# 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 Engineering**

**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 **"TITLE TO BE THE SAME AS FRONT COVER, CAPITAL LETTER, BOLD"** was prepared by **STUDENT'S NAME** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical & Electronic Engineering at Universiti Tunku Abdul Rahman.

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Date : August 29, 2016

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## ABSTRACT

The efficiency of photovoltaic system mainly based on solar irradiance, the higher solar irradiance, the more power generated by solar panel. However, the temperature effect on solar panel causes the performance of photovoltaic system decreases. To solve this issue, few cooling factors had been implemented to sustain the temperature of solar panel. In this final year project , there are two cooling factors had been used which are natural convection method and water dripping method. Natural convection method was carried out by adjusting the tilting angle of solar panel and the band gap between the solar panel and metal deck. While, water dripping system was carried out at the same moment for high expectation in getting better performance compare with just only natural convection method. With combination of different tilting angle and band gap, different cooling effect was given and these results had been shown in discussion. In overall, solar panel with 10° tilting angle and 10cm band gap has highest generated current and best cooling effect. Besides, the comparison between both cooling method was carried out for study purpose and solar panel with water dripping system had high performance compare to solar panel with natural convection only. However, water dripping system has high capital cost compare to natural convection method due to installment of water circulation system. Therefore, the further study and research on water circulation system will reduce the cost of whole system to a minimum amount.

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# LIST OF SYMBOLS / ABBREVIATIONS

| | |
|---|---|
| $V_{oc}$ | open circuit voltage, V |
| $I_{sc}$ | short circuit current, I |
| $\beta$ | temperature coefficient |
| $\eta_e$ | photoelectric conversion efficiency |
| $P_{max}$ | maximum output power, W |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

To achieve vision 2020, growth of energy demand has become necessity. According data given from Malaysia Energy Statistics Handbook 2015, energy consumption is dramatically increasing and predicted the rate of energy consumption will keeps on growing in high rate of ratio. Hence, fossil fuels has become the main energy source. As data shown, fossil fuels is 95% or above of all energy source including renewable energy like solar, hydro, geothermal and more. However, burning fossil fuels brings heavy air pollution especially carbon dioxide and carbon monoxide gases produced while burning. Those gases are green house gases (GHG) which bring global warming or green house effect to earth surface. This will causes harmful impact to earth like sea water level increase due to melting ice at north pole.

Thus, solar energy shall takes place instead of taking non renewable energy source.Furthermore, Malaysia is located at equator where having full sun light along the years. In other words, Malaysia is a country that has huge solar irradiance and it can used as main energy income to replace non renewable energy sources. Due to this, solar energy should be develop to take parts as a character of energy supply.

When solar panel expose to full sun light with zero cosine effect , it having highest efficiency of output voltage. However, due to tremendous increasing of temperature during solar noon time, it affects the performance of solar panel. The more temperature for solar panel increase, the worst performance on solar panel power generating. To improve the efficiency of output voltage for solar panel, the ambient temperature surrounding the solar panel should be as lower as possible. This will reduces the chance of solar panel being heat up and enhance the efficiency of output voltage. Besides, some natural cooling system can be carry out to lower down the temperature of solar panel. For example, increase gap between solar panel and roof, install water sprinkler around solar panel, choose roof material with high rate of nature convection and more. These methods will help solar panel synchronize with the ambient temperature, so it can perform in high efficiency condition.

In this final year project, optimization of rooftop power plant has been carry out to figure out the best performance for solar panel by investigation or reference from journal and books. Thus, natural convection had been used for natural cooling effect by adjusting the tilting angle of solar panel and the band gap between solar panel and metal deck. In addition, water dripping also added to the experiment to observe the cooling effect on solar panel and its performance in current generating. Each of the experiments was design to have constant water flow rate and ignore the cost of water used. The results were shown in discussion part.

## 1.2 Aims and Objectives

1. To study the cooling factors that affect the temperature of solar PV module under local climate.
2. To analyse the temperature performance of solar PV module installed on a rooftop under various factors.
3. To propose an experiment set up configuration of solar PV module on a rooftop that have best temperature performance.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Solar Cell

Solar cell also known as photovoltaic cell (PV), which “photo” imply as sunlight while “voltaic” means electricity. Overall, solar cell is a device for converting sunlight to electricity by using working principle of photodiode or photovoltaic effect. The whole solar system normally consists of photovoltaic cell, batteries for storage energy, inverters and interconnection wires. The performance of solar cell normally judged by the amount of sunlight hit on solar panel. The more sunlight hit on photovoltaic cell, the more electricity power generate.

## 2.2 Photodiode Working Principle

Solar cell also known as large-area semiconductor diode which operates in reverse bias mode. It consists of a p-n junction, n-region and p-region. P-n junction normally created by an impurity addition into the semiconductor crystal and these impurities are phosphorus atoms which have five free electrons. These five free electrons will form covalent bonding with silicon. In other words, these five free electrons will fit in the four holes in silicon crystal structure and left one free and mobile electrons. Due to these free electrons, n-region has been created and it also named as majority charge carries. While for p-region, high concentration of holes, this region basically created when doping the silicon crystal with boron atoms, which only have three free electrons and one more hole is left. This causes p-region is in high concentration of positive charges. Hence, it also called as minority charge carries.

Photodiode normally operate under reverse bias due to the depletion region inside photodiode. This depletion region will separate the electrons and holes being contact. Until there is a photon energy with 1.1eV or higher hit on it, electron-hole pairs are created. Electrons will flow to cathode region and holes will be attracted by majority charge region ( anode ), thereby photocurrent generated. The intensity of photon energy absorption depends on the energy of photon contain. The lower energy in photon, the deeper absorption, which means red color light will be absorb more by solar cell compare with yellow color light since yellow light has more photon energy than red light.

## 2.3 Main Factors Affecting Performance of Solar Cell

Temperature and shading are the main factors which will downgrade the performance of photovoltaic cell. Besides, the tilting angle of solar panel also important due to cosine effect.

### 2.3.1 Impact to Efficiency of Solar Panel in High Temperature

Energy generation efficiency is the most important parameter to solar panel which represents the performance of photovoltaic cell. There are few factors will affect the efficiency of solar panel. However, the most factor is mounting of temperature. When sunlight shine on solar panel, it gives photon energy to solar cell and generate electrical energy. At the same moment, sunlight also provide heat energy to solar panel which cannot be convert to electrical energy. This heat energy will energies the electrons inside the solar cell and causes the band gap of semiconductor become lower. In other words, electrons just need small amount of energy to cross over the depletion region and makes open circuit voltage become lower. This affects the efficiency of solar panel and the maximum power point since the area for $I_{mp}$ and $V_{mp}$ decrease.

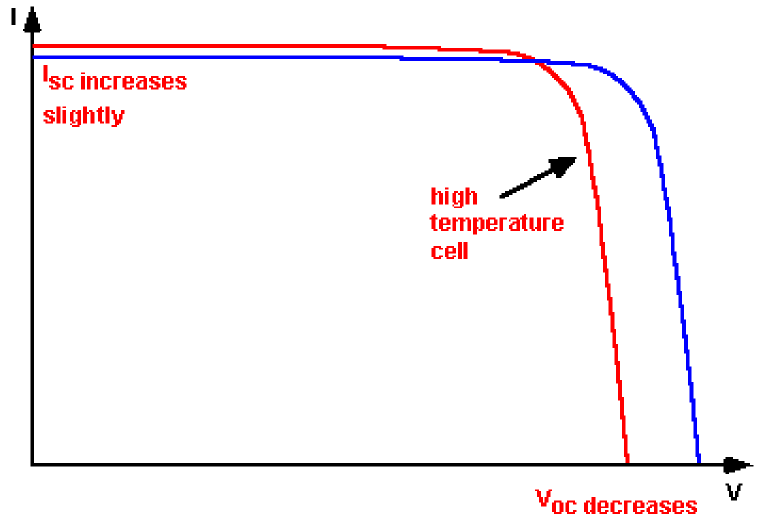


**Figure 2.1: Electrical Characteristic of Solar Panel in High Temperature**

Besides, this phenomena also can be explain by equation which shown as follow :

$$V_{oc2} = V_{oc1}\left[1 + \beta\left(T_2 - T_1\right)\right]$$

$V_{oc2}$ is open circuit voltage in currently temperature ($T_2$), while $V_{oc1}$ is open circuit voltage in 25°C ($T_1$) which also can known as the highest open circuit voltage since solar panel is surrounding with the lowest temperature. $T_2$ is the currently temperature on solar panel while $T_1$ is set to 25°C as room temperature. β is temperature coefficient of solar panel. With different type of solar panel, they will contain different temperature coefficient. For example, monocrystalline and polycrystalline solar panel are having within - 0.44% to -0.50% while for Sanyo HIT hybrid cells and bifacial cells are having lower temperature coefficient of -0.34% compare to monocrystalline and polycrystalline. This gives the most efficiency since more sunlight was absorbed by solar panel when it having lower temperature coefficient.

For non-ideal case, maximum power for solar panel is shown as below :

$$P_{\max} = FF \times I_{sc} \times V_{oc}$$

FF is the fill factor of solar panel which can calculated by using ratio of actual power output ( $V_{mp}$ . $I_{mp}$ ) and ideal power output ( $V_{oc}$ . $I_{sc}$ ). For common solar panel, fill factor is within 70% to 80%. The lower value for fill factor, the lower maximum power output will obtain.

In conclusion, the temperature of solar panel will have greatly impact to maximum power output or efficiency of solar panel.

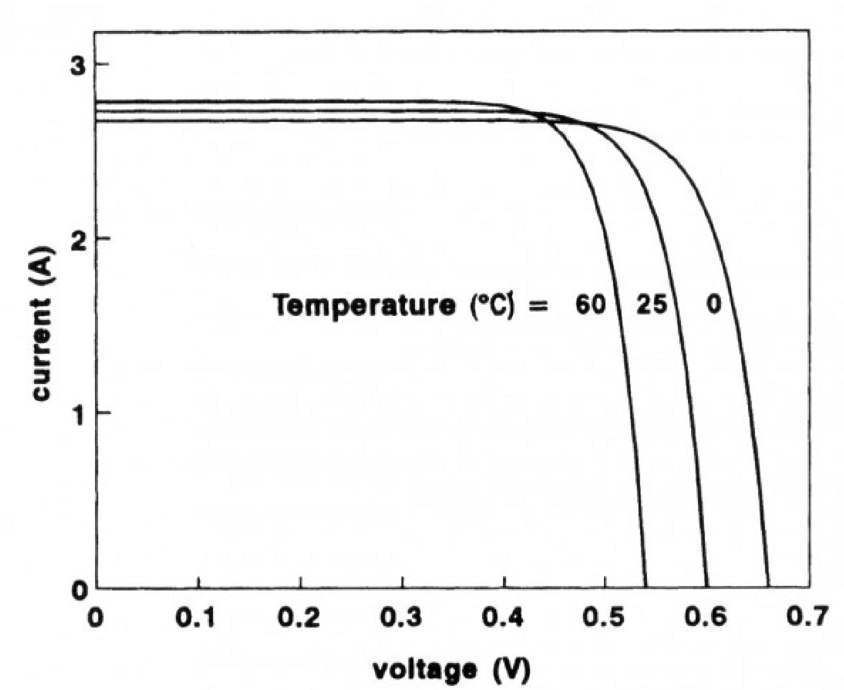


**Figure 2.2: Electrical Characteristic at Different Temperature**

## 2.4 Tilted Angle Effect on Solar Panel

The way of installation for solar panel will affect the efficiency of solar panel, especially the tilted angle between solar panel and roof or metal deck. When higher value of tilted angle has been choose, the more cosine effect we get. Thus, a suitable and reasonable tilted angle should be selected to achieve greatest performance. Due to data obtained, 10° tilted angle had proved good ventilation and less cosine effect.

### 2.4.1 Cosine Effect

The rate of absorption for solar energy mostly depends on the cosine effect. When the surface of solar panel and solar irradiance form 90° (normal) to each others, solar panel will has full sunlight condition. This can be proved by using formula below:

$$G_{oh} = G_o \cos\theta_z$$

where $G_{oh}$ is solar irradiance falling on solar panel, $G_o$ is extraterrestrial radiation and $\theta_z$ is zenith angle. When solar panel is perpendicular to sunlight, zenith angle will become 0°, then solar irradiance falling on solar panel will equal to solar irradiance from sun. Thus, loss on solar irradiance will be minimize approximately zero.

In addition, cosine effect also proved by the following formula :

$$\cos\theta = \frac{V_{oc} \times I_{sc}}{V_{oc}^{'} \times I_{sc}^{'}}$$

where $\theta$ is tilted angle. Solar panel will has highest maximum power when $\theta$ = 0°. While slowly increase tilted angle, the maximum power will linearly decrease due to the cos effect. Hence, solar panel will has zero power output when the tilted angle is 90°.

To achieve long term of maximum power output, a sun-tracking is an necessity to solar system. This will ensure solar panel has zero cosine effect.

## 2.5 Type of Roof Materials

There are two common types of roof materials been used in Malaysia which are roof tiles and metal deck. Roof tiles are common for residential area while metal decks are frequently used in factory area.

### 2.5.1 Roof Tiles

The most common roof materials in Malaysia for residential area. It has high heat absorption when expose to sunlight and heat energy will easily penetrate though. Hence, solar panel will have lower temperature since there are no reflection of heat for roof tiles. Besides, the rate of heat absorption for roof tiles can be improve by choosing a darker color roof tiles. This will increase the efficiency of heat absorption since the darker color the more heat can be absorb. Orange color is the most common color for roof tiles in Malaysia.

**Figure 2.3: Roof Tiles**

### 2.5.2 Metal deck

High reflectance is one of the characteristic for metal deck. Due to its high reflectance, it can reflect the most heat energy from sunlight and keep maintains the coolest temperature compare to others roof materials. However, this gives some heat impact to solar panel. When sunlight expose to metal deck, heat energy is reflected and being absorbed by solar panel which dramatically raise up the temperature of solar panel and lower down the efficiency. Metal decks are commonly used as roof for factories.

**Figure 2.4: Metal Deck**

## 2.6 Ventilation Effect

Solar panel with good ventilation effect will having higher efficiency due to less heat energy store inside solar panel. To carry out ventilation effect, the gap between solar panel and roof need to be study. The ventilation efficiency can be calculated by using photoelectric conversion efficiency as below:

$$\eta_e = \frac{P}{A_t P_{in}}$$

Where P is output power of solar panel (W), $A_t$ is total surface area of solar module, $P_{in}$ is the solar radiation intensity.

### 2.6.1 Effect of Gap between Solar Panel and Roof

The purpose to set a gap between solar panel and roof is to ensure nature wind can pass through and cool down PV module. In other words, the function of gap is to increase the ventilation effect. Hence, by using natural convection, PV module can be cool down with more effective. The more gap between PV module and roof, the higher open circuit voltage. However, when the gap is too large, it raise up wind load effect which will cause solar panel being pull off from the rooftop when strong wind blowing.

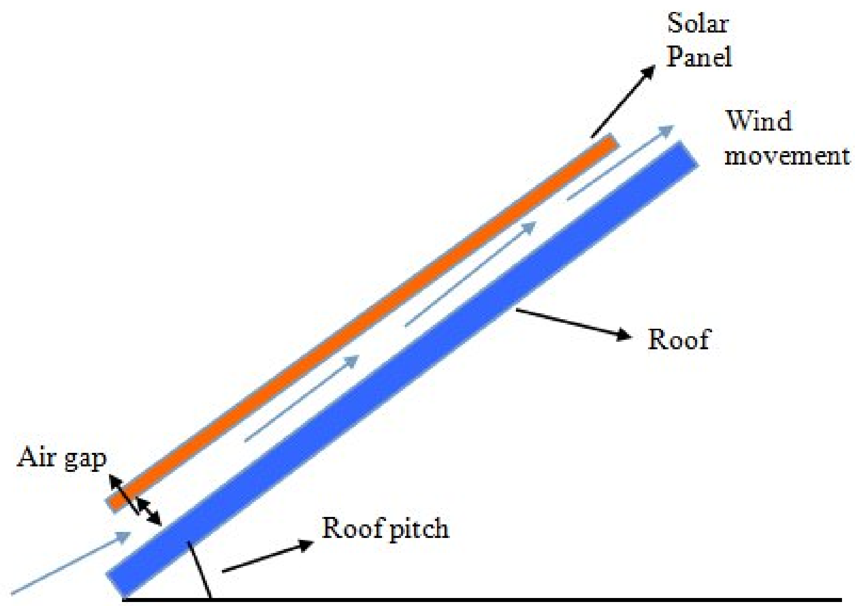


**Figure 2.5: Ventilation Effect between Gap and Roof**

## 2.7 Optimization

Optimization is a procedure or methodology that making something in fully perfect condition or in highest efficiency. To obtain higher efficiency of solar system, few factors had been considered and studied. This is to ensure that PV module can carry out full potential or efficiency when each of the factors had been maximized performance. In this final year project, optimization has been carry out to give the highest performance for cooling down the temperature of PV module or sustain the temperature as ambient temperature. To do so, two main factors have been consider which are the choice of roof material and the gap between PV module and roof. There two choices for roof materials which are metal decks and roof tiles while the gap is been fixed as 20cm.

## 2.8 Related Journal

1. The Effect of Temperature on Mono-crystalline Solar PV-panel ( N.H.Zaini 2015)
In this journal, they find out different locations in Malaysia will have different temperature effect. The cooler the temperature, the higher performance of solar panel.

2. Effect of Temperature on a Poly-Crystalline Solar Panel in Large Scale Solar Plants in Malaysia ( N.I.Ahmad )
Temperature effect of poly-crystalline solar panel has higher impact than mono-crystalline solar panel by doing comparison data between two journals.

3. Simulation and Analysis on Heat Transfer and Pre-cooling Characteristic of New Solar Power Vehicle Parking Ventilation System. ( Du YingMeng )
To have cooler temperature, the wind flow rate should be high to ensure the heat exchange is more faster. Besides, the different between ambient temperature and cell temperature is the main key to perform high rate of heat exchange. The more differences between two side of temperature, the more heat exchange rate. In other words, the higher ventilation effect obtain.

4. The Evaluation of Cooling of Solar Panels On-Demand to Increase Power Output and Revenue.
The evaporative cooling system will bring 10% to 12% of efficiency to solar panel but it increase the cooling demand by $0.09 to $0.25.

5. Performance Comparison of Modular Photovoltaic-Thermal Solar Panel ( Nicole C.Annis )
In this journal, the cooling factors of solar panel basically focus on the materials used, flow rate of wind and the way to set the solar panel. The thermal analysis are made based on these factors.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overall Procedure for Final Year Project

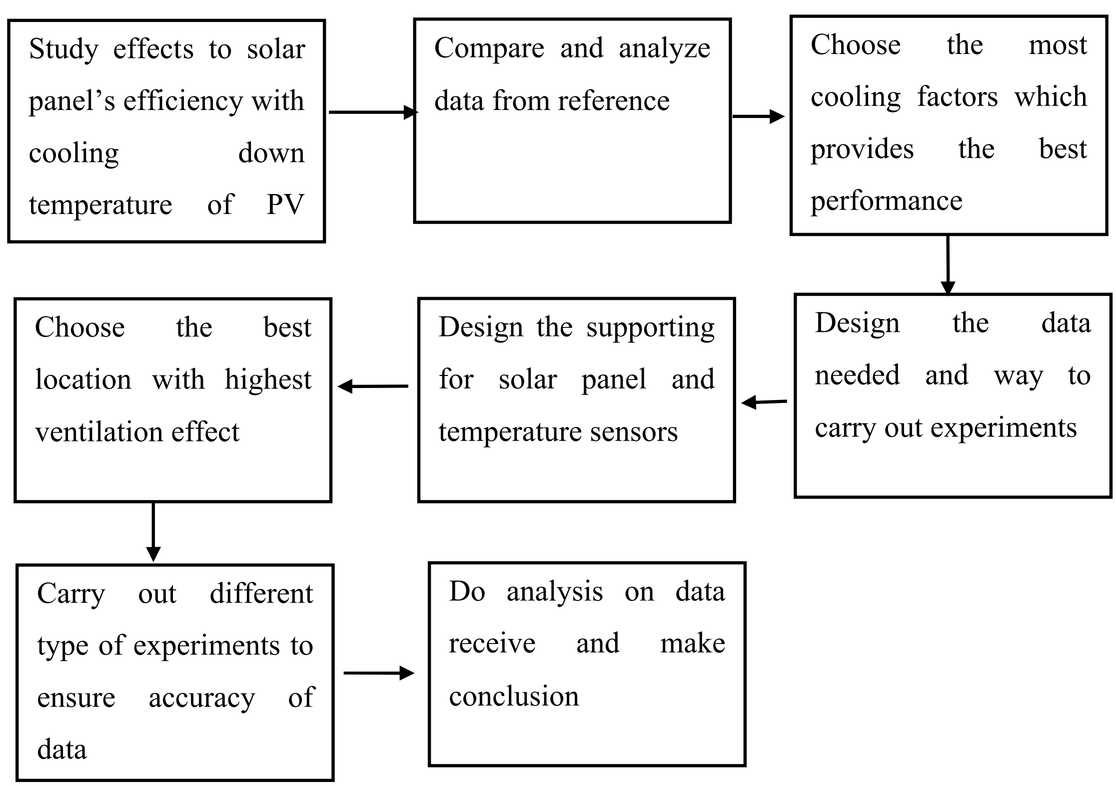


**Figure 3.1.1 Overall Procedure for Final Year Project**

In this final year project, the first step is to study the importance of temperature against the performance of solar panel. Again, we figure out the higher raise for temperature, the poor performance we have for power generated by solar panel. Thus, few factors have been consider which are the air gap between roof and PV module, tilted angle and the type of roof materials.

The factor of air gap basically is affecting the ventilation performance of solar panel. The more air gap between PV module and roof, the higher the efficiency for solar panel. However, when longer air gap has been used, the higher wind loading effect which will causes PV module blow out of the roof by wind. While for tilted angle, it is duel with the cosine effect which justified the rate of solar irradiance absorption. The more tilted angle, the less sunlight will be expose to solar panel.

There are two common types of roof materials will been used in Malaysia which are roof tiles and metal decks. By doing researching, we conclude that metal decks provide more heat to PV module due to its high rate of reflection for heat energy. While roof tiles have good heat absorption which will transfer heat to inner direction and keep solar panel maintains in cooler temperature.

After the study of those factors, optimization work has been carry on by comparing and analyzing data from reference given.

## 3.2 Data Analyse and Compare

The investigation of performance for PV module by using different roof materials had been done in comprehensive way. There are few more experiments carried out like average cell temperature versus ambient temperature for 0° tilting angle, open circuit voltage versus time with 0° tilting angle different roof materials, open circuit voltage versus solar irradiance with 0° tilting angle and different roof materials and more. Overall, from those experiment's data, a conclusion has been made as solar panel has the greatest power loss from metal deck compare to roof tiles.

**Table 1 Overall experiments for optimization rooftop performance**

| | 0° | 9° | 18° |
|---|---|---|---|
| Metal decks | Open circuit voltage Power loss, Cell temperature, | Open circuit voltage Power loss, Cell temperature, | Open circuit voltage Power loss, Cell temperature, |
| Concrete Tiles | Open circuit voltage Power loss, Cell temperature, | Open circuit voltage Power loss, Cell temperature, | Open circuit voltage Power loss, Cell temperature, |
| Concrete floor | Open circuit voltage Power loss, Cell temperature, | Open circuit voltage Power loss, Cell temperature, | Open circuit voltage Power loss, Cell temperature, |

Ventilation effect was applied to solar panel by leaving a gap between solar cell and roof. By referring tables above, we can conclude that when more gap and titled angle between roof and solar cell, the more efficiency on ventilation effect. However, there are no details by showing how much power been generated when higher tilted angle used. As cosine effect showed, when higher titled angle been chosen, the higher cosine effect which gives conflict to open circuit voltage, $V_{oc.}$. Thus, few experiments has been plan to carry out before optimization.

### 3.2.1 Selection of Roof Material

By analyze and compare data above, roof tiles is the best choice to increase the efficiency of PV module due to its good heat absorption. However, to achieve the goal for optimization, metal deck is chosen as roof material. This is because industrial area will have higher energy demand compare to residential area. Thus, it shows higher marketing chances.

### 3.2.2 Selection of Gap and Tilted Angle

Based on data, the efficiency for ventilation effect will get better when more gap between solar panel and roof. Thus, the gap between PV module and roof has been fixed to 20cm. While 10° of tilted angle has been chosen, to prevent accumulation of water and perform good ventilation effect. Besides, 10° of tilted angle do not provide high cosine effect since cos 10° will equal to 0.98 which approximately equal to 1.

### 3.3 Experiment Design

**Figure 6 Experiment Set Up**

Figure 6 shows the overall experiment set up. There are two solar panels was set up with water dripping system by attaching a pipe at the top of the solar panel. Then, water was allowed to flow to the surface of solar panels for achieving cooling effect. On the right hand side, the solar panel was set to 10° tilting angle and 10cm band gap, while on the left side, the solar panel was set to different tilting angle and band gap like 20° tilting angle and 5cm band gap or 10° tilting angle and 5cm band gap. Both solar panels will have same flow rate of water and comparison on performance between both solar panels will be made.

### 3.3.1 Experiment Procedure

1. The experiment is set up like the Figure 3.2.

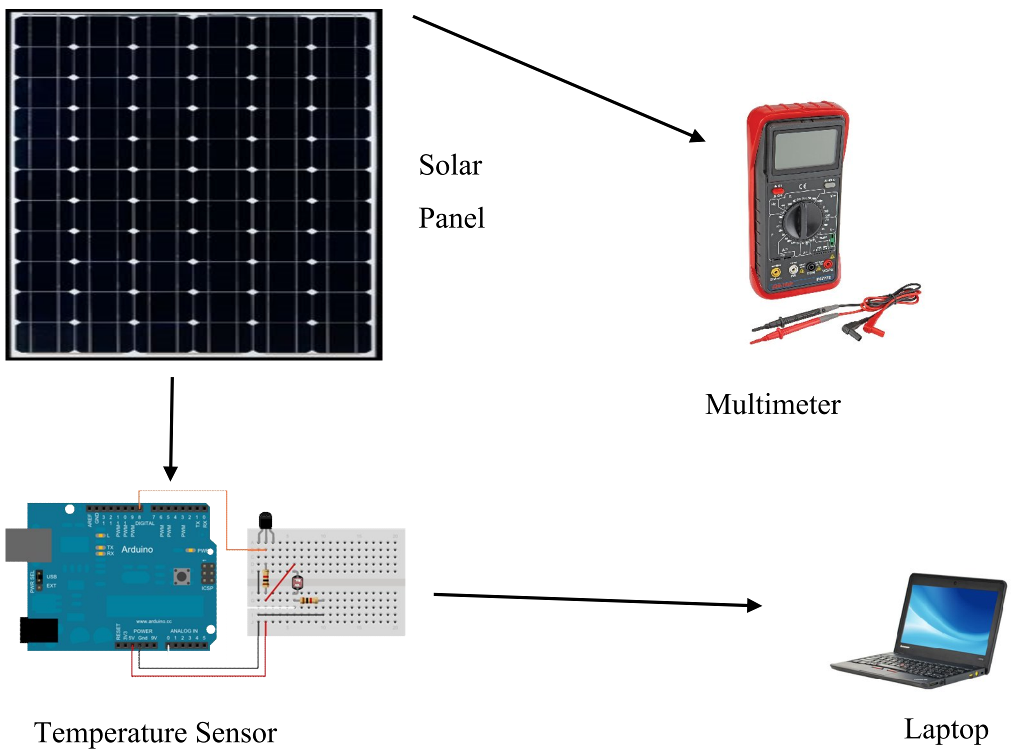


**Figure 3.2: Experiment Setup**

2. The gap between roof and solar panel is set to 20 cm while tilted angle is set to 10°. Metal deck is used as roof material.

3. The open circuit voltage and short circuit current will be collected by the multimeter manually. The time taken for multimter is set to 5 minutes. Hence, the data will be taken by every to 5 minutes. While the time setting for temperature sensor is set to 5 minutes. This is to improve the accuracy of rate of change of cell temperature.

4. Pyranometer is used as solar irradiance measurement.

5. Step 2 to step 3 are repeated for 2 or 3 days to ensure the accuracy of data.

6. Step 2 to step 5 are repeated by carrying out different combination of gap and tilted angle like table 3.7.

## 3.4 Experiment Apparatus and Equipment

1. Anemometer
2. Data Logger
3. Temperature sensor
4. Pyranometer

### 3.4.1 Anemometer

Anemometer is a wind speed measurement device. In this experiment, it is used to estimate the wind speed at tall buildings. This can determine the ventilation effect to solar panel.


**Figure 3.7: Anemometer**

### 3.4.2 Multimeter

Multimeter is an electronic device for taking measurement on solar panel's voltage and current.

**Figure 3.8: Multimeter**

### 3.4.3 Temperature Sensor

To measure the temperature of solar cell, DHT 22 temperature sensor is used which has higher accuracy and most stable output data. This temperature sensor is attached to three different parts of solar cell which are top, middle and bottom of solar cell. Then, average cell temperature will be calculated.

**Figure 3.9: DHT 22**

### 3.4.4 Pyranometer

Pyranometer is a device that measure the solar irradiance when it expose to sunlight. In this experiment, solar irradiance profile is need to perform matches of data and weather. In other words, it shows the accuracy and reliance of those data collected.

**Figure 3.10: Pyranometer**

## 3.5 Data Collect

The following tables show the data will be collected in future.

**Table 2 Data collect by set 0° tilted angle and 0 cm, 10cm, 20cm gap**

| Metal Deck and 0° tilted angle | Open circuit Voltage, $V_{oc}$ | Short Circuit Current, $I_{sc}$ | Maximum Power Output, $P_{mp}$ | Photoelectric Conversion Efficiency, $\eta_e$ | Cell Temperature, °C |
|---|---|---|---|---|---|
| 0 cm gap | | | | | |
| 10 cm gap | | | | | |
| 20 cm gap | | | | | |

**Table 3 Data collect by set 10° tilted angle and 0 cm, 10cm, 20cm gap**

| Metal Deck and 10° tilted angle | Open circuit Voltage, $V_{oc}$ | Short Circuit Current, $I_{sc}$ | Maximum Power Output, $P_{mp}$ | Photoelectric Conversion Efficiency, $\eta_e$ | Cell Temperature, °C |
|---|---|---|---|---|---|
| 0 cm gap | | | | | |
| 10 cm gap | | | | | |
| 20 cm gap | | | | | |

**Table 4 Data collect by set 20° tilted angle and 0 cm, 10cm, 20cm gap**

| Metal Deck and 20° tilted angle | Open circuit Voltage, $V_{oc}$ | Short Circuit Current, $I_{sc}$ | Maximum Power Output, $P_{mp}$ | Photoelectric Conversion Efficiency,$\eta_e$ | Cell Temperature,° C |
|---|---|---|---|---|---|
| 0 cm gap | | | | | |
| 10 cm gap | | | | | |
| 20 cm gap | | | | | |

## 3.6 Gantt Chart

The Gantt Chart has been shown in Appendix A.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Collection and Analysis of Data

Regrading to the previous methodology, the briefly data will been taken are open circuit voltage, $V_{oc}$ , short circuit current, $I_{sc}$ , solar irradiance, ambient temperature, °C and cell temperature which divided into three parts, bottom, middle and top part of the back of PV module. For further analysis, these data will be perform in graph and table form.

## 4.2 Cell Temperature Data Analysis

To manifest the effect of cooling on PV module, cell temperature data are the most convincing evidence to proof it. In addition, more comparison between cell temperature also been made to perform the cooling effect.

The average cell temperature was calculated by using the formula below :

$$Average = \frac{TopTemperature + MidTemperature + BottomTemperature}{3}$$

### 4.2.1 Cell Temperature With Dripping Water vs Without Dripping Water

The following diagram shows the result of average cell temperature without water dripping for two solar panel with different tilting angle and same band gap

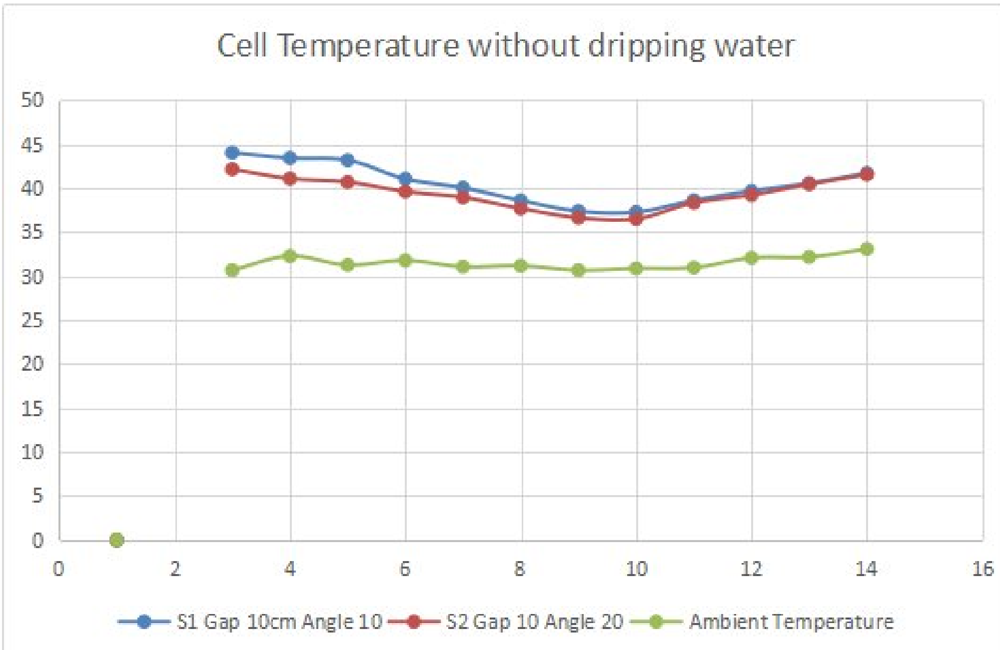


**Figure 4-1 Cell Temperature,°C without dripping water**

From figure 4.1, there are two solar panel were set in different tilting angle which are 10° and 20°. Obviously, when starting of the experiment, S1 has higher temperature than S2. This is due to the time exposure to sunlight for solar panel 1 is longer than solar panel 2. While, with the ambient temperature slowly increase, solar panel 1 starting to cool down at a fast rate and slowly synchronize with the cell temperature of solar panel 2. Then, when ambient start increase from point 12 to point 14, both solar panel also start rise up to the same cell temperature. After this, dripping water is add on for cool down purpose and study the effect of dripping water and wind ventilation at the same time.

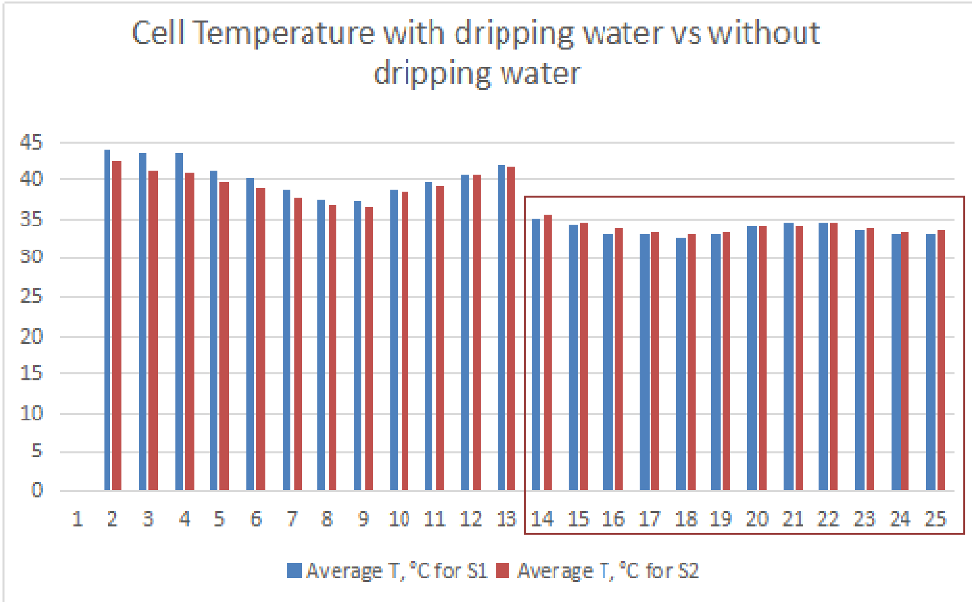


**Figure 4-2 Cell Temperature with dripping water vs without dripping water**

The bar chart above shows change of cell temperature of solar panel 1 and solar panel 2 with tilting angle 10° and 20° respectively. From the first bar to 13$^{th}$ bars, there are the average cell temperature for both solar panel without dripping water, while from 14$^{th}$ to 25$^{th}$ bars show the gradually decrease on temperature when dripping water was added to both solar panel. From the bar chart above, the cell temperature having a huge amount change, which around 6.4°C.

The experiment still going on for investigating the wind ventilation effect on different tilting angle and same band gap. The figure below shows the cell temperature for S1(band gap 10cm, tilting angle10°) and S2 (band gap 10cm, tilting angle 20°).

### 4.2.2 Cell Temperature Comparison with Different Tilting Angle and Same 10cm Gap

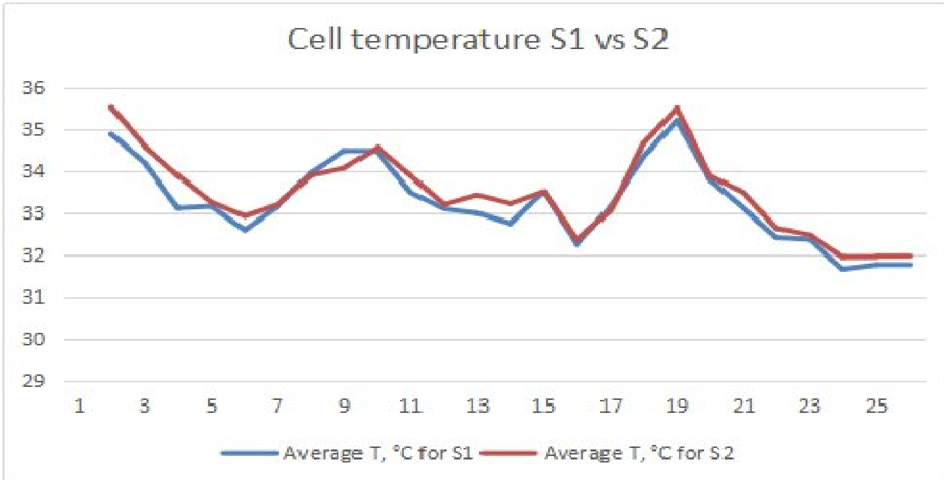


**Figure 4-3 Average Cell temperature S1 vs S2**

With further analysis from the data above, we found out that S1 with 10° tilting angle has more cooling effect than S2 with 20° tilting angle. At the x-axis point 9, the cell temperature S2 is lesser than S1, this will caused by the failure data logging for S2 cell temperature.

### 4.2.3 Cell Temperature Comparison with 10° Tilting Angle, 10 cm gap and 20° Tilting Angle, 5cm gap

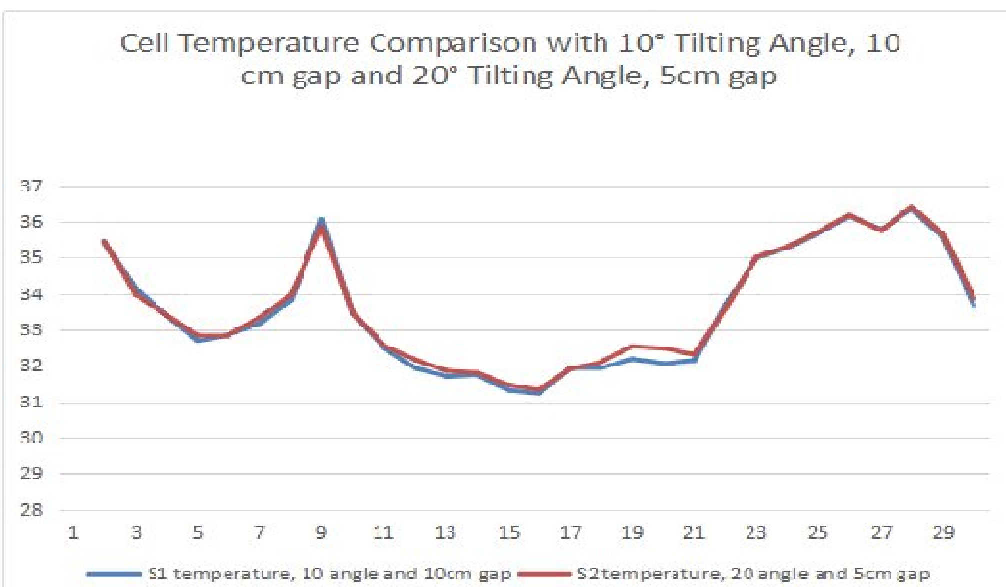


**Figure 4-4 Cell Temperature Comparison with 10° Tilting Angle, 10 cm gap and 20° Tilting Angle, 5cm gap**

From the figure above, solar panel 1 has better ventilation effect than solar panel 2. This is shown when cell temperature for S1 is around 32.50 °C which at the x-axis point 11,the cell temperature for S2 is higher than S1 until the cell temperature start to rise up to 34°C at x-axis point 21. This may caused by the trapped heat inside the 5cm band gap and it maintains the cell temperature around 32 °C which is slightly higher than S1's cell temperature.

### 4.2.4 Cell Temperature Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 5cm gap

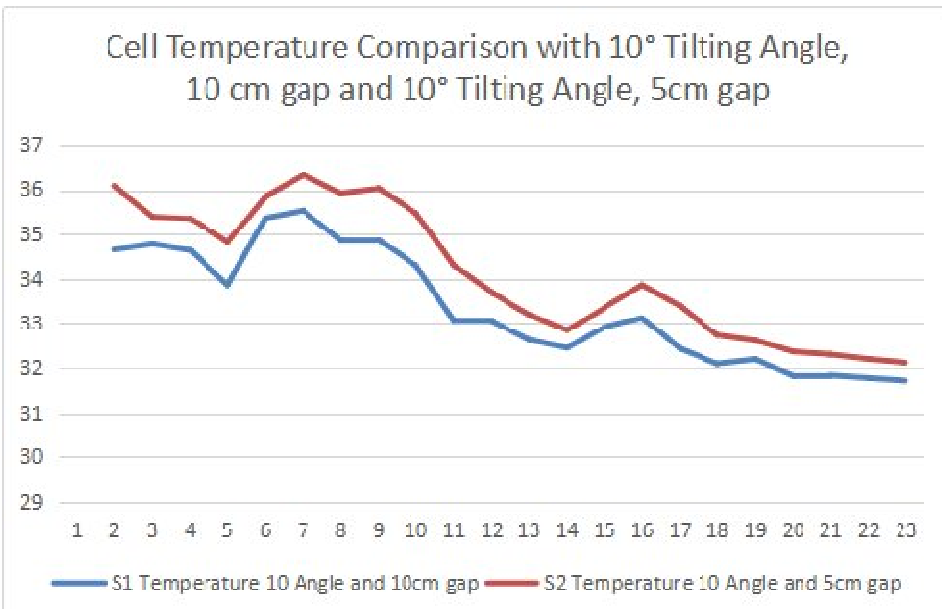


**Figure 4-5 Cell Temperature Comparison with 0° Tilting Angle, 10 cm gap and 10° Tilting Angle, 5cm gap**

Due to the poor ventilation for smaller band gap, the average cell temperature for S2 is much higher than S1. This also due to heat trapped between the gap and solar panel which causes average cell temperature keep maintain in higher rate compare to S1.

### 4.2.5 Cell Temperature Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 20cm gap

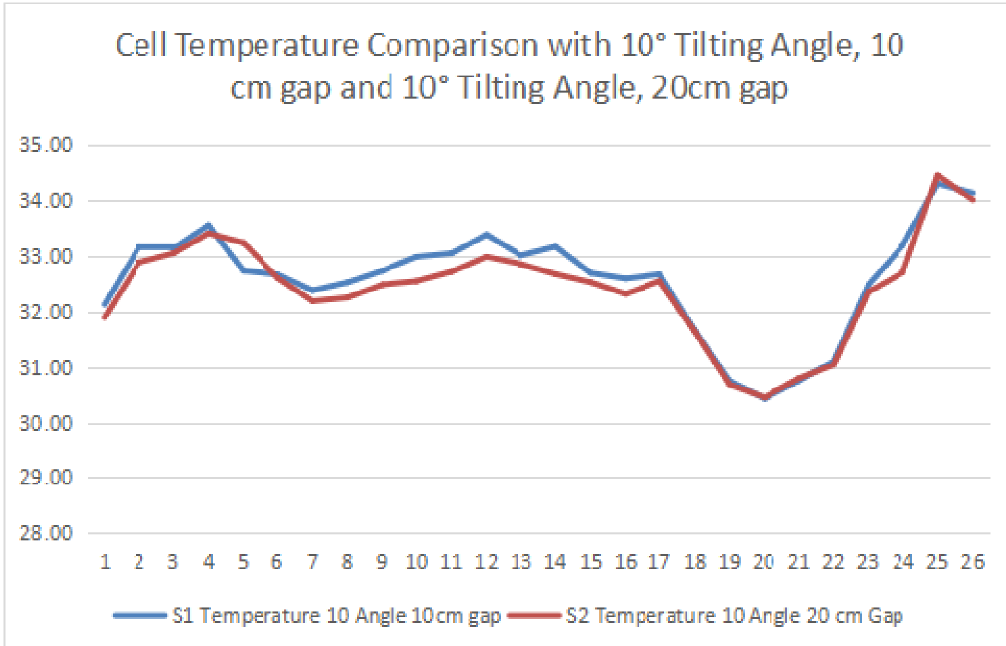


**Figure 4-6 Cell Temperature Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 20cm gap**

While band gap was set to 20cm, the cell temperature for S2 is perform better than S1 with only 10cm band gap. This means the ventilation effect of S2 is much better than S1. From the x-axis point 7 to point 17, S1 has higher cell temperature than S2 which around 0.4 °C difference.

## 4.3 Voltage and Current Analysis

The amount of current generated by solar panel mostly affected by the cell temperature and the solar irradiance. Thus, few results were made to show the relationship between cell temperature and current and voltage generated.

### 4.3.1 Voltage and Current Comparison with Different Tilting Angle and Same 10cm Gap

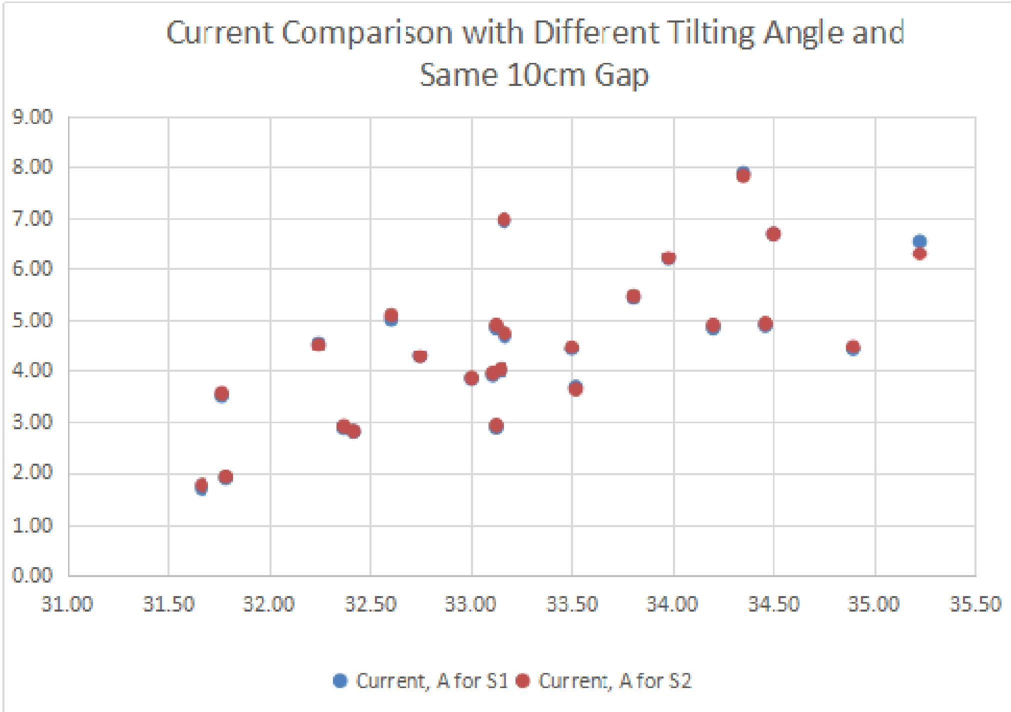


**Figure 4-7 Current Comparison between S1 10° tilting angle, 10cm gap and S2 20° tilting angle, 20cm gap**

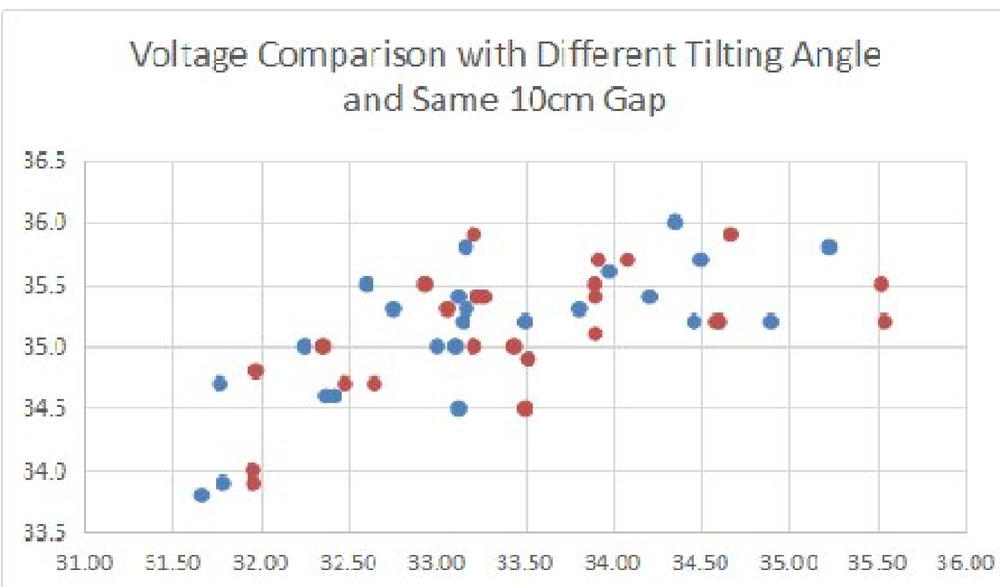


**Figure 4-8 Voltage Comparison with Different Tilting Angle and Same 10cm Gap**

From the two diagrams above, they show the relationship between cell temperature to voltage and current. For current part, there are no huge different between S1 and

S2. While for voltage part, the data taken were not in accuracy way due to delay time of data take and frequency change to weather.

### 4.3.2 Voltage and Current Comparison with 10° Tilting Angle, 10cm gap and 20° Tilting Angle, 5cm gap

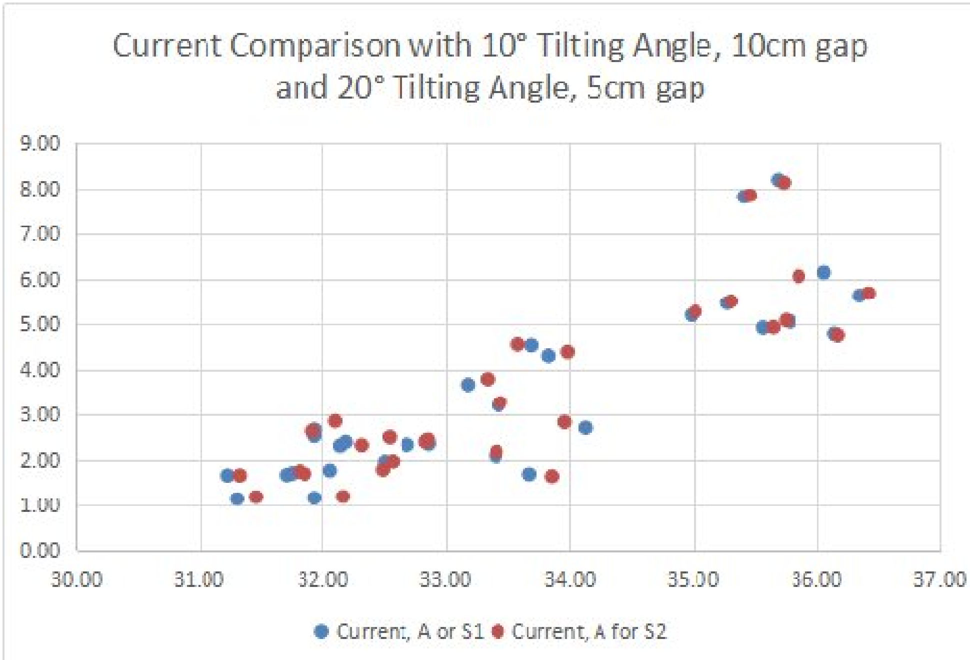


**Figure 4-9 Current Comparison with 10° Tilting Angle, 10cm gap and 20° Tilting Angle, 5cm gap**

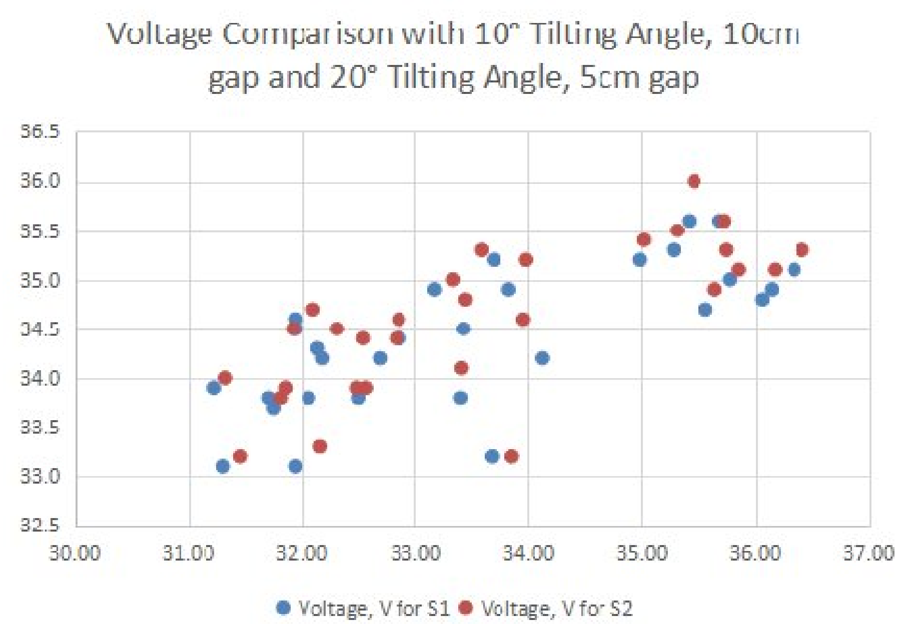

**Figure 4-10 Voltage Comparison with 10° Tilting Angle, 10cm gap and 20° Tilting Angle, 5cm gap**

### 4.3.3 Voltage and Current Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 5cm gap

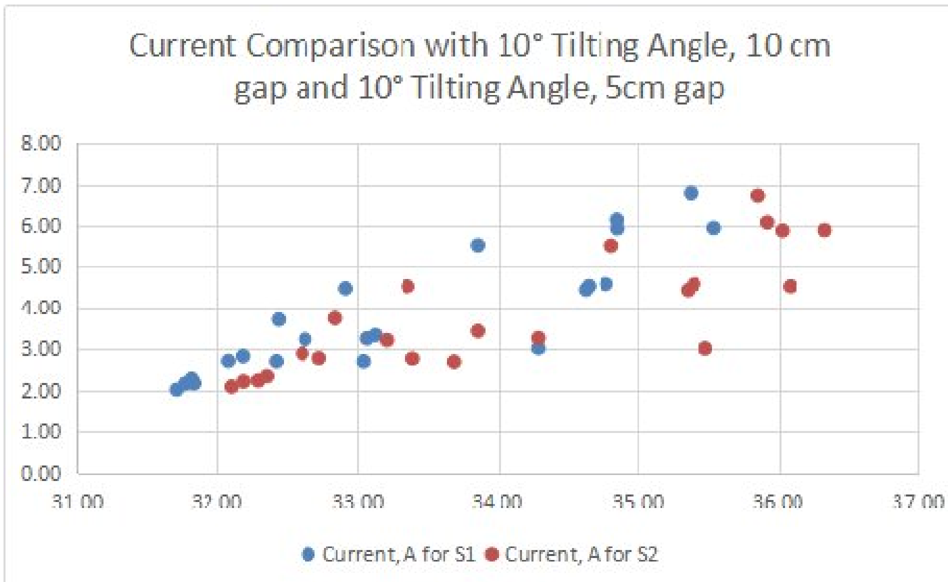


**Figure 4-11 Current Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 5cm gap**

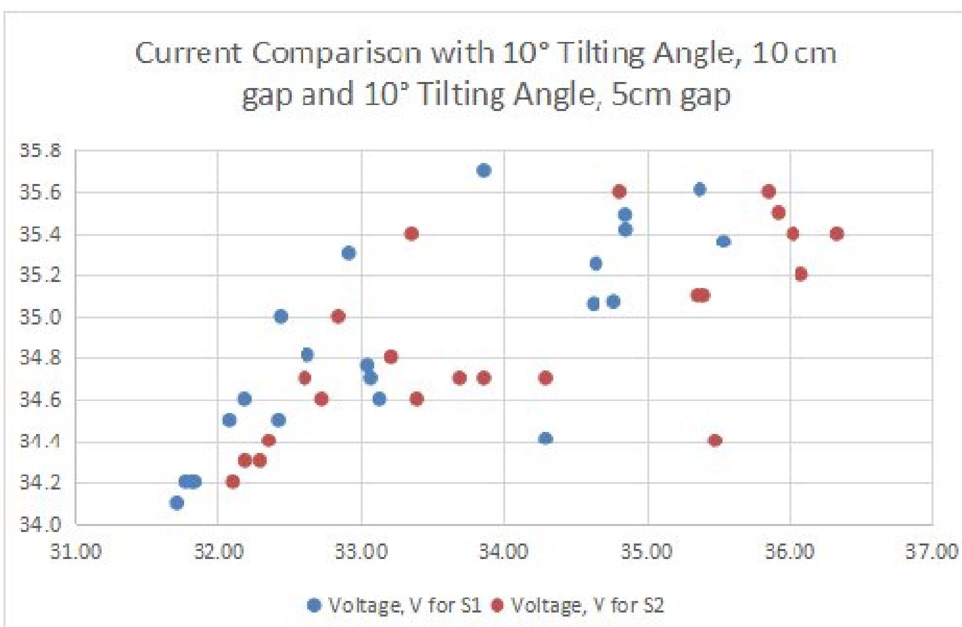

**Figure 4-12 Voltage Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 5cm gap**

### 4.3.4 Voltage and Current Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 20cm gap

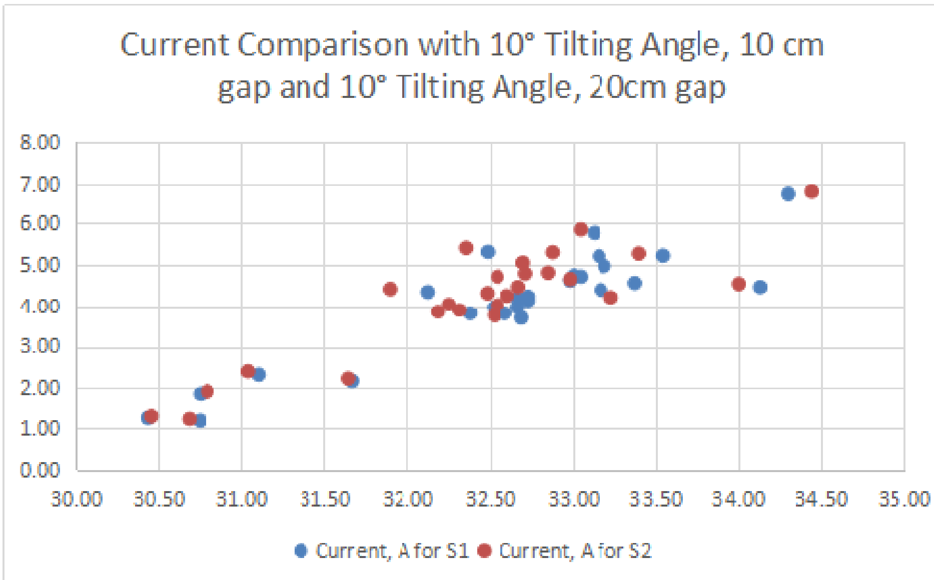


**Figure 4-13 Current Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 20cm gap**

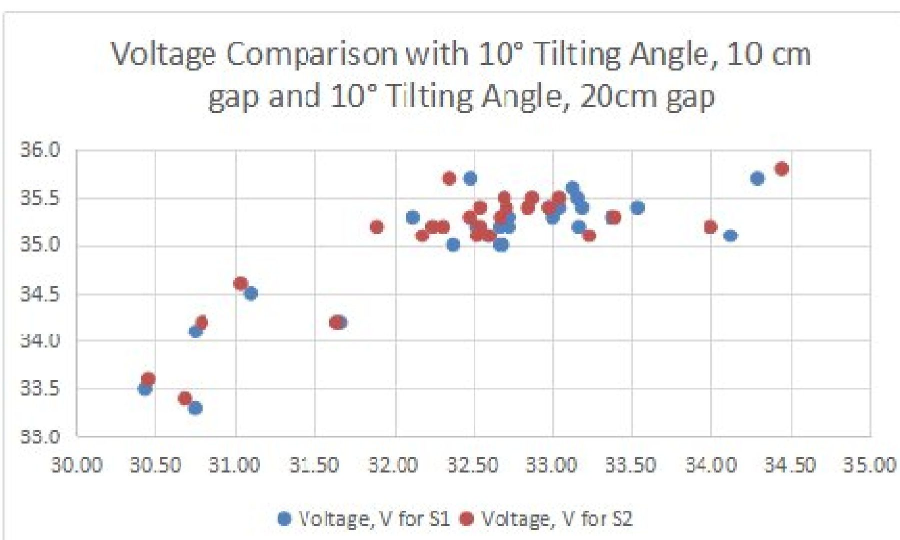


**Figure 4-14 Voltage Comparison with 10° Tilting Angle, 10 cm gap and 10° Tilting Angle, 20cm gap**

From the results above, S2 will have higher current, A compare to S1. This is due to the cell temperature of S2 is slightly lower than S1. Thus, the performance of S2 is better than S1.

# CHAPTER 5

# CONCLSUION AND RECOMMENDATIONS

## 5.1 CONCLUSION

According to chapter 4 results, we found out that :

- Dripping water will have higher efficiency for cooling down the solar panel rather than wind ventilation effect.
- The amount of current generated depends on two factors which are solar irradiance and cell temperature. When solar irradiance is above 6.0mV, the solar panel with lower cell temperature will generate more current. While, solar irradiance is below 6.0mV, solar panel with higher cell temperature will generate more current.
- When higher band gap is set, the better the wind ventilation, the lower the cell temperature.
- Solar panel with 10° tilting angle and 10cm band gap can perform better than others.

## 5.2 RECOMMENDATIONS

From the past experience, the most factor that will affects whole experiment is the data obtained. Thus, data taken from solar panel especially current, A and voltage,V should be take before the solar irradiance change. This may cause the data obtain cannot be sufficient enough to match with others. Therefore, we suggest that more data logger for collecting voltage and current from solar panel. This will increase the efficiency of whole experiment and accuracy of data rather than taking voltage and current by using multimeter manually.

# REFERENCES

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# APPENDICES

APPENDIX A: Gantt Chart

| | Task | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | W11 | W12 | W13 | W14 |
| 1 | Literature review | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| 2 | Equipment survey | | | | | | √ | √ | √ | | | | | | |
| 3 | Measurement on apparatus | | | | | | | | | | | √ | √ | | |
| 4 | Design on supporting PVmodule | | | | | | | | | | | | √ | | √ |
| 5 | Report Writting | | | | | | | | | | | √ | √ | √ | |

| | Task | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | W11 | W12 | W13 | W14 |
| 1 | Equipment Preparation | √ | √ | √ | | | | | | | | | | | |
| 2 | Experiment Set up | | | | √ | √ | √ | √ | | | | | | | |
| 3 | Data Analyze | | | | | | √ | √ | √ | | | | | | |
| 4 | Final Report | | | | | | | | | √ | √ | √ | √ | √ | |

# APPENDIX B : Arduino 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

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);

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);

// 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(const 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



  // 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, Datetime, Humidity,DHT22, Temp 1,Temp 2,Temp 3,Temp 4,Temp 5,Temp 6");
#if ECHO_TO_SERIAL
  Serial.println ("Millis, Stamp, Datetime, Humidity,DHT22, Temp 1,Temp 2,Temp 3,Temp 4,Temp 5,Temp 6");
#endif //ECHO_TO_SERIAL

  sensors_1.begin();
  sensors_2.begin();
  sensors_3.begin();
  sensors_4.begin();
  sensors_5.begin();
  sensors_6.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();

  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));


  #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));


  #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);
  }
```