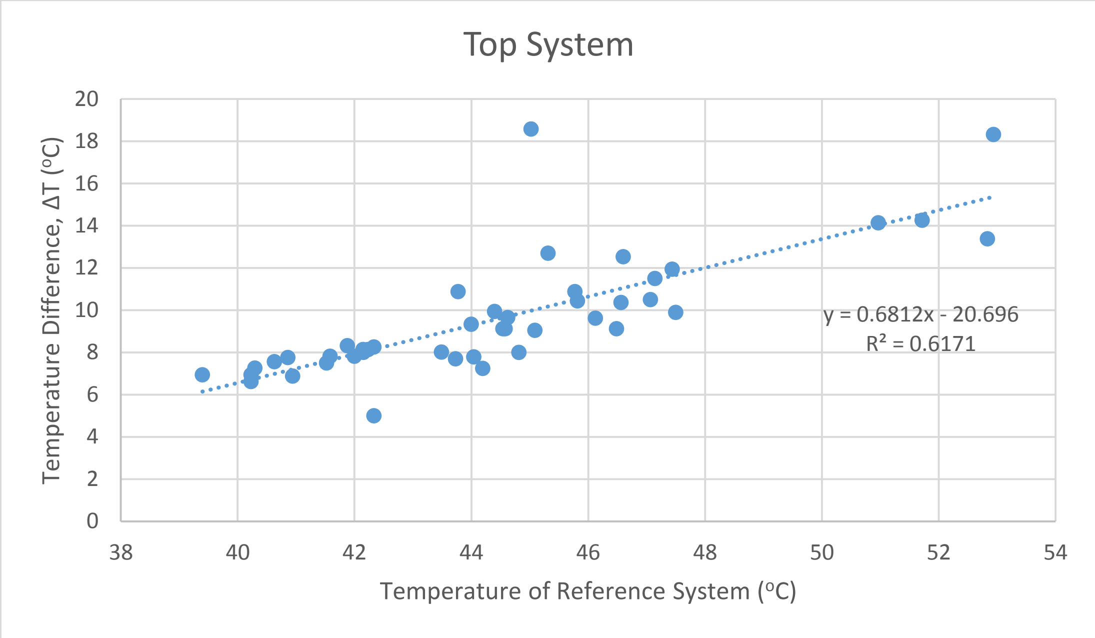


Figure 4.25: Graphs of Bottom, Middle and Top System of Temperature Difference, ΔT Against Temperature of Reference System

Once again, the same cooling performance is done in experiment 5 and 6. It can be seen in Figure 4.25 that the cooling performance increases as the temperature of the reference system increases. Experiment 5 and 6 steepest increase in cooling performance is the top system while experiment 1, 2, 3, and 4 steepest increase in cooling performance is the middle system. Natural convection also plays a role in which system has a highest temperature, thus affecting the cooling performance. In experiment 5 and 6, it can be seen that natural convection cool down the bottom and middle system more than the top system. This causes the top system to be slightly hotter than the other 2 systems. Due to the higher temperature in the top system, the cooling performance is the best in the top system.

4.5 Power Analysis of Addition Experiment of Water Spraying and Dripping System

Below is the formula to calculate the fill factor and power of the solar panel:

Fill Factor = Rated P_{max} / (V_{oc} x I_{sc})

= 260 / (37.96 x 9.01)

= 0.7602

Power = Fill Factor x V_{oc} (measured) x I_{sc} (measured)

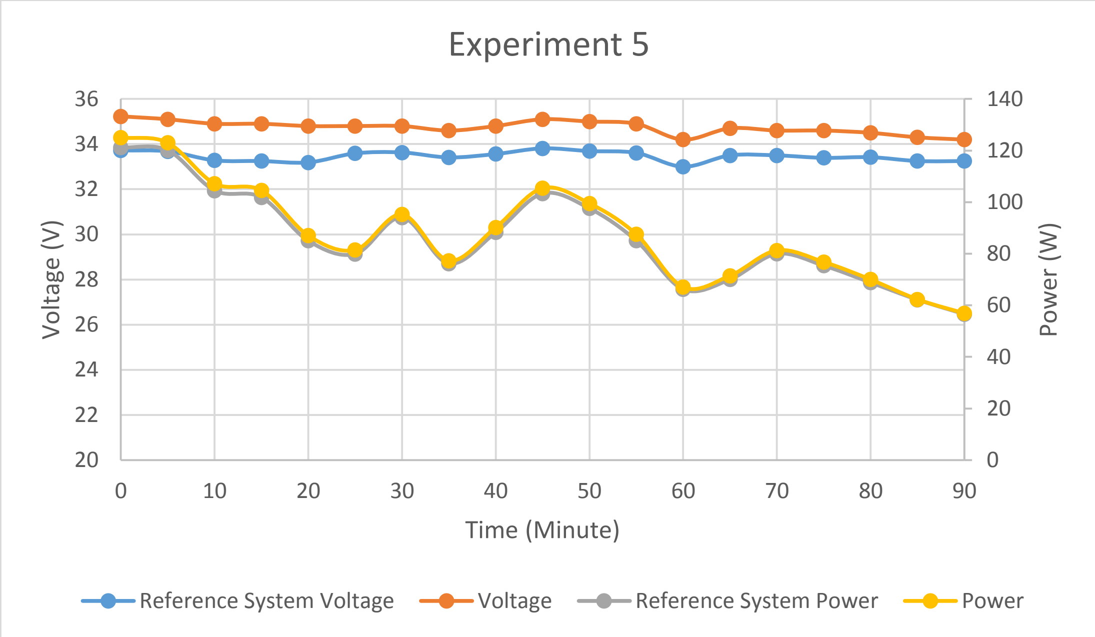


Figure 4.26: Comparison of Voltage and Power with Their Respective Reference (Spray Solar Panel and Metal Deck)

Based on Figure 4.26, the voltage and power of the sprayed solar panel and metal deck is higher than the reference. The average increase in voltage is 1.21V, giving the efficiency of 3.62%. The highest increase in voltage is 1.51V, giving the efficiency of 4.48%. Highest increase in power is 3.82W. Comparing the result with experiment 1, it can be observed that the increase in voltage, power and efficiency is slightly lower. The performance of the solar panel is lower due to the low solar irradiance on that day. The water sprayed onto the solar panel and the metal deck does not increase any performance.

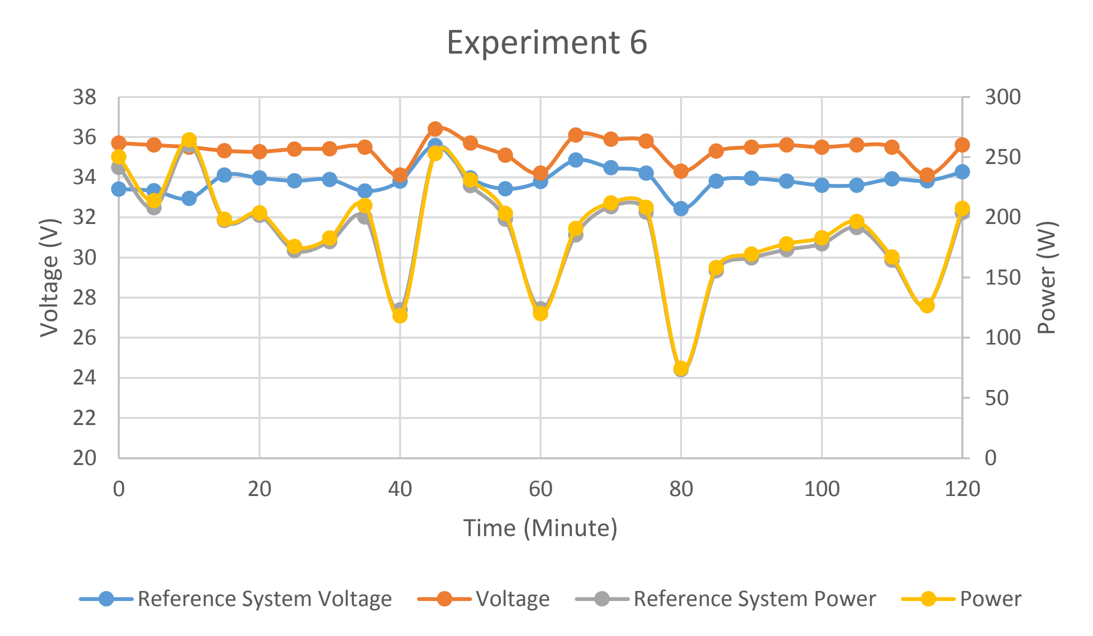


Figure 4.27: Comparison of Voltage and Power with Their Respective Reference (Drip Solar Panel and Metal Deck)

The voltage and power of the dripped solar panel and metal deck are lower than the reference. The average increase in voltage is 1.43V, giving 4.15% efficiency while the highest increase in voltage is 2V, giving the efficiency of 4.69%. Highest increase in power is 8.68W as shown in Figure 4.27. By comparing with experiment 3, the result in experiment 3 gives a higher yield of performance compared to experiment 6. This shows that dripping water onto the solar panel and metal deck does not further increase the performance.

4.6 Performance of Additional Experiments of Water Spraying and Dripping System

Performance of the water spraying and dripping system of the additional experiments are carried out. Power and voltage gained are calculated using the formula below:

Power Gained = Rated P_{max} [1 + (γ x ΔT)] – Rated P_{max}

Voltage Gained = Rated V_{oc} [1 + (β x ΔT)] – Rated V_{oc}

ΔT = Temperature difference between reference system and the solar panel

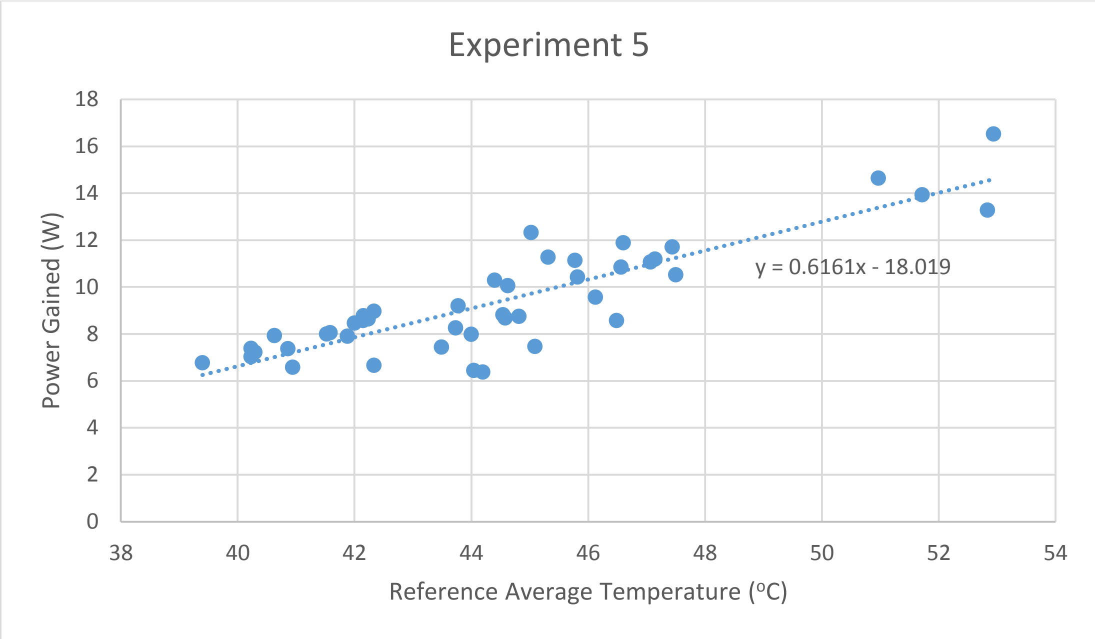


Figure 4.28: Power Gained against Reference Average Temperature (Spray Solar Panel and Metal Deck)

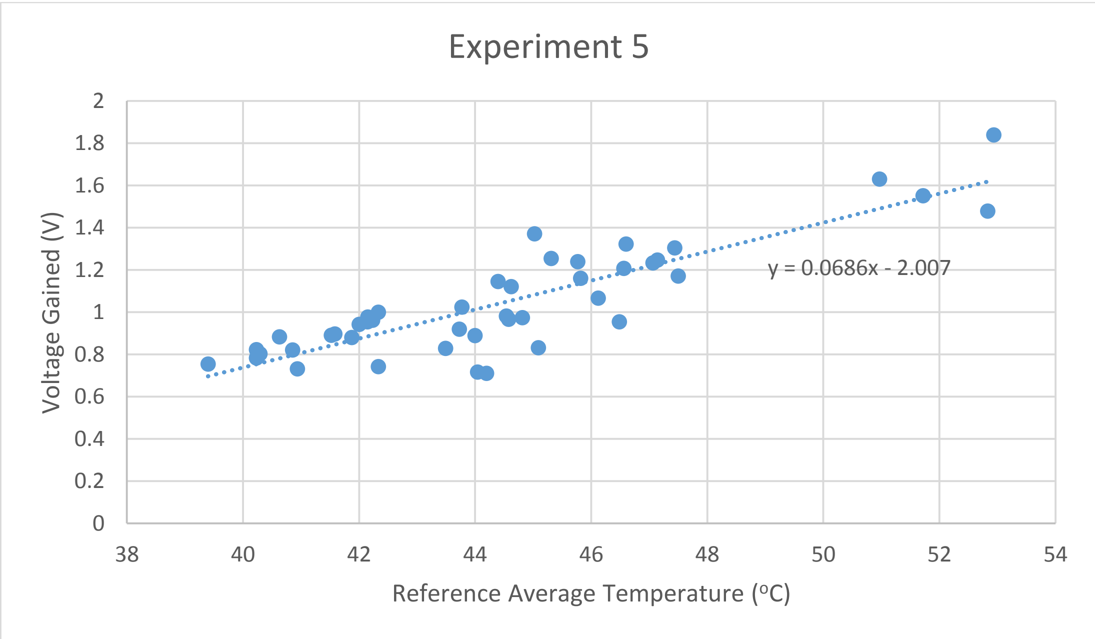


Figure 4.29: Voltage Gained against Reference Average Temperature (Spray Solar Panel and Metal Deck)

The above 2 formula used to calculate the power and voltage gained are very dependent on the temperature. Figure 4.28 and Figure 4.29 can be observed that the higher the reference average temperature, the higher the power and voltage gained. It can be mention that the power and voltage gained are linear as the temperature increases. The highest power and voltage gained are 11.13W and 1.24V. By comparing experiment 1, the power and voltage gained are slightly higher.

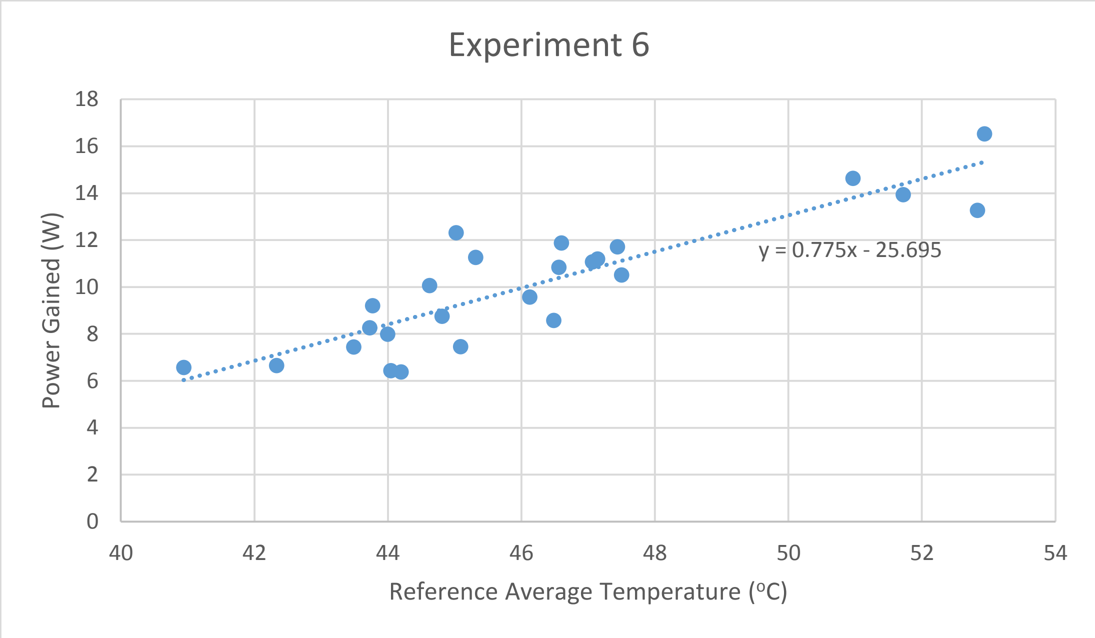


Figure 4.30: Power Gained against Reference Average Temperature (Drip Solar Panel and Metal Deck)

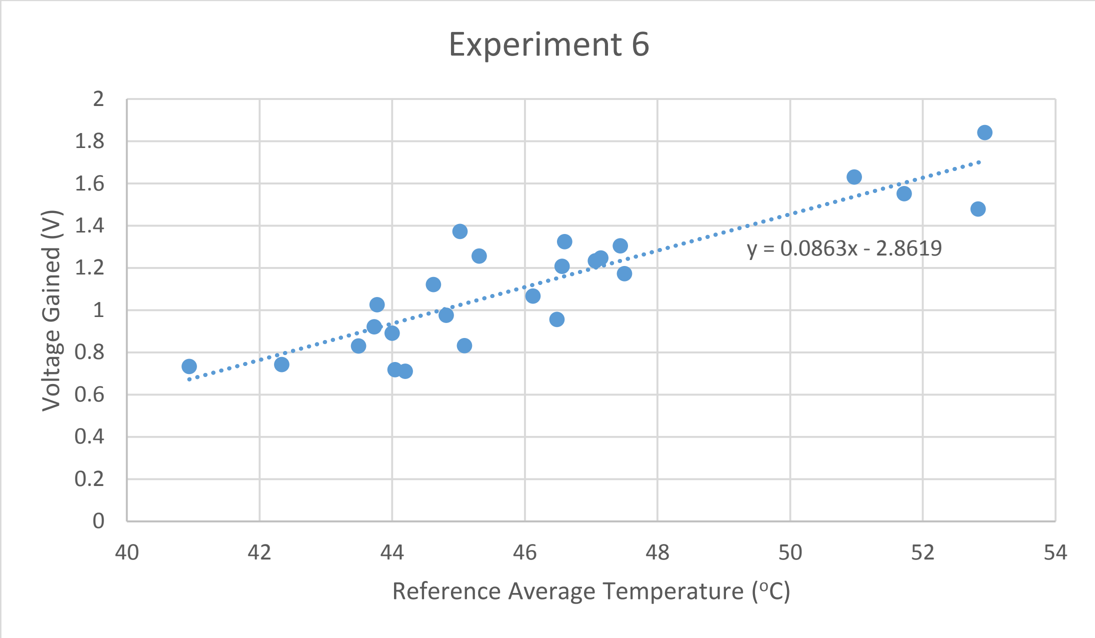


Figure 4.31: Voltage Gained against Reference Average Temperature (Drip Solar Panel and Metal Deck)

Experiment 6 voltage and power gained are almost the same as experiment 3 based on Figure 4.30 and Figure 4.31. This shows that the dripping system is only effective when the water is dripped onto the solar panel but has no effect when dripped onto the metal deck. The solar irradiance of experiment 6 is slightly lower to experiment 3. Highest power and voltage gained are 16.53W and 1.84V respectively. After conducting all 6 experiments, it can be finalize that no matter what system is used such as water spraying or dripping system, water does not have any effect on the metal deck.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There are 2 systems that are used for this project which are the water spraying and dripping system. Total of 3 experiments were conducted for each system. Each experiment has a different configuration to evaluate the performance of the solar panel. Throughout all the experiments, it can be conclude that water has no effect on the metal deck. Furthermore, in this project, water is used as an external cooling factor to cool down the solar panel. When the solar panel temperature drops, the performance of the solar panel increases. Based on all of the experiments, the average temperature drop is around 7^{o}C on a normal sunny day but decreases as high as 18.31^{o}C on a scorching sun based on experiment 6.

Cooling performance of the solar panel increases as the solar irradiance increases. This is because the solar irradiance will cause the average temperature of the solar panel to increase giving more room for water to cool it down. Besides that both water spraying and dripping system use different amount of water to cool down the solar panel. Based on the result, dripping system uses around 0.0032 litres per second which is 0.016 litres per second less than the water spraying system. The dripping system uses less water and also gives better performance compared to the water spraying system.

In all of the 6 experiments, dripping system yield a better performance when compared to the water spraying system. Experiment 3 has the best result among the 6 experiments. The average rise in voltage is 1.72V, giving an efficiency of 5.08% while the highest rise in voltage is 2.61V with the efficiency of 7.91%. In addition to this, the highest rise in power obtained is 10.62W. The average power generated for every hour is around 2.522 kWh. Water bill is estimated by using the highest rate which is the most expensive which gives around RM168 per month. The electricity bill that can be saved per month is estimated to be RM113, this does not include overcharge for peak hour. This will result in a loss. However, if the water bill is calculated using the medium rate, it will cost around RM87. This will result in a profit. Therefore, profit or loss of the electricity bill is depend on the usage of both water and electricity. There are a few major factors that contribute to the high efficiency. Firstly, the solar irradiance is the highest in experiment 3 which is 1119.22 W/m^2. The next factor is the dripping system which drips water on the whole solar panel unlike the water spraying system which focuses on the center part of the solar panel. The following factor is the evenly distribution of water by the dripping system. All of the solar cells of the solar panel have low temperature giving better performance since they are connected in series. It can be observed that in experiment 5 and 6, spraying or dripping water on the solar panel and metal deck does not increase the performance of the solar panel. In a nutshell, the dripping system is better than the water spraying system because it uses less water and gives better performance.

5.2 Recommendations

After conducting 6 experiments regarding optimization of the performance of the solar panel, it can be seen that they are rooms for improvement. It is recommended that a piping system is installed to the dripping system. By doing this, the water used by the dripping system can be reused, thus saving more water. When the piping system is enclosed, it will also increase the pressure of the water inside, hence it can cool down the temperature of the solar panel further. Furthermore, in a large solar farm, there are many solar panels. Therefore, installing a piping system will not have enough pressure to circulate the water back to the solar panel for recycle. A small piping system with a water pump can be installed within the solar farm. The power used by the water pump is small and does not use up a lot of energy generated by the solar farm. Thus, piping system with a water pump is essential to a dripping system.

Another potential area of study is a misting system. An average misting system costs around RM2000. Misting system is basically a piping system with a pump connected with several nozzle to spray mist. By using mist instead of water, more water can be save if compared to the dripping system. However, misting system can only be used if the total area of the solar panel is wide enough. This is due to the minimum installation cost of RM2000.

Lastly, there is another potential area of study which is the feedback of solar cell voltage. The feedback of solar cell voltage can be used to control the flow of water. By using a simple circuit with a feedback of solar cell voltage, the water valve can be controlled based on the voltage obtained. If the voltage obtained is high, the water valve will be close, hence saving water. On the other hand, if the voltage obtained is low, this indicates that the solar panel is very hot, thus the water valve will be open. This simple feedback of solar cell voltage circuit can be installed easily onto any system such as dripping system or the misting system.

REFERENCES

Armstrong, S. & Hurley, W. G., 2010. A Thermal Model for Photovoltaic Panels under Varying Atmospheric Conditions. [Online] Available at: http://www.nuigalway.ie/power_electronics/documents/applied_thermal_engineering_2010.pdf
[Accessed 12 March 2010].

Autodesk, Inc, 2016. Arduino DIY SD Card Logging Sheild. [Online] Available at: http://www.instructables.com/id/Arduino-DIY-SD-Card-Logging-Shield/
[Accessed 3 May 2016].

Avion Tech Sdn Bhd, 2016. PVC Pipe. [Online] Available at: http://buildingmaterials.com.my/polyvinyl-chloride/pvc-pipe/
[Accessed 13 April 2015].

Bloomberg New Energy Finance, 2014. Solar Insight – Research Note. [Online] Available at: http://about.bnef.com/content/uploads/sites/4/2014/04/2014-04-16-PV-production-2013-an-all-Asian-affair.pdf
[Accessed 16 April 2014].

Boxwell, M., 2006. *Solar Electricity Handbook: A Simple, Practical Guide to Solar Energy*. U.K.: Greenstream Pub.

Coutts, T. J., Allman C. S. & Benner, John. P., 1997. *Thermophotovoltaic Generation of Electricity*. Woodbury, N.Y.: AIP Press.

Dennis, L., 2016. Solar Cells. [Online] Available at: http://www.pvresources.com/en/solarcells/solarcells.php
[Accessed 10 September 2016].

Dobrzanski, L. A. & Drygala, A., 2008. Surface Texturing of Multicrystalline Silicon Solar Cells. *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 31, pp. 77-82. [Online] Available at: http://www.journalamme.org/papers_vol31_1/31111.pdf
[Accessed 1 November 2008].

Dobrzanski, L. A., et al., 2012. Monocrystalline Silicon Solar Cells Applied in Photovoltaic System. *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 53, pp. 7-13. [Online] Available at: http://www.journalamme.org/papers_vol53_1/5311.pdf
[Accessed 1 July 2015].

Enhance Photovoltaics, 2015. Enhance Photovoltaic Modules. [Online] Available at: http://enhance-photovoltaics.com/
[Accessed 10 March 2016].

Electro Schematics, 2016. Arduino Mega 2560 Pinout. [Online] Available at: http://www.electroschematics.com/7963/arduino-mega-2560-pinout/
[Accessed 2 November 2014].

Gail, A. M., 2013. Study of The Operating Temperature of a PV Module. [Online] Available at: http://www.ht.energy.lth.se/fileadmin/ht/Kurser/MVK160/2012/Gail-Angee_Migan.pdf
[Accessed 16 May 2013].

Harbor Freight Tools, 2016. 5/8 in. x 100 ft. Heavy Duty Garden Hose. [Online] Available http://www.harborfreight.com/5-8-eighth-inch-x-100-ft-heavy-duty-garden-hose-67018.html [Accessed 26 May 2015].

Jef, P. & Giovanni, F., 2003. Photovoltaic Stacks. [Online] Available at: http://web.archive.org/web/20071013061056/http://www.imec.be/wwwinter/energy/space_main.shtml
[Accessed 23 December 2003].

Kalogirou, S. A., 2013. *Solar Energy Engineering Processes and Systems*. 2nd ed. Burington, MA: Elsevier/Academic Press.

Kazmerski, L., 1994. The First NREL Conference on Thermophotovoltaic Generation of Electricity. [Online] Available at: http://webapp1.dlib.indiana.edu/virtual_disk_library/index.cgi/4298428/FID2471/m94011831.pdf
[Accessed 27 July 1994].

Markvart, T., 2000. *Solar Electricity*. 2nd ed. Chichester: Wiley.

Mayur, S., 2015. China: The New Silicon Valley. [Online] Available at: http://marketrealist.com/2015/02/china-new-silicon-valley/
[Accessed 2 February 2015].

ModernEnviro, 2014. Home Solar Energy Guide: Part III. [Online] Available at: http://www.modernenviro.com/home-solar-energy-guide-part-3/
[Accessed 25 May 2016].

Moharram, K. A., et al., 2013. Enhancing The Performance of Photovoltaic Panels by Water Cooling. [Online] Available at: http://www.sciencedirect.com/science/article/pii/S2090447913000403
[Accessed 16 May 2013].

New Energy and Fuel, 2016. A New Thermal Energy to Electricity Device. [Online] Available at: http://newenergyandfuel.com/http:/newenergyandfuel/com/2011/07/28/a-new-thermal-energy-to-electricity-device/
[Accessed 28 July 2011].

OPVAP, 2011. I-V Curve. [Online] Available at: http://opvap.com/jsc.php
[Accessed 15 March 2016].

Solar Feeds, 2012. Polycrystalline vs Monocrystalline Solar Modules. [Online] Available at: http://www.solarfeeds.com/polycrystalline-vs-monocrystalline-solar-modules/
[Accessed 1 June 2012].

The Eppley Laboratory, INC., 2016. Standard Precision Pyranometer. [Online] Available at: http://www.eppleylab.com/instrumentation/standard_precision_pyranometer.htm
[Accessed 13 May 2016].

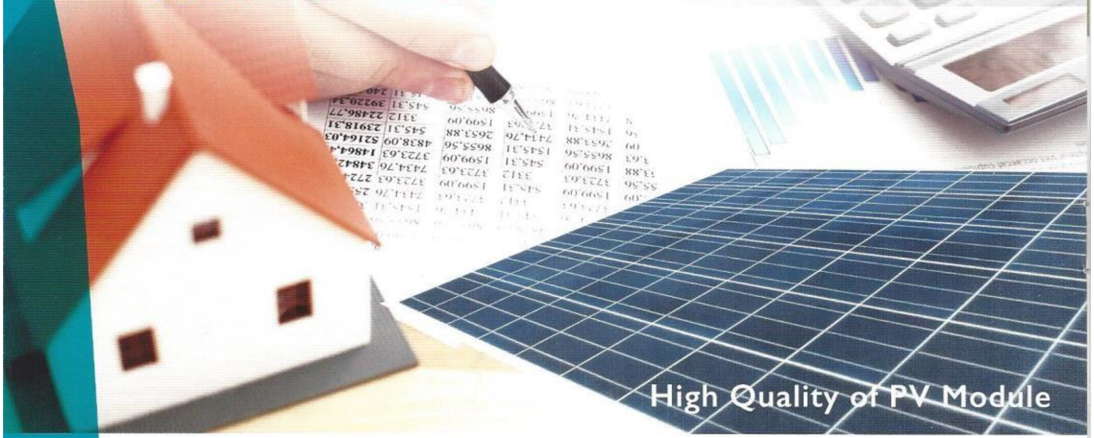
The New York Times Company, 2016. Is Solar Power Expensive or Competitive?. [Online] Available at: http://green.blogs.nytimes.com/2009/11/13/is-solar-power-expensive-or-competitive/
[Accessed 13 November 2009].

Thomas Publishing Company, 2016. Digital Multimeters. [Online] Available at: http://www.thomasnet.com/articles/engineering-consulting/digital-multimeters
[Accessed 10 September 2016].

APPENDICES

APPENDIX A: MSR Multi-Crystalline Photovoltaic Module MYS-60 CF-260 Data Sheet

Multi-Crystalline
Photovoltaic Module MYS-60P | MYS-72P



Our product MYS 60 cells and MYS 72 cells are distinguished by multi-crystalline solar cells with efficiency up to 15.90% high output per square meter of module area. MSR delivers modules with positive tolerance from 0 - 4.99 watt. Only modules of the highest quality would be able to provide this level of reliability.

- Modules with high output quality
- Excellent performance due to outstanding low-light performance
- Withstand high wind pressure and extreme temperature variations
- High transparent 3.2mm / 4mm low-iron tempered glass
- Unique technology ensures no water freezing and warping do no occur
- 25 years power output warranty (long life span)
- TUV Rheiland certified modules accordance to IEC 61215 ed. 2 2005, IEC 61730, Part 1, 2004 and IEC 61701 Salt mist corrosion testing of photovoltaic (PV) modules.

Mechanical Parameters

		MYS 60 cells	MYS 72 cells
Overall dimensions (frame)	L x W x T	1666mm x 997mm x 42mm	1984mm x 997mm x 42mm
Weight	Mass	19 +/-1	27 +/-1
Tested static back load (1 h)	Pressure	5'400	5'400
Tested static front load (1 h)	Pressure	5'400	5'400

General Electrical Parameter

Maximum system voltage	1,000V DC
Maximum series fuse	15A
Operating Temperature range	-40˚C to +85˚C
NOCT	46 +/- 2˚C

Components

Glass	Tempered 3.2mm / 4mm solar glass
Photovoltaic cells	60 / 72 mono-crystalline 6" silicon-cells (156mm x 156mm)
Frame	MSR Standard, Anodized or Black coated Aluminium
Junction box	IP 67.3 diode
Plug connector type / Cable length / cross section size (mm2)	MC4 compatible or Solarlok / 2 x 1000mm / 4mm2

Certificates, Safety Class and Warranty

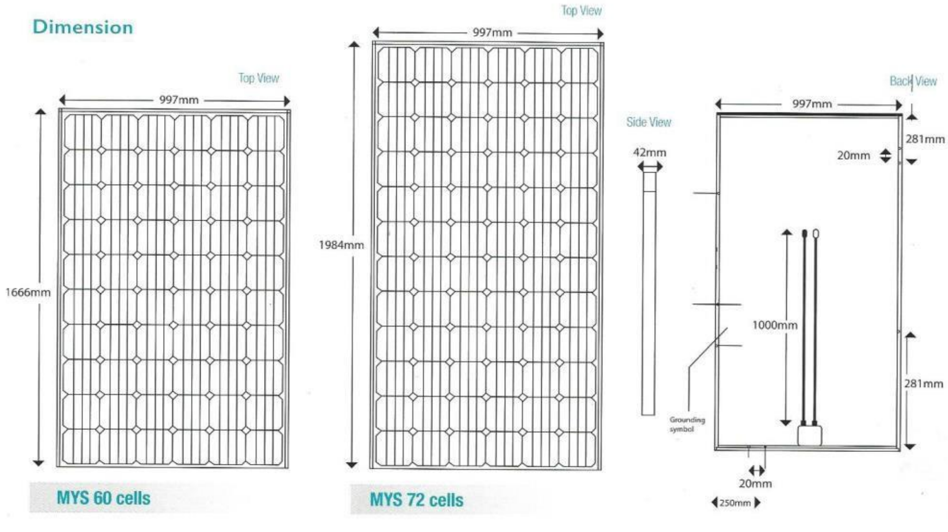
IEC 61215 ed.2	IEC 61215 ed. 2 = Registration No. PV60033123
IEC 61730	IEC 61730 = Registration No. PV60033124
IEC 61701	IEC 61701 = Registration No. PV60037080
CE certified	CE Compliance = SHEM010060074501TXC
Safety class	II
IP protection level	67
Warranty	10 years product warranty 10 years 90% nominal performance 25 years 80% nominal performance

Electrical Data at Standard Testing Conditions (STC) 1

1) Irradiance 1000 W/m2, module temperature 25°C, spectrum at air-mass AM 1.5

Model	CF-250	CF-255	CF-260	CF-300	CF-305	CF-310
Rated Maximum Power at STC (W) Pmax	250	255	260	300	305	310
Maximum Power Voltage (Vmp/V)	30.13	30.33	30.67	36.55	36.75	36.95
Maximum Power Current (Imp/A)	8.30	8.41	8.48	8.21	8.3	8.39
Open circuit voltage (Voc/V)	37.63	37.8	37.96	45.21	45.38	45.46
Short circuit current (Isc/A)	8.88	8.96	9.01	8.71	8.80	8.86
Temperature Coefficient of Pmax (γPmp)	-0.4112% / °C					
Temperature Coefficient of Voc (βVoc)	-0.3137% / °C					
Temperature Coefficient of Isc (αIsc)	+0.0427% / °C					
	MYS 60 cells			MYS 72 cells		

Dimension



APPENDIX B: Arduino Data Logger Code

```
#include <SD.h>
#include <Wire.h>
#include "RTClib.h"
#include <SPI.h>
#include <OneWire.h>
#include <DallasTemperature.h>

//DHT22
#include "DHT.h"
#define DHTPIN 2     // what pin we're connected to
#define DHTTYPE DHT22   // DHT 22 (AM2302)
DHT dht(DHTPIN, DHTTYPE);
//

//DS18B20
#define ONE_WIRE_BUS_1 22
#define ONE_WIRE_BUS_2 24
#define ONE_WIRE_BUS_3 26
#define ONE_WIRE_BUS_4 28
#define ONE_WIRE_BUS_5 30
#define ONE_WIRE_BUS_6 32
#define ONE_WIRE_BUS_7 34
#define ONE_WIRE_BUS_8 36
#define ONE_WIRE_BUS_9 38

OneWire oneWire_1(ONE_WIRE_BUS_1);
OneWire oneWire_2(ONE_WIRE_BUS_2);
OneWire oneWire_3(ONE_WIRE_BUS_3);
OneWire oneWire_4(ONE_WIRE_BUS_4);
OneWire oneWire_5(ONE_WIRE_BUS_5);
OneWire oneWire_6(ONE_WIRE_BUS_6);
OneWire oneWire_7(ONE_WIRE_BUS_7);
OneWire oneWire_8(ONE_WIRE_BUS_8);
OneWire oneWire_9(ONE_WIRE_BUS_9);

DallasTemperature sensors_1(&oneWire_1);
DallasTemperature sensors_2(&oneWire_2);
DallasTemperature sensors_3(&oneWire_3);
DallasTemperature sensors_4(&oneWire_4);
DallasTemperature sensors_5(&oneWire_5);
DallasTemperature sensors_6(&oneWire_6);
DallasTemperature sensors_7(&oneWire_7);
DallasTemperature sensors_8(&oneWire_8);
DallasTemperature sensors_9(&oneWire_9);

// A simple data logger for the Arduino analog pins

// how many milliseconds between grabbing data and logging it. 1000 ms is once a second
#define LOG_INTERVAL 1000 // mills between entries (reduce to take more/faster data)

// how many milliseconds before writing the logged data permanently to disk
```

```
// set it to the LOG_INTERVAL to write each time (safest)
// set it to 10*LOG_INTERVAL to write all data every 10 datareads, you could lose up to
// the last 10 reads if power is lost but it uses less power and is much faster!
#define SYNC_INTERVAL 1000 // mills between calls to flush() - to write data to the card
uint32_t syncTime = 0; // time of last sync()

#define ECHO_TO_SERIAL   1 // echo data to serial port
#define WAIT_TO_START    0 // Wait for serial input in setup()

// the digital pins that connect to the LEDs
#define redLEDpin 2
#define greenLEDpin 3

// The analog pins that connect to the sensors
//#define photocellPin 0           // analog 0
//#define tempPin 1                // analog 1
//#define BANDGAPREF 14            // special indicator that we want to measure the bandgap

//#define aref_voltage 3.3         // we tie 3.3V to ARef and measure it with a multimeter!
//#define bandgap_voltage 1.1      // this is not super guaranteed but its not -too- off

RTC_DS1307 RTC; // define the Real Time Clock object

// for the data logging shield, we use digital pin 10 for the SD cs line
const int chipSelect = 10;

// the logging file
File logfile;

void error(char *str)
{
  Serial.print("error: ");
  Serial.println(str);

  // red LED indicates error
  digitalWrite(redLEDpin, HIGH);

  while(1);
}

void setup(void)
{
  Serial.begin(9600);
  Serial.println();
  dht.begin();
  // use debugging LEDs
  pinMode(redLEDpin, OUTPUT);
  pinMode(greenLEDpin, OUTPUT);

#if WAIT_TO_START
  Serial.println("Type any character to start");
  while (!Serial.available());
#endif //WAIT_TO_START

  // initialize the SD card
  Serial.print("Initializing SD card...");
  // make sure that the default chip select pin is set to
  // output, even if you don't use it:
  pinMode(10, OUTPUT);
```

```
  // see if the card is present and can be initialized:
  if (!SD.begin(53, 51, 50, 52)) {
    error("Card failed, or not present");
  }
  Serial.println("card initialized.");

  // create a new file
  char filename[] = "LOGGER00.CSV";
  for (uint8_t i = 0; i < 100; i++) {
    filename[6] = i/10 + '0';
    filename[7] = i%10 + '0';
    if (! SD.exists(filename)) {
      // only open a new file if it doesn't exist
      logfile = SD.open(filename, FILE_WRITE);
      break;  // leave the loop!
    }
  }

  if (! logfile) {
    error("couldnt create file");
  }

  Serial.print("Logging to: ");
  Serial.println(filename);

  // connect to RTC
  Wire.begin();
  if (!RTC.begin()) {
    logfile.println("RTC failed");
#if ECHO_TO_SERIAL
    Serial.println("RTC failed");
#endif  //ECHO_TO_SERIAL
  }


  logfile.println("Millis,  Stamp,      Date         Time,  Humidity,DHT22, Temp 1,Temp 2,Temp 3,Temp
4,Temp 5,Temp 6,Temp 7,Temp 8,Temp 9");
#if ECHO_TO_SERIAL
  Serial.println ("Millis,  Stamp,      Date         Time,  Humidity,DHT22, Temp 1,Temp 2,Temp 3,Temp
4,Temp 5,Temp 6,Temp 7,Temp 8,Temp 9");
#endif //ECHO_TO_SERIAL

  sensors_1.begin();
  sensors_2.begin();
  sensors_3.begin();
  sensors_4.begin();
  sensors_5.begin();
  sensors_6.begin();
  sensors_7.begin();
  sensors_8.begin();
  sensors_9.begin();
}

void loop(void)
{
  DateTime now;

  // delay for the amount of time we want between readings
  delay((LOG_INTERVAL -1) - (millis() % LOG_INTERVAL));
```

```
  digitalWrite(greenLEDpin, HIGH);

  // log milliseconds since starting
  uint32_t m = millis();
  logfile.print(m);           // milliseconds since start
  logfile.print(", ");
#if ECHO_TO_SERIAL
  Serial.print(m);         // milliseconds since start
  Serial.print(", ");
#endif

  // fetch the time
  now = RTC.now();
  // log time
  logfile.print(now.unixtime()); // seconds since 1/1/1970
  logfile.print(", ");
  logfile.print("");
  logfile.print(now.year(), DEC);
  logfile.print("/");
  logfile.print(now.month(), DEC);
  logfile.print("/");
  logfile.print(now.day(), DEC);
  logfile.print(" ");
  logfile.print(now.hour(), DEC);
  logfile.print(":");
  logfile.print(now.minute(), DEC);
  logfile.print(":");
  logfile.print(now.second(), DEC);
  logfile.print("");
#if ECHO_TO_SERIAL
  Serial.print(now.unixtime()); // seconds since 1/1/1970
  Serial.print(", ");
  Serial.print("");
  Serial.print(now.year(), DEC);
  Serial.print("/");
  Serial.print(now.month(), DEC);
  Serial.print("/");
  Serial.print(now.day(), DEC);
  Serial.print(" ");
  Serial.print(now.hour(), DEC);
  Serial.print(":");
  Serial.print(now.minute(), DEC);
  Serial.print(":");
  Serial.print(now.second(), DEC);
  Serial.print("");
#endif //ECHO_TO_SERIAL

//DHT22
  float h = dht.readHumidity();
  // Read temperature as Celsius
  float t = dht.readTemperature();
  // Read temperature as Fahrenheit
  float f = dht.readTemperature(true);

    // Check if any reads failed and exit early (to try again).
  if (isnan(h) || isnan(t) || isnan(f)) {
    Serial.println("Failed to read from DHT sensor!");
  }

  sensors_1.requestTemperatures(); // Send the command to get temperatures
```

```
  sensors_2.requestTemperatures();
  sensors_3.requestTemperatures();
  sensors_4.requestTemperatures();
  sensors_5.requestTemperatures();
  sensors_6.requestTemperatures();
  sensors_7.requestTemperatures();
  sensors_8.requestTemperatures();
  sensors_9.requestTemperatures();

  logfile.print(", ");
  logfile.print(h);
  logfile.print(", ");
  logfile.print(t);
  logfile.print(", ");
  logfile.print(sensors_1.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_2.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_3.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_4.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_5.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_6.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_7.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_8.getTempCByIndex(0));
  logfile.print(", ");
  logfile.print(sensors_9.getTempCByIndex(0));

  #if ECHO_TO_SERIAL
  Serial.print(", ");
  Serial.print(h);
  Serial.print(", ");
  Serial.print(t);
  Serial.print(", ");
  Serial.print(sensors_1.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_2.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_3.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_4.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_5.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_6.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_7.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_8.getTempCByIndex(0));
  Serial.print(", ");
  Serial.print(sensors_9.getTempCByIndex(0));

  #endif //ECHO_TO_SERIAL

  logfile.println();
#if ECHO_TO_SERIAL
```

```
  Serial.println();
#endif // ECHO_TO_SERIAL

  digitalWrite(greenLEDpin, LOW);

  // Now we write data to disk! Don't sync too often - requires 2048 bytes of I/O to SD card
  // which uses a bunch of power and takes time
  if ((millis() - syncTime) < SYNC_INTERVAL) return;
  syncTime = millis();

  // blink LED to show we are syncing data to the card & updating FAT!
  digitalWrite(redLEDpin, HIGH);
  logfile.flush();
  digitalWrite(redLEDpin, LOW);

}
```