# PERFORMANCE COMPARISON OF PV PANELS AT DIFFERENT ORIENTATIONS IN TROPICAL CLIMATE

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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**

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**May 2019**

## 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 COMPARISON OF PV PANELS AT DIFFERENT ORIENTATIONS IN TROPICAL CLIMATE"** was prepared by **TAYALAN A/L RAMACHANDRAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

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## ABSTRACT

The orientation of a Photovoltaic (PV) panel is important in ensuring that its power output is maximized. Most of the installations just follow the rule of thumb for panel orientation, but the rule of thumb may not be suitable in tropical climate. A lot of work and studies have also been done for improving the performance of PV systems. However, the studies are more focused on improving the components of solar panel, but less focused on the orientation of the solar panels. Even if there are studies of orientation effect, most of the studies are using theoretical methods which includes calculations by using different sky models, like Perez model. Therefore, this project has studied and analyzed the energy generated for different oriented (North, North-East, East, South-East, South, South-West, West, and North-West) solar panels in a real practical situation for a period of one month. Besides, the orientation of the solar panels is very important due to the higher amount of diffuse solar irradiance in tropical climate zones compared to the direct solar irradiance. Therefore, this project has also studied whether the distribution of diffuse solar irradiance is isotropic or not at different orientations. The temperature data logging system was also setup to compensate the temperature effect on the performance of panels. From the results, it can be seen that the panel that was oriented in East direction generated the highest energy which is different from the rule of thumb and theoretical results, while the diffuse component of solar irradiance found was anisotropic in tropical climates.

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## LIST OF SYMBOLS / ABBREVIATIONS

| | |
|---|---|
| $P_{max}$ | maximum power, W |
| $P_{out(max)}$ | maximum output power, W |
| $V_{mpp}$ | voltage at maximum power, V |
| $V_{in(max)}$ | maximum input voltage, V |
| $I_{mpp}$ | current at maximum power, I |
| $V_{oc}$ | open circuit voltage, V |
| $\beta$ | tilt angle, ° |
| $\delta$ | declination angle, ° |
| $\omega$ | hour angle, ° |
| $\alpha_s$ | altitude angle, ° |
| $\gamma_s$ | solar azimuth angle, ° |
| $\gamma$ | panel azimuth angle, ° |
| $\theta$ | cosine angle, ° |

| | |
|---|---|
| PV | photovoltaic |
| ECU | energy communication unit |
| EMA | energy monitor and analysis |
| MPPT | maximum power point tracking |
| STC | standard test condition |
| DC | direct current, A |
| AC | alternative current, A |
| EOT | equation of time |
| LCT | local clock time |
| N | day number |

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# CHAPTER 1

# INTRODUCTION

## 1.1 General Introduction

Over the past 20 years, the economic growth on the damage of environment and the expense of the natural resources. The natural resources will be finished in the near future and the polluted environment also creates a lot of extreme consequences such as climate change and greenhouse effect. Today, the whole world is emphasizing on the green and sustainable development in order to protect the environment and replace the natural resources by renewable resources. Solar energy is one of the important renewable resources to generate the power and energy. The solar energy can be obtained from everywhere and it will not cause any environmental issues. Photovoltaic(PV) panel is a very promising technology for the electricity generation.

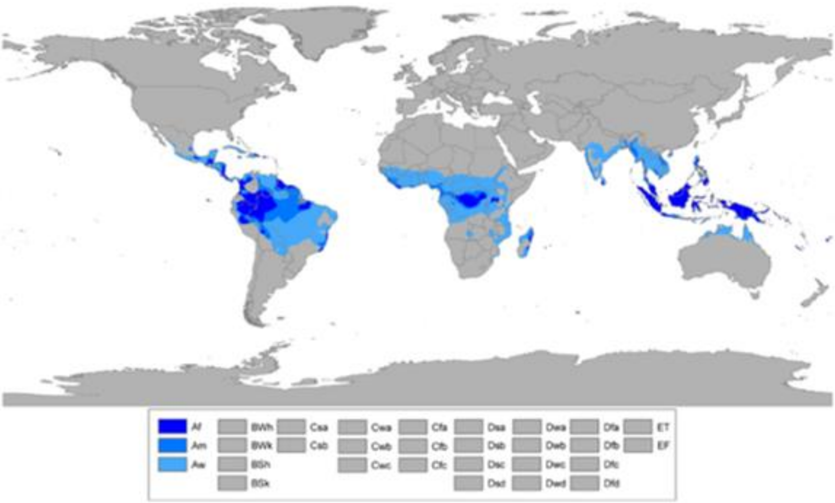


Figure 1.1: Map of Tropical Climate’s Countries

Although the solar energy can be obtained from everywhere, but the amount of solar energy will be varied from place to place. The PV panels are weather or climate dependant; different location will have different kinds of weather of climate that affect the performance significantly. Figure 1.1 shows the countries that have the tropical climate, the blue regions of the map are the areas with tropical climate. As shown in the dark blue region of Figure 1.1, Malaysia is one of the country that having the tropical climate, and this climate is known as Tropical Rainforest or Equatorial climate.

The temperature will be high in average throughout all the year, the rainfall typically will be more than 2000 mm per annual. ("The Climate of Tropical Regions," n.d.) Therefore, Malaysia is experiencing the hot and humid weather. There are two seasons experienced in Malaysia, which are dry and wet. The dry season typically starts from May to September whereas the wet season starts from November to March. The rainfall happens very rapidly during the wet season. ("Climate," n.d.)

Malaysia is located within the equator, which is between 23.5 °N and 23.5 °S. As the Earth is also tilted at 23.5 ° of it orbit and therefore, the sun is directly overhead on these areas at the equinoxes which are around 20$^{th}$ March and 22$^{nd}$ September. (US Department of Commerce, n.d.) The amount of solar irradiance received by the PV panels will be different for different orientations of panels. Therefore, studies have to be done for installing the PV panels in order to improve the performance.

A significant goal when installing a PV panel is to obtain the maximum energy output. Therefore, the orientation of the PV panel will be very important, as to get the maximum solar irradiance, the panel must be orientated and positioned directly to the solar irradiance so that the direct sunlight can reach the panel vertically. A solar tracker can also be used to increase the direct sunlight received. However, solar trackers are more expensive, more maintenance is needed and consume more spaces than the fixed PV systems. Thus, the fixed solar system is a better choice compared to solar trackers most of the time.

In this study, the orientation of PV panels will be the main focus. Various orientations of PV panels are placed and the performance of PV panels are obtained and analysed in order to understand the optimum orientation. Solar Irradiance is the key factor that affect the PV output. However, a higher irradiance also produces a higher module temperature which in turn degrade the performance. In addition, wind effect. So, it is necessary to evaluate how much deviation of PV output as compared to the solar irradiance. As the solar fields are very competitive nowadays, the PV panels are keep on improving in term of efficiency, materials, sun tracker and so on. This study is more focus on the PV system level, and it is done in a real practical operation. The theoretical or calculation methods are not being chosen for this study because these methods are impossible to consider a lot of factors that will affect the performance of PV panels such as temperature, weather, shading and so on. Therefore, this study will be in more detail manner as the PV panels are placing in a real practical study in Bandar Sungai Long, Selangor, Malaysia.

## 1.2 Problem Statement

Although a lot of works and study have been done for optimizing and improving the performance of solar panels. However, the studies are more focus on improving the components or elements of solar panel, but less likely focus on the orientation of the solar panels. Even if there are studies of orientation effect, but most of the study are using the theoretical methods which are calculations by using different models. For example, using the Cooper's equation to calculate the optimum tilt angle and orientation of the solar panels. However, the performance of the solar panels at different orientation have not been collected and analysed practically.

The orientation of the solar panels is very important due to the higher amount of diffuse solar irradiance in tropical climate as compared to the direct solar irradiance, but the problem is that how to know which is a better orientation for solar panels and how to get the data in a real practical situation. Therefore, the setup of PV system and solar irradiance measurement system are needed. Also, the studies and analysis have to be done in order to proving the data collected is accurate and reliable.

## 1.3 Importance and Contribution of the Study

This study is important to the future solar energy performance in tropical climate countries like Malaysia. As orientation and tilt angle of solar panel in Malaysia are mostly follow the rule of thumb of other country, which is facing true South as Malaysia is located immediately North to the Equator. However, it is not right as the latitude and weather of Malaysia is different from other countries. Therefore, this study could introduce and give a practical guideline for the PV plant design about the optimum and excellent orientation of solar panel in tropical climate countries.

Moreover, the good and suitable tilt angle and orientation would increase the performance of the solar panel as the solar panel can get the highest direct solar irradiance compared to other orientations. Thus, the collected yield of the solar panel would increase and the power loss would be greatly decrease.

Other than that, the usage of natural resources could be reduce effectively as the solar energy increased. Due to the higher performance of all solar panels, the energy and power generated by the solar systems will also become higher. Therefore, the solar energy could generate more and more electricity supply to your home, business or other purpose. The energy consumption from non-renewable resources can be reduce significantly and the environment would also get protected.

## 1.4 Hypothesis

If the PV system is setup with the solar panels placed at various orientation, then the optimum orientation of solar panels in tropical climate can be obtained, and the output performance of the PV system can be improved by placing the panels at the optimum orientation.

Besides that, if the output performance obtained and analysed from the solar panels at various orientation is identical with the data received from the solar irradiance measurement system, then the data received from the measurement system can also be proven.

## 1.5 Aims and Objectives

There are three objectives in this project:

1. To setup a PV system and temperature measurement system at various orientations on the rooftop.
2. To setup a data logging system to collect the performance of each solar panel through micro-inverter as well as the module temperature for a period of one month.
3. To analyse and compare the power and energy generated for different oriented solar panels.

## 1.6 Activities

There are a series of activities needed to be done for the proposed project. The planning of activities is significant for the smooth flow and succession of the project. Therefore, the important activities are briefly listed by using the work breakdown structure method. Table 1.1 shows the activity list with some descriptions for the proposed project.

Table 1.1: Activity List

| Level | WBS code | Activities | Description |
|---|---|---|---|
| **1** | 1 | Performance comparison of PV panels at orthogonal orientation in tropical climate | |
| **2** | 1.1 | Project planning | -Project initiation plan |
| **3** | 1.1.1 | Define objectives and scope | |
| **3** | 1.1.2 | Define resources requirement | -Find out the material and equipment needed |
| **3** | 1.1.3 | Project scheduling | -Arrange and organize the time for each activity |
| **3** | 1.1.4 | Project budgeting | -Calculate and estimate the cost |
| **2** | 1.2 | Setup solar panels | |
| **3** | 1.2.1 | Fabricate structure for holding solar panels | -Design dimensions of structure<br>-Use slotted angle as the material |
| **3** | 1.2.2 | Place solar panels on rooftop | -Determine the location that has the minimum shading<br>-Place the panels in an orthogonal orientation |
| **2** | 1.3 | Setup temperature logging system | |
| **3** | 1.3.1 | Connection of veroboard with Arduino Mega 2560 | -Soldering electronic components (resistors, jumper wire and so on)<br>-Insert micro-SD card for data logging |

Table 1.1 (Continued)

| | | | |
|---|---|---|---|
| **3** | 1.3.2 | Programming using Arduino software | -Coding to log the temperature data from each sensors<br>-Test the coding before experiment |
| | 1.3.3 | Temperature sensors setup | -Place one sensor under each solar panel<br>-Connect the temperature sensors to the board |
| **2** | 1.4 | Micro-inverter installation | |
| **3** | 1.4.1 | Pre-installation | -Estimate cable length and cable size needed<br>-Test the function of micro-inverter |
| **3** | 1.4.2 | Electrical connection | -Connect solar panels with micro-inverters in three phase<br>-Connect micro-inverters to the distribution board |
| **3** | 1.4.3 | Output power performance data logging | -Connect micro-inverters to ECU<br>-Connect ECU to broadband router<br>-Go to EMA web server for data logging |
| **2** | 1.5 | Analysis and Comparison | |
| **3** | 1.5.1 | Data gathering | -Temperature data gathering<br>-Output power data gathering |
| **3** | 1.5.2 | Data analysis and detail observation | -analyse temperature effects on solar panel<br>-analyse and compare output power performance of solar panels at various orientations |

## 1.7 Gantt Chart

There are a lot of activities going on in this project and all of them are important and significant to the succession of this project. Therefore, the planning and scheduling of the activities is very important to keep the project staying on the right track all the time and avoid the delay or not completed of project. Besides that, the productivity or speed of completing the works will become faster and done in lesser time. Gantt chart is a "powerful tool" used in the project management and thus, Gantt chart is used to organize and control the activities of this project. Figure 1.2, 1.3 and 1.4 show the Gantt chart for the whole planning of the proposed project.

| Task Name | Duration | Start |
|---|---|---|
| **1 Project Planning** | **10 days** | **4/6/18** |
| 1.1 Define objectives and scop | 5 days | 4/6/18 |
| 1.2 Define resources requirements | 3 days | 11/6/18 |
| 1.3 Project schedulling | 3 days | 12/6/18 |
| 1.4 Project Budgeting | 2 days | 14/6/18 |
| **2 Setup Solar Panels** | **88 days** | **4/6/18** |
| 2.1 Determine design of structure for holding solar | 7 days | 18/6/18 |
| 2.2 Fabricate eight structures for eight solar panels | 70 days | 27/6/18 |
| 2.3 Determine the location that has the minimum | 2 days | 30/9/18 |
| 2.4 Place eight solar panels in an orthogonal orientation | 1 day | 3/10/18 |
| **3 Setup Temperature Data Logging System** | **15 days** | **17/10/18** |
| 3.1 Soldering the components (jumper wire, resistor, 3 way connector) on veroboard | 3 days | 17/10/18 |
| 3.2 Connect the veroboard to Arduino Mega 2560 with micro-SD card & temperature sensors | 1 day | 19/10/18 |
| 3.3 Do the programming of Arduino software for temperature data logging | 7 days | 22/10/18 |

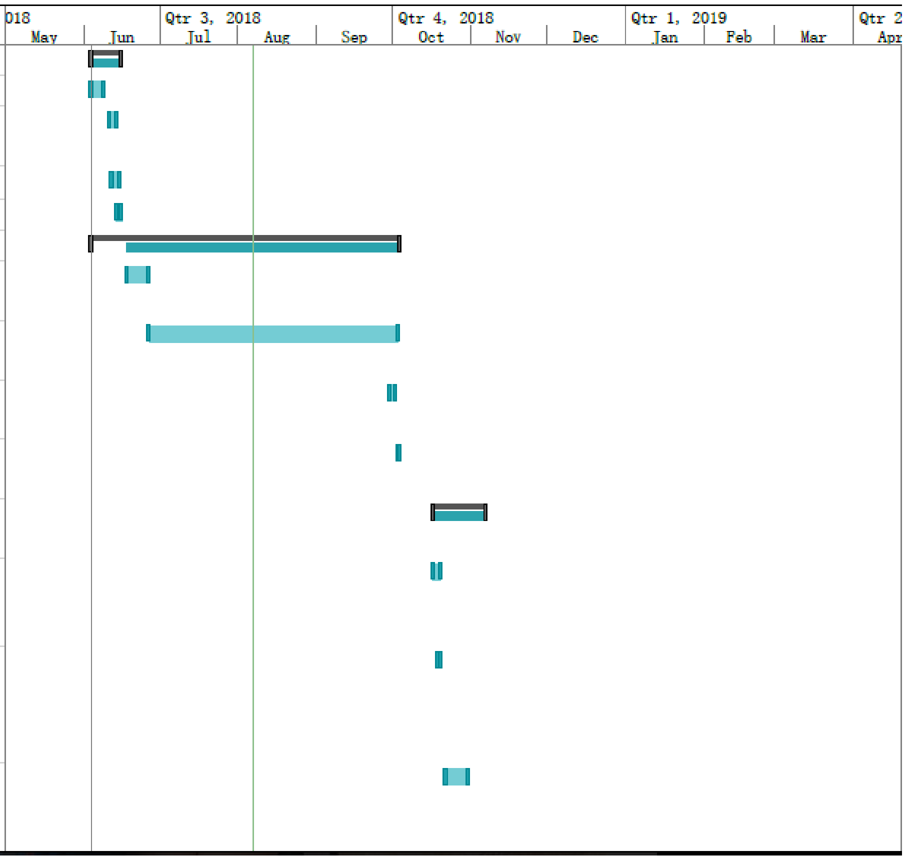


Figure 1.2: Gantt Chart for Activities 1 to 3

| Task Name | Duration | Start |
|---|---|---|
| 3.4 Test the programming of Arduino coding | 3 days | 31/10/18 |
| 3.5 Place one temperature sensors under each solar panels (at the middle) | 2 days | 5/11/18 |
| **4 Micro-inverter Installation** | **65 days** | **14/8/18** |
| 4.1 Estimate the cable length for connection between microinverters & distribution board (DB) | 2 days | 14/8/18 |
| 4.2 Determine the cable size | 2 days | 15/8/18 |
| 4.3 Test the function of microinverters (YC500A) | 6 days | 16/8/18 |
| 4.4 Connect four microinverters to eight solar panels (1 microinverter -> 2 solar | 2 days | 6/11/18 |
| 4.5 Connect microinveters in a three-phase way (2 inverters -> 1 phase 1 inverter -> 1 phase 1 inverter -> 1 phase) | 1 day | 7/11/18 |
| 4.6 Connect microinverters to DB which consists of SPD and | 1 day | 8/11/18 |
| 4.7 Connect microinverters to broadband router & ECU | 2 days | 9/11/18 |
| **5 Equipment & Material Prepara** | **36 days** | **18/6/18** |

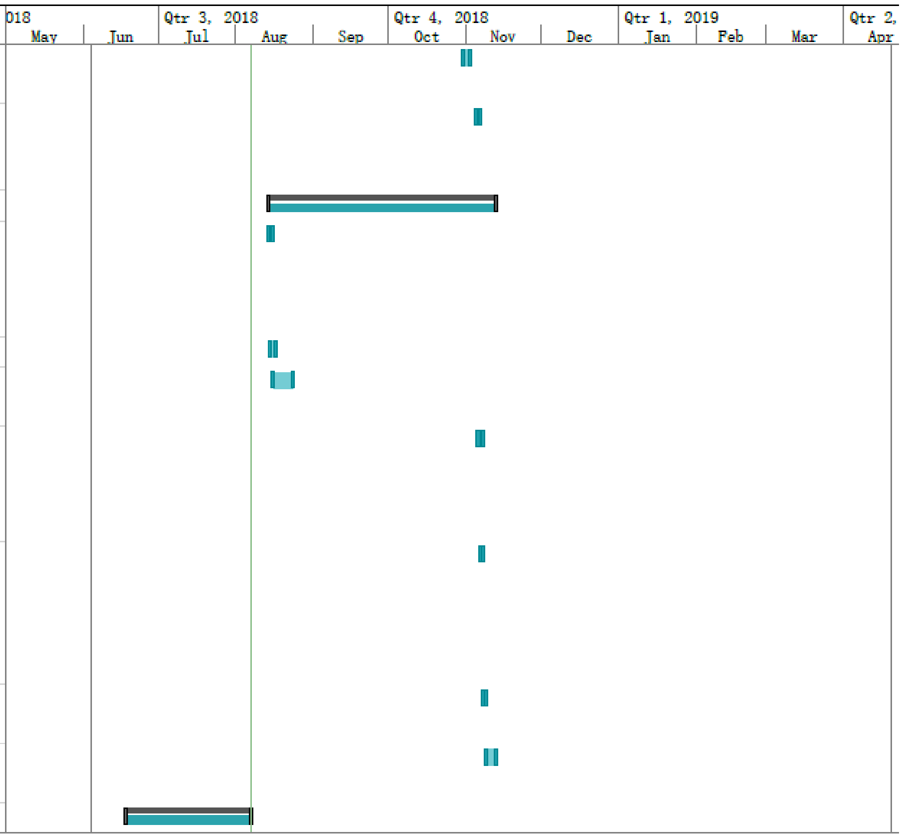


Figure 1.3: Gantt Chart for Activities 3 to 4

| Task Name | Duration | Start |
|---|---|---|
| 5.1 Bolt and Nut | 1 day | 18/6/18 |
| 5.2 Slotted Angle | 31 days | 25/6/18 |
| 5.3 Electronic components (temperature sensors ds18b20, resistors, head to head jumper wires, veroboard) | 1 day | 5/7/18 |
| 5.4 Arduino Mega 2560 with Data Logger Shield & Casing | 1 day | 5/7/18 |
| **6 Data Analysis** | **80 days?** | 26/11/18 |
| 6.1 Temperature Data Gatheri | 31 days | 26/11/18 |
| 6.2 Ouput Power Performance Data Gathering | 31 days | 26/11/18 |
| 6.3 Data Analysis & Detail Observation | 45 days | 14/1/19 |
| **7 Report Writing** | **230 days?** | 4/6/18 |
| 7.1 Introduction | 14 days | 4/6/18 |
| 7.2 Literature Review | 45 days | 4/6/18 |
| 7.3 Methodology | 25 days | 16/7/18 |
| 7.4 Result | 45 days | 21/1/19 |
| 7.5 Discussion | 20 days | 22/3/19 |
| 7.6 Conclusion & Recommend | 1 day | 19/4/19 |

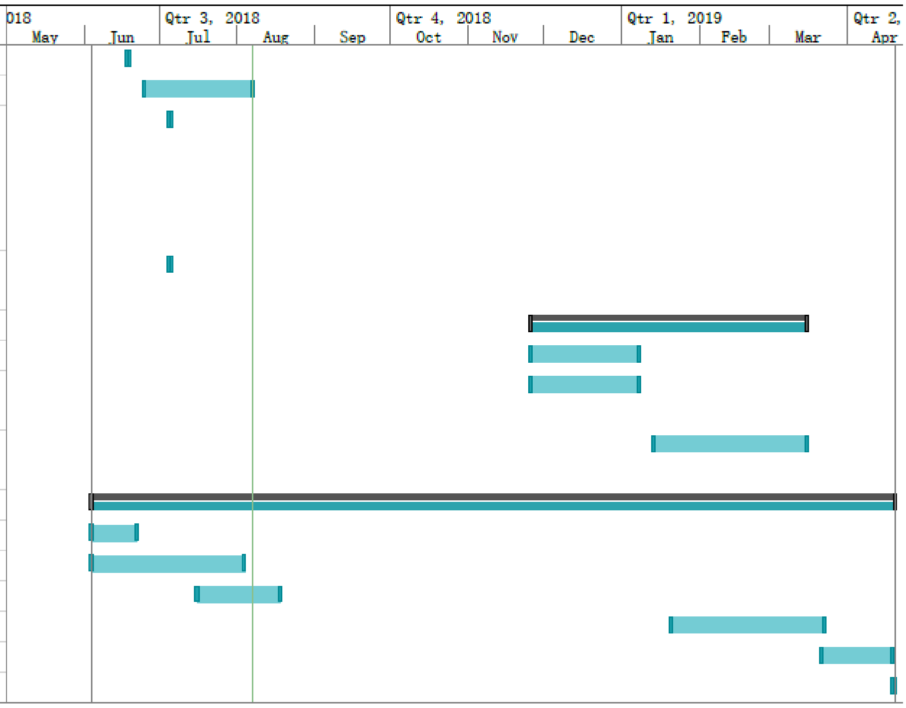


Figure 1.4: Gantt Chart for Activities 5 to 7

## 1.8 Scope and Limitation of the Study

There are some limitations of this study such as the capability of components, time, weather and etc.

Firstly, the thermal sensors would not be able to measure and collect the temperature every second. Therefore, the performance and power loss affected by the temperature may not be very precise.

Moreover, similar to the temperature, the solar irradiance could not be measured and collected every second. The micro-inverter requires a period of time to invert DC to AC, and complete a data collection.

Besides that, the reflection of the solar irradiance from ground should be avoided in this study. However, not all of the reflection would be able to eliminate, and this would affect the accuracy of date collected.

Lastly, the statistical and data limitations of this study. It is difficult to obtain the data as the weather cannot be predicted accurately. As the data collected are limited, thus, the analysis may not be very accurate and precise. However, a further research can be done by using a larger period of time to collect more data and the analysis will be accurate and precise.

## 1.9 Report Overview

The report contains several chapters and each chapter discusses on the respective topics and contents in a manner whereby the readers are able to understand easily. Below are the summaries of each chapter contents.

**Chapter 1 Introduction**

A brief introduction and description on the whole project. Basic understanding on what is this project about. The activities and Gantt chart are discussed in this chapter.

**Chapter 2 Literature Review**

Researches on related projects and backgrounds that have been done practically before.

**Chapter 3 Methodology**

Discussion on the project hardware and software implementation. Design and construction of project structure base, orientation, tilt angle are discussed in this chapter. The components and parts used in the project are also discussed. The flow of project is presented in flowchart from as well as the circuit designs are discussed.

**Chapter 4 Results and Discussion**

Discussion on the results measured and calculated from the project, including the shading time, calibration of panels, energy generation in period of one month, and the diffuse component of solar irradiance.

**Chapter 5 Conclusion and Recommendation**

Summary of the results, and suggestions on the future study on this project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The methods to improve the output performance of PV panels are still finding and improving as there are a lot of factors will cause the power loss of solar panels. The crucial factors that are difficult to control and estimate include the orientation, tilt angle, solar irradiance, weather, shading, temperature and soiling.

For the orientation and tilt angle of the solar panels, the maximum solar irradiance can be received and absorbed when the panels are facing directly to the sun radiation. The shading and dust factors are also causing the power losses of the solar panel. The solar panels are very sensitive to the shading, where the dust can also be considered as a shading element. The shading may cause by the dust, bird droppings, building, tree and etc. The solar irradiance will be blocked and therefore, the panels would not be able to receive the maximum radiation from the sun. A significant reduction will happen if these factors are not being solved. For example, if half of the solar panels are being shaded, and the panels are connected in series, then the current from the shaded panels will decrease, and the overall output performance will also decrease.

Therefore, various fields that are the most relevant to the proposed project are being studied, including orientation and tilt angle of PV panels and temperature or weather effects on performance of PV panels. Among all of these fields, the orientation and tilt angle effects on the solar panels are the most important and focuses on the proposed project and therefore, the review of these topics are relatively more compared to the other topics. Moreover, a lot of journals and articles have been studied and learned as to absorb the knowledge and experience from their studies in order to improve the proposed project. This chapter shows the review of the studies which are the most relevant and useful to the proposed project.

## 2.2 Solar Panel Orientation (Azimuth and Zenith)

Figure 2.1 shows the angle of solar azimuth orientation. It is measured on the horizontal plane, and it is the direction of the coming solar irradiance. The azimuth angle is keep varying along a day. As shown in Figure 2.1, the azimuth angle is 90 ° at East, 180 ° at South, 270 ° at West, and 360 °/ 0 ° at North. During the solar noon, the sun is exactly at the South and North for the Northern hemisphere and Southern hemisphere respectively. (“Azimuth Angle | PVEducation,” n.d.)

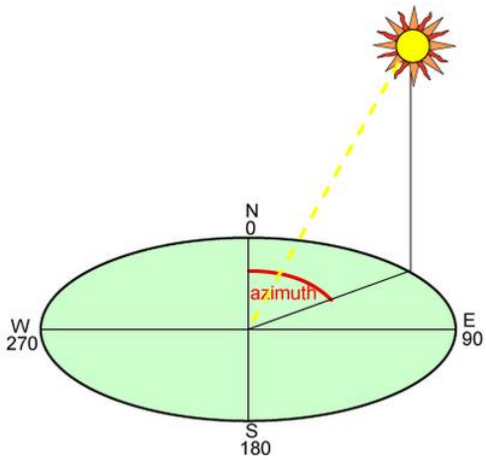


Figure 2.1: Angle of Solar Azimuth Orientation (“Azimuth Angle | PVEducation,” n.d.)

Apart from that, Figure 2.2 shows the solar zenith angle. It is measured by using the shortest distance of the Sun to the Earth’s surface. The zenith angle is varied with the location, local date and also time. (“SZA,” n.d.)

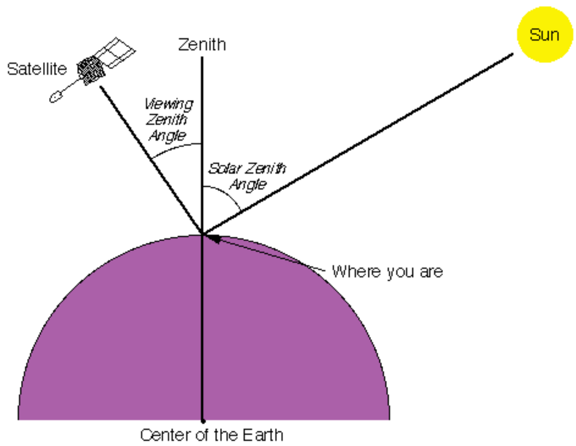


Figure 2.2: Angle of Solar Zenith Orientation (“SZA,” n.d.)

## 2.3 Types of Solar Radiation

There are three main types of solar radiation, which are diffuse, direct and reflected radiation as shown in Figure 2.3.

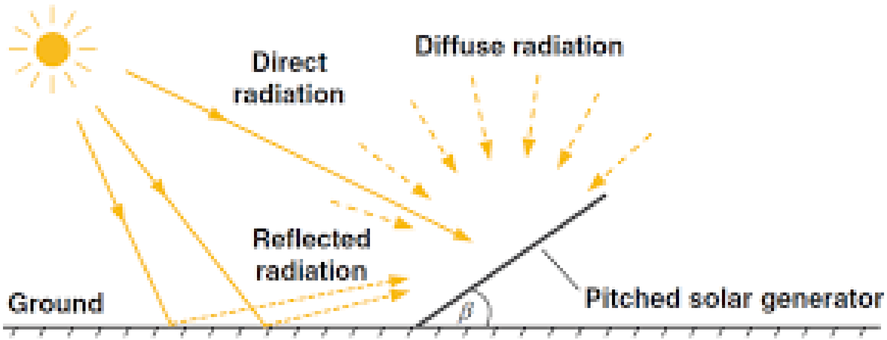


Figure 2.3: Diffuse, Direct, and Reflected Radiation

Firstly, for the diffuse radiation, it is the scattering of insolation that reach the earth's surface by the molecules like oxygen, nitrogen, water, dust and etc. Secondly, for the direct radiation, it is also known as beam which means that the solar radiation reaches the surface of earth directly from the sun. Thirdly, for the reflected radiation, it is the reflection of insolation to the photovoltaic panels by the objects like ground, building and etc. Apart from that, the diffuse and reflected solar irradiance are less affected by the orientation and tilt angle, but the direct solar irradiance is greatly relied on the orientation and tilt angle.

## 2.4 Distribution of Solar Radiation

For the solar radiation, the diffuse solar radiation is higher than the direct solar radiation in Malaysia. Figure 2.4 shows the distribution of diffuse solar radiation in Malaysia whereas Figure 2.5 shows the distribution of direct solar radiation.

For the study area of the proposed project which is near the Kuala Lumpur, the diffuse and direct solar radiation are at the middle range. The diffuse solar radiation is around 4.6 to 4.8 kWh/m$^2$ for daily total and 1680 to 1753 kWh/m$^2$ for yearly total. For the direct solar radiation, it is around 2.4 to 3.0 kWh/m$^2$ for daily total and 876 to 1100 kWh/m$^2$ for yearly total. As the direct irradiance is much lower than the diffuse irradiance, so the orientation and tilt angle is better fixed at an optimum angle instead of installing a solar tracker. (© *2017 The World Bank, Solar resource data: Solargis*.)

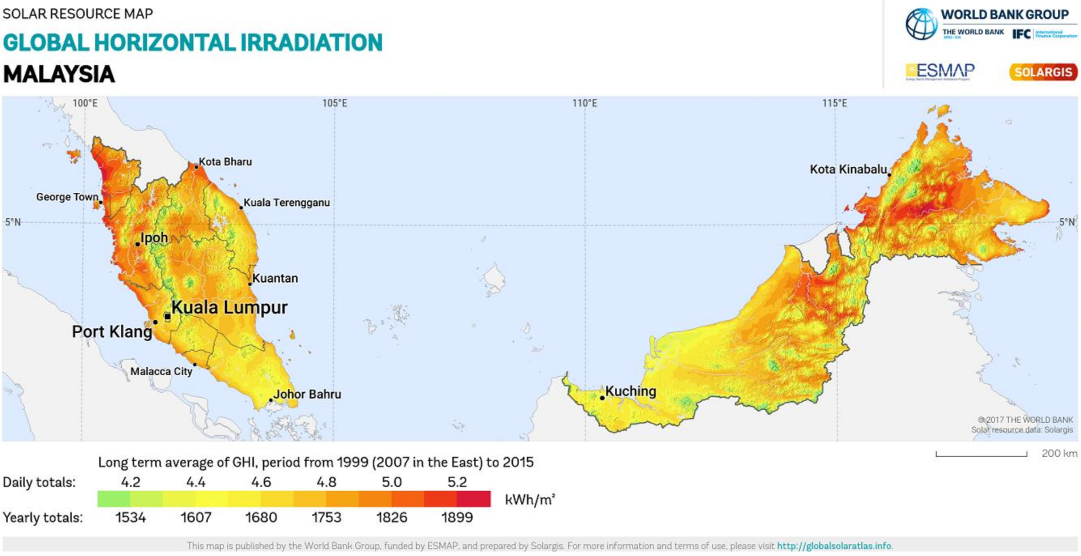


Figure 2.4: Diffuse Solar Radiation in Malaysia (© *2017 The World Bank, Solar resource data: Solargis*.)

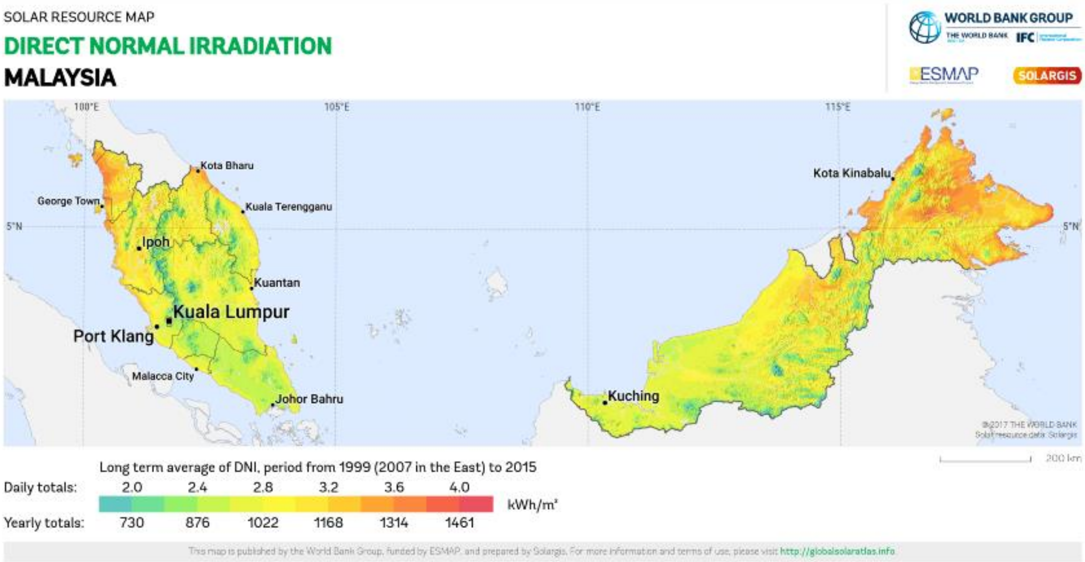


Figure 2.5: Direct Solar Radiation in Malaysia (© *2017 The World Bank, Solar resource data: Solargis*.)

## 2.5 Orientation Effects on Solar Panel's Performance

There was a study conducted at Haramaya University which is located in Ethiopia. The time chosen for this study was in spring season which are March, April and May. The time for the study is limited and not long enough, thus, the results obtained may not be very accurate and precise. This study was done practically by installing solar panels on the ground to get the practical results instead of theoretical calculations. Three solar panels were oriented at different direction and tilted at different angle in order to achieve better performance by obtaining highest solar power. The tilting angle of solar panels was in North-South direction whereas the orientation was in East-West direction which are highly influence the solar irradiance on the solar panels. (Yirga Belay Muna, 2016)

Figure 2.6 shows the setup of solar panels in the study. The solar panels were installed above the ground, and setup on a revolving pedestal which consists of rotating axis for changing the orientation and tilt angle of panels.

Figure 2.6: Experimental Setup of Solar Panels (Yirga Belay Muna, 2016)

This study was done only one week for each of the three months. As there were three panels, each panel used to face different directions, one was oriented to East, one was oriented to West, and one was fixed at the horizon position. As there are three panels used for the irradiance collection, so the performance of the other two panels are able to analysed effectively and efficiently. Besides that, the tilt angle of solar panels was changed from 0° to 90° to determine the power output at different angle. (Yirga Belay Muna, 2016) The tilt angle effect also taken into account in this project, both of the orientation and tilt angle were changed and therefore, the performance of the solar panels able to be analysed well. However, the orientation angle of solar panel was changed every day; it was not fixed the orientation angle for a longer period of time to have accurate results.

For the solar that is east-oriented, the orientation angles that have the highest power output were around 0 ° to 5 °. The angle of 5 ° was the best in March and May, and 0 ° was the best in April. For the solar panel that is west-oriented, the orientation angles that have the highest power output were around 0 ° to 5 ° also. The angle of 0 ° was the best in March and April, and 5 ° was the best in May. (Yirga Belay Muna, 2016) However, the period of data collection and measurement is long, which was 15 minutes for one data. The long period may lead to inaccuracy of the measurements.

In the study, the maximum power output of solar panels was increased, thus, the solar panels have a better performance with the optimum orientation. If the orientation changes monthly according to the optimum value, the power outputs were increased by 9.15 %, 12.34 % for the month of March and May respectively whereas the power output in April was remained constant as the optimum orientation and tilt angle is zero degree respective to East and West. If the orientation and tilt angle changes seasonally, the solar panels still have a better performance where increase 5.51 % of the power output. (Yirga Belay Muna, 2016)

In conclusion, the orientation of solar panels will affect the performance greatly. If the solar panels are oriented at optimum direction, the power output will be higher, so that each panels can be utilizing effectively and efficiently. The orientation of solar panels is unique for every places and locations; installation of solar panels should not follow the thumb of rule or follow the orientation of other countries as every places have different factors that will affect the output performance of solar panels. As there are no such studies have been done in Sg. Long, Selangor area before. Therefore, the proposed project is needed to determine the optimum orientation in this area so as to obtain the best output performance of solar panels.

## 2.6 Temperature Effects on Solar Panel's Performance

There was study conducted at Perlis, Malaysia to investigate the effect of temperature on the performance of solar panel. This study was done by both simulation and outdoor experimentation. For the simulation, PVsys software was used to simulate the output performance of panel. For the outdoor experiment, temperature sensor, LM 35 was used to measure the temperature under panel with a ten minutes' time interval. The panels and sensors were located in Perlis where 6.43 °N latitude and 100.19 °E longitude. (Razak et al., 2016)

The standard test condition, which 25 °C temperature rating, 1000 W/m$^2$ and 1.5 of air mass was simulated. According to the results obtained, the simulated output performance of PV panel would decrease when the operating temperature of the panel increase. (Razak et al., 2016)

For the aim and objectives of the proposed project, the review is going to be more focus on the outdoor experimental method. For the outdoor condition, the panel and temperature sensor, LM 35 were placed at shown in Figure 2.7. Four LM 35 with 10-minute interval of data collection was started from 9.00 am until 5.00 pm for a day.

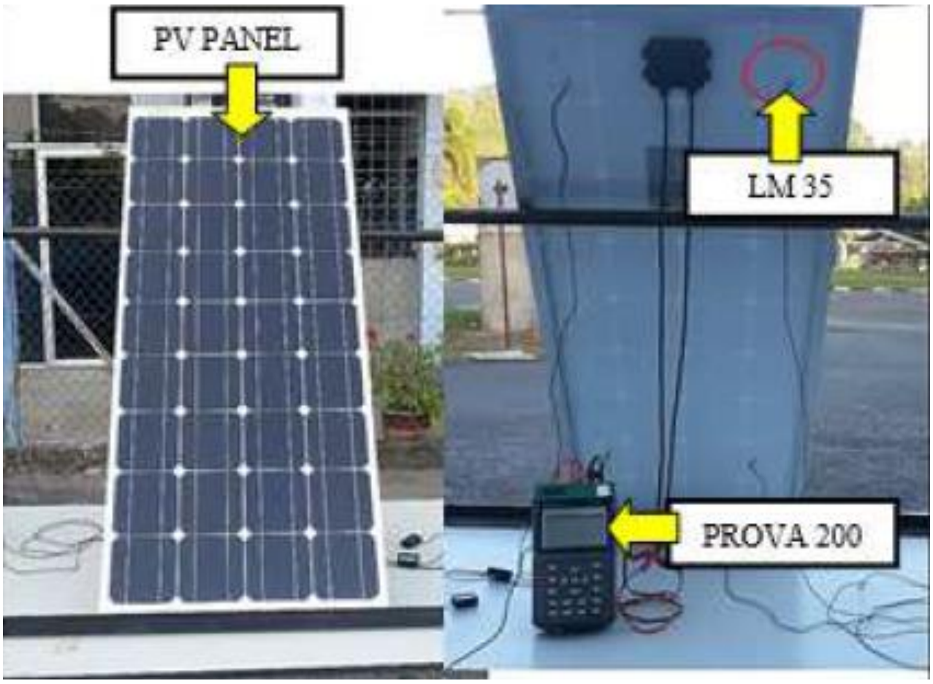


Figure 2.7: PV Panel with Temperature Sensor for Outdoor Experiment. (Razak et al., 2016)

According to the practical results, the higher solar irradiance and lower operating temperature of PV panels were able to generate the higher output power of the PV panels. During the peak sun hours, the solar irradiance was the highest among the other time, but the temperature of the solar panels was also the highest at that time. The temperature was not only equal to the ambient temperature, but it was much higher, where the highest temperature found was 63.20 °C. (Razak et al., 2016) As the thermal imaging camera, FLIR was used to capture the variation of temperature distributed on the PV panel during the outdoor experiment. The temperature difference and distribution can be seen clearly through the camera. Therefore, the analysis of the results will be more precise.

When the solar irradiance is stronger and higher, the operating temperature will also become higher. Conversely, the current will be increase when the solar irradiance increase and therefore, the output power of the solar panels will increase. Although the output power increase with the higher solar irradiance, but the efficiency of the panel will decrease, it cannot perform its function 100 %. At the end, the power generated by the solar panels in higher temperature condition is still lower than the one in a lower temperature environment.

For the comparison between PVsyst software and practical result, the conclusion of both methods are the same. The output performance of PV panel is affected by the surrounding temperature, where output performance will decrease when the surrounding temperature increase.

In a conclusion, the higher the temperature of the PV panel, the higher the output current will be produced. However, when the temperature is high, the output voltage will be low, and the reduction of output voltage is much higher than the output current. Therefore, the overall output power of the PV panel will be lower when the temperature is higher, the performance of the PV system will be poor as the efficiency of the PV system is lower.

## 2.7 Tilt Angle Effects on Solar Panel's Performance

There was a study conducted at Kerman University which is located in Iran. Two methods were used to observe and measure the tilt angle effects on performance of PV panel, which were mathematical approach and outdoor experiment. For the aim and objectives of this proposed project and therefore, this review will focus on the outdoor experimental approach. (Rouholamini et al., 2013)

The time for the outdoor experiment was from July until November, a period of five months was used to measure the output performance of PV panels. Six solar panels were used simultaneously with various tilt angles to collect the data. The comparison between various tilt angles can be seen clearly and analysed effectively. The PV panels were installed at the location where 30 ° latitude and 50 ° longitude. Each of the panels were placed at different tilt angle, from 0 ° to 50 °. Figure 2.8 shows the experimental setup of the PV panels. (Rouholamini et al., 2013) However, the tilt angle used were too broad. The tilt angle of 0 ° and 50 ° should not be used for the outdoor experiment. That was not really necessary as the maximum output power would not happen in those angles.

Figure 2.8: Setup of PV Panels (Rouholamini et al., 2013)

From this study, it showed that the optimum tilt angles are changed from month to month. For example, the optimum tilt angle in July was 10 °, whereas 40 ° in October. Therefore, the tilt angle of the PV panels has to be changed monthly in order to achieve the highest output power and the highest efficiency. Besides that, a mathematical model also has been calculated for the purpose of comparison with the outdoor experiment. This shows the different between the mathematical approach and practical result, as there are a lot of factors will affect the overall performance of PV panels, which are not possible to be calculated by only mathematical model.

As compared the mathematical model and practical model, the output power was totally different. The output power of the practical model was much lesser than the mathematical model as there are a lot of factors which will reduce the performance of PV panel such as dust, temperature, wind speed and etc. (Rouholamini et al., 2013)

In a conclusion, different places should have different tilt angles of PV panels because of a lot of factor like local weather, dust, latitude and longitude differences. Therefore, tilt angle of solar panels should have gone through studies first before the installation and cannot follow other places or the thumb of rule.

## 2.8 Summaries Existing Studies from Review

Table 2.1 shows the summary of the existing studies from the literature review which includes the features, advantages and disadvantages for each of the studies.

Table 2.1: Summary of Existing Studies

| No. | Journal | Summaries Feature of Project | Advantages | Disadvantages |
|---|---|---|---|---|
| **1.** | Orientation Effects on Solar Panel's Performance | - Three panels placed at various orientations<br>- Use rotating axis to change the orientation<br>- Study for one week for each three months. | - Analysis can be done effectively due to one panel fixed at horizon level | - Time to study is short<br>- 15 minutes for one data, period of data collection is long<br>- Not very accurate due to weather condition |
| **2.** | Temperature Effects on Solar Panel's Performance | - Performance of solar panel simulated using PVsys.<br>- Outdoor experiment using a PV panel with LM 35<br>- Data collection from 9.00 am to 5.00 pm | - Thermal imaging camera, FLIR is used to capture temperature distribution<br>- Four temperature sensor, LM 35 used to measure the temperature on PV panel. | - Only one solar panel with fixed orientation and tilt angle used. |
| **3.** | Tilt Angle Effects on Solar Panel's Performance | - Performance of solar panel calculated using mathematical model<br>- Outdoor experiment using six PV panels<br>- Data collection from July until November | - Six PV panels used at the same time with various tilt angle<br>- Comparison with the mathematical model | - Tilt angle chosen is too wide |

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

The purpose and objectives to be achieved of this project are to setup a PV system, temperature data logging system, and analyse and compare the output power performance of the solar panels with various orientations. This chapter is going to explain and discuss about the process, equipment, electrical connection, installation, setup, and procedure that used to complete the project.

Firstly, the flow of the project was discussed in the form of flowchart. After that, the researches were done on the material and equipment used. Besides that, setup of the structure and the electrical connection of PV system were also explained and discussed. Moreover, the temperature data logging system was discussed and the method of analysing the performance of panels and diffuse component of solar irradiance were shown and explained clearly.

## 3.2 Process Flowchart

A flowchart was done before the project started as to provide a brief guideline and better understanding when starting to do the project. The process flowchart of the proposed project is shown in Figure 3.1.

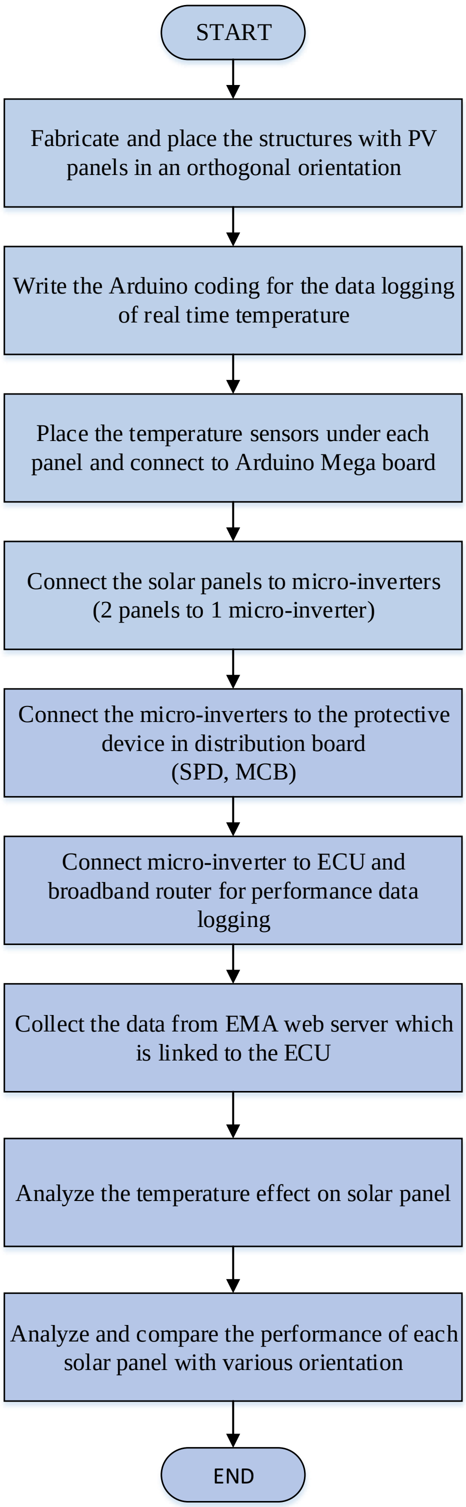


Figure 3.1: Process Flowchart

## 3.3 Experimental Setup and Procedure

For this proposed project, the PV system was set up at the rooftop of KB block, Universiti Tunku Abdul Rahman, Sungai Long, Selangor, Malaysia.

The structure for holding the PV panels was designed, and the dimensions of the structure were determined. The height, length, inner width, and the outer width of the structure used were 40 mm, 220 mm, 120 mm, and 300 mm respectively. The length and width of the PV panels were considered when deciding the structure dimensions. Moreover, the height was chosen as 40 mm in order to get the tilt angle of 10 °.

After that, the structure was fabricated by using slotted angle, and it was placed in an orthogonal orientation, which is facing North, North-East, East, South-East, South, South-West, West, and North-West. The tilt angle was set as 10 ° as it is the angle that most commonly used by the industries in tropical climate. Figure 3.2 shows the setup of the orthogonal structure on the rooftop.

Figure 3.2: Setup of Orthogonal Structure

As shown in Figure 3.3, the acrylic box in the middle of the structure consists of the Arduino Mega, which is connected to the temperature sensors, and the distribution box which is connected to the micro-inverters. There was one temperature sensor placed under the middle of each panel, and thus, eight temperature sensors were connected to the Arduino Mega and data logger with micro-SD card.

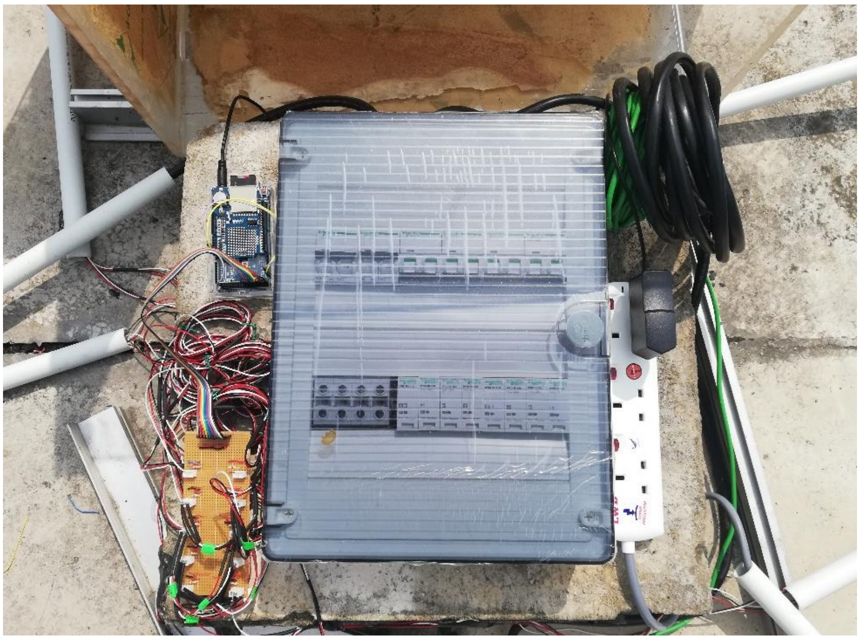

Figure 3.3: Arduino Mega and Distribution Box

As shown in Figure 3.4, all of the wires including the temperature sensors wiring, micro-inverter wiring and the main electric circuit wiring were protected by using the PVC conduit.

Figure 3.4: Protection for Wiring

### 3.3.1 Minimization of Shading Effect

Figure 3.5 shows the dimensions of the orthogonal structure where the scale is in millimetres, and the location of PV panels that installed on the rooftop. The reason to place the panels at the location is the shading effect.

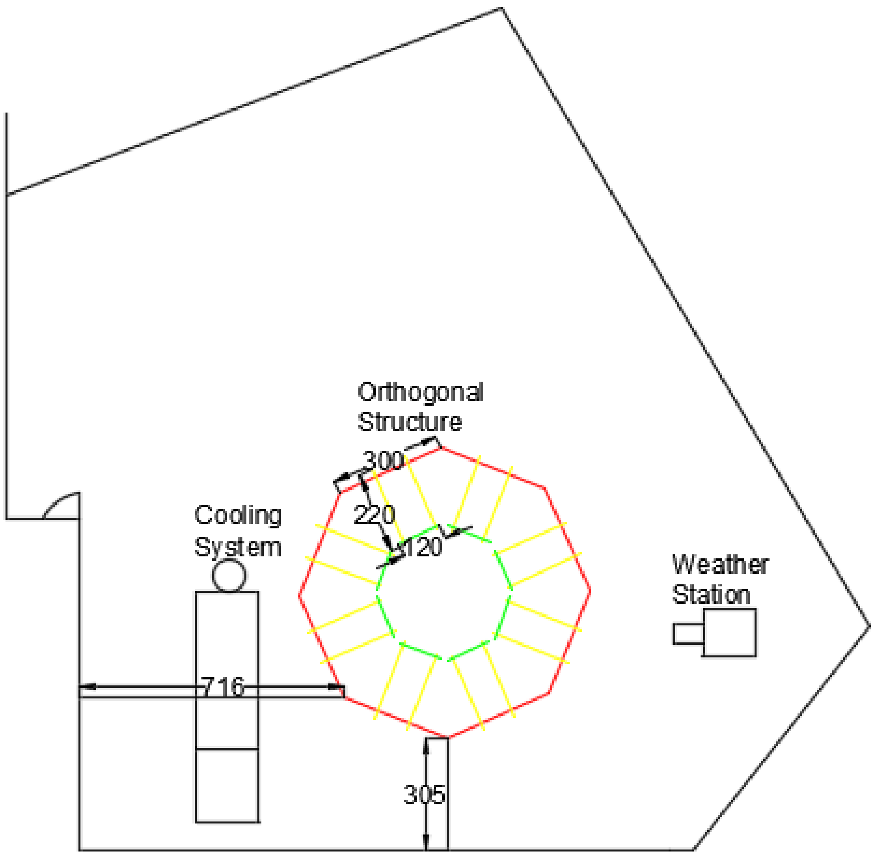


Figure 3.5: Location of PV Panels

Due to the limitation of the space on the rooftop, there must be some shading effect on the PV panels, and therefore, the shading time was find out in order to have fair justification on the analysis on output power. The floor plan on the rooftop was drawn using Autocad for finding the distance, *d* between each panel and the blocking building. The height of the buildings was measured, and the height difference, $h_d$ between each panel and buildings were calculated. For each orientation, the altitude angle blocked by the buildings or objects were calculated and put into the Malaysia's sun-path chart to find out the shading time on each panel. The formula used to calculate the blocked altitude angle, $\alpha_b$ is:

$$\alpha_b = \tan^{-1}\left(\frac{h_d}{d}\right) \tag{3.1}$$

The different blocked altitude angles from different buildings on a panel were marked on the sun-path chart. After that, all the blocked altitude angles were connected in a best fit line to approximate the shading times on the particular panel for a day, and this process was repeated for all the eight panels. For the analysis, the period of time for increasing 14 ° altiude is 60 minutes, thus the formula used to calculate the shading time is:

$$shading\ time = \frac{30}{7}\ minutes \tag{3.2}$$

After calculating the shading time for all panels in a day, the longest shading time of each panel was compared. The shading time must be almost the same for each panel in order to have the fair justification, and thus, the locations of panels were adjusted in the Autocad first until the shading time calculated achieves the objective. After the shading time was balanced for each panel, the real structures were only moved and setup according to the distance and location drew in the Autocad software.

### 3.3.2 Electrical Connection of PV System

Figure 3.6 shows the connection of PV system whereas Figure 3.7 shows the schematic diagram of the connection. For this project, the micro-inverters YC500A were used, one micro-inverter was connected to two PV panels and there were total eight panels, and therefore the total unit of micro-inverter used was four. Two micro-inverters were connected in series and linked to one voltage phase where the voltage and power rating on each phase was equal in order to get the balanced three-phase system. The micro-inverters used have the function of auto-synchronized the frequency, which the voltage phase is separated 120 ° from the other.

After that, the distribution board, which connected to the micro-inverters consists of miniature circuit breaker (MCB), and surge protection device (SPD) to provide safety for personnel and to protect from the lightning surge, voltage spikes, overload and short circuit. Apart from that, the micro-inverters were also connected to the Energy Communication Unit (ECU), which is used to collect the statistics of output performance from each of the micro-inverter and send the real time data to the Energy Monitoring and Analysis (EMA) database through a broadband router. The ECU was able to function if it is connected to either live wire one (L1), live wire two (L2).

For the connection between the micro-inverters and the distribution board, the cable size used was 2.5 $mm^2$ for the live and neutral wire, whereas the cable size used for the ground wire was 10 $mm^2$. The cable size was decided by referring to the standard from Energy Commission in order to achieve the safety of the system.

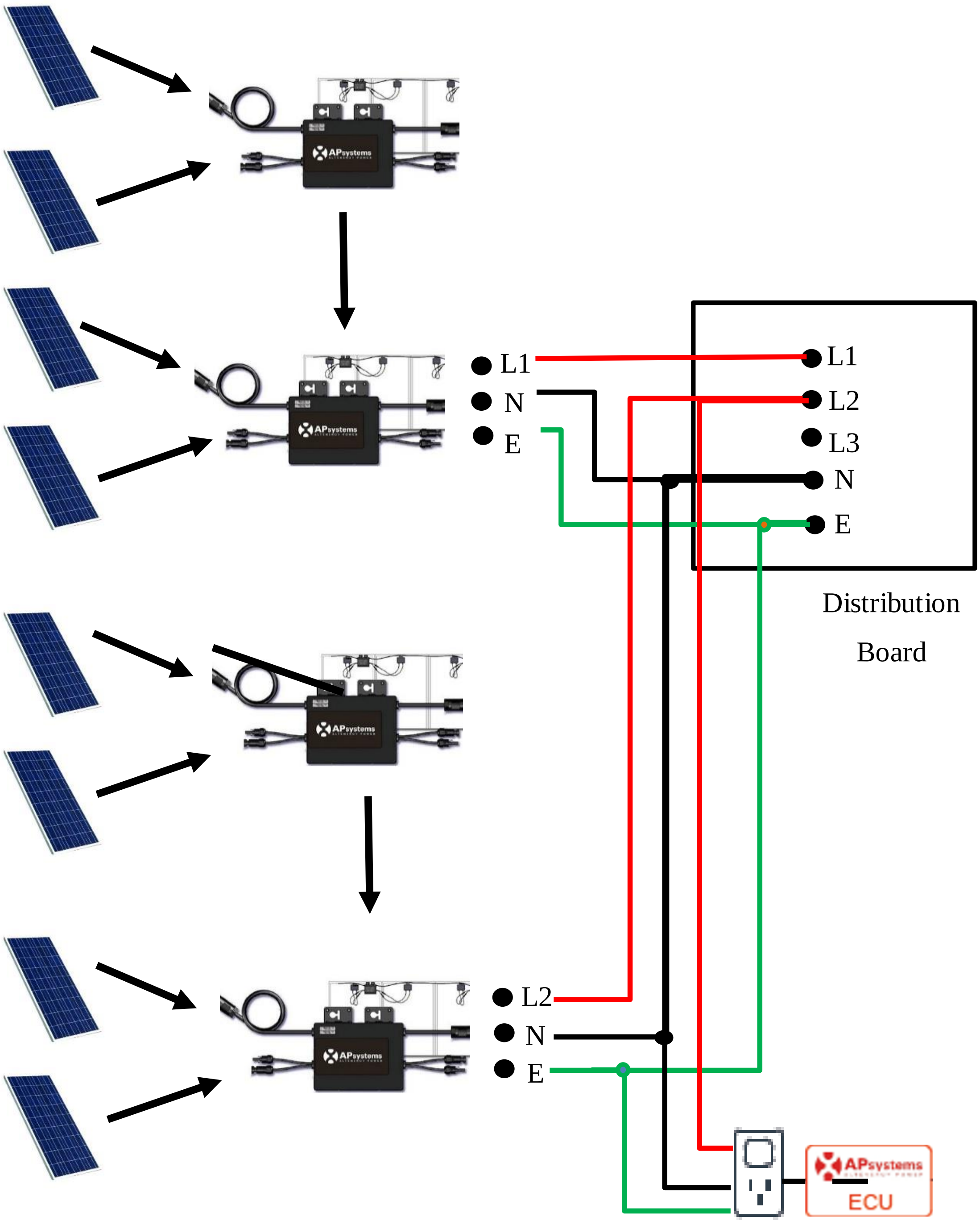


Figure 3.6: Connection of PV System

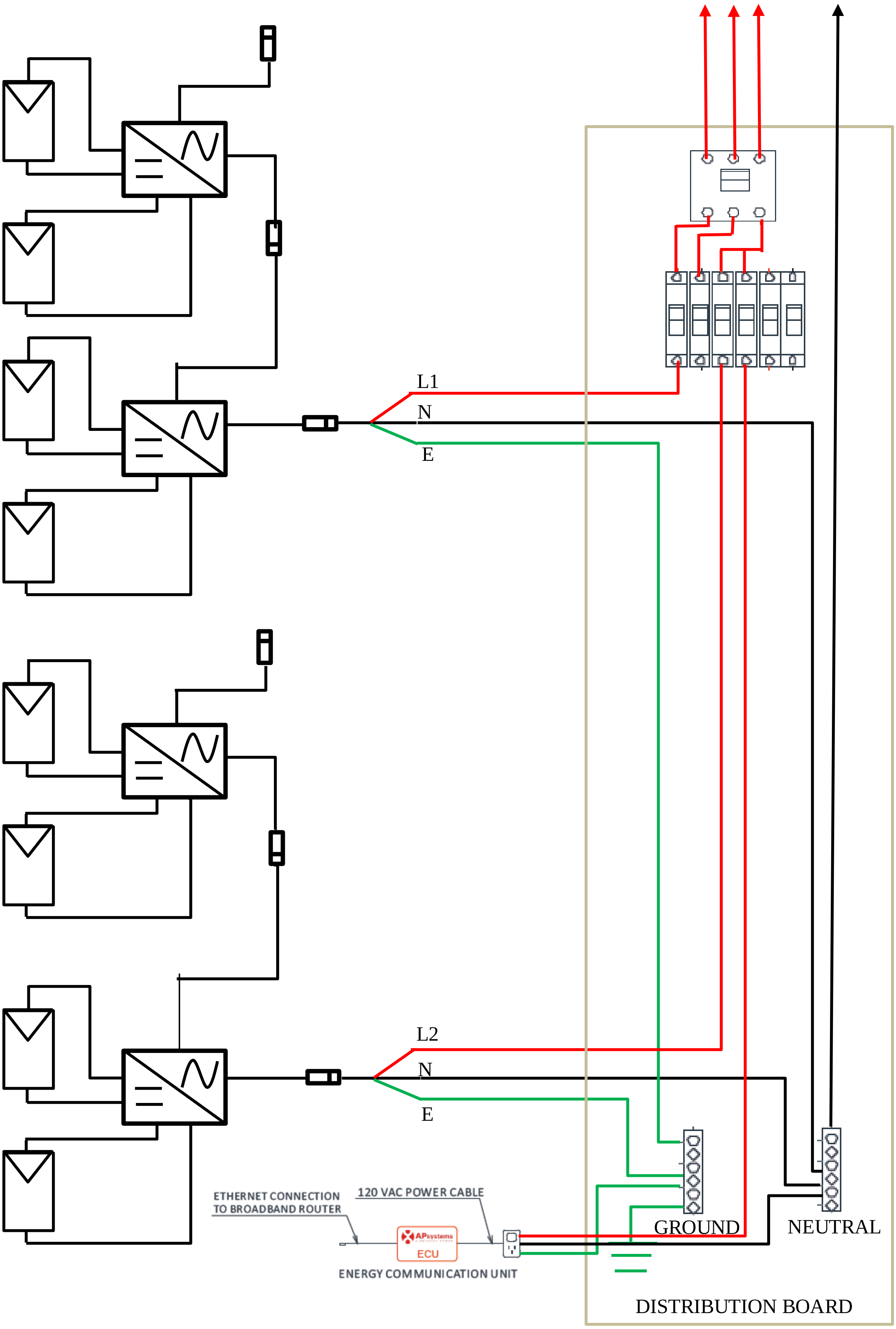


Figure 3.7: Schematic Diagram of PV system Connection

### 3.3.3 Temperature Data Logging System

Figure 3.8 shows the schematic diagram of Arduino connection with the eight temperature sensors DS18B20, which was drew by using Proteus software. As shown in Figure 3.8, all the ground pins of the sensors are linked together and connected to the GND pin of the Arduino Mega, which is 0 V whereas the VCC pins of all the sensors are connected to +5 V from Arduino. The pull-up resistors with 4.7 k**Ω** resistance are used in the circuit as the resistors are needed on the DQ pins of all sensors to pull it up to 5 V.

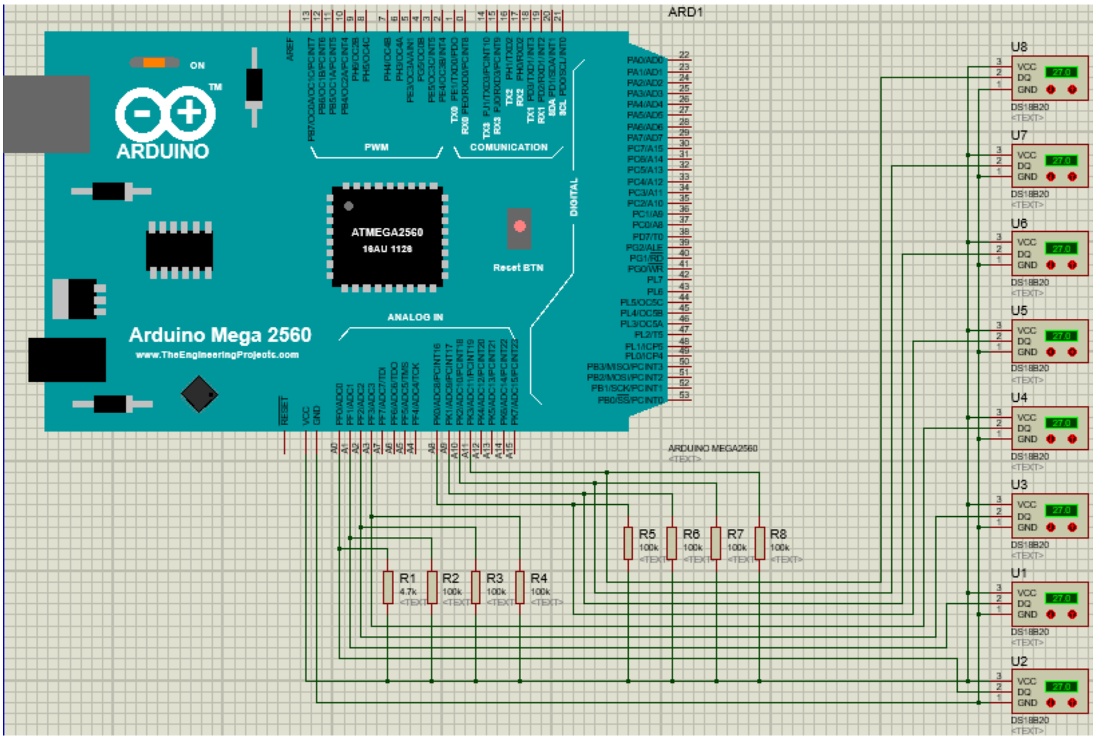


Figure 3.8: Circuit Connection of Arduino with Temperature Sensors

For the practical circuit built, the resistors, and jumping wires were soldered on a Vero board, and the jumping wires were connected to the Arduino board as shown in Figure 3.9. The temperature sensors, DS18B20 were placed under each PV panel for the analysis of temperature effects on the performance of each panel. The sensors were connected to the pin 22, 24, 26, 28, 30, 32, 34, and 36 of the Arduino Mega 2560 board, where the sensors were placed under North, North-East, East, South-East, South, South-West, West, and North-West panel respectively.

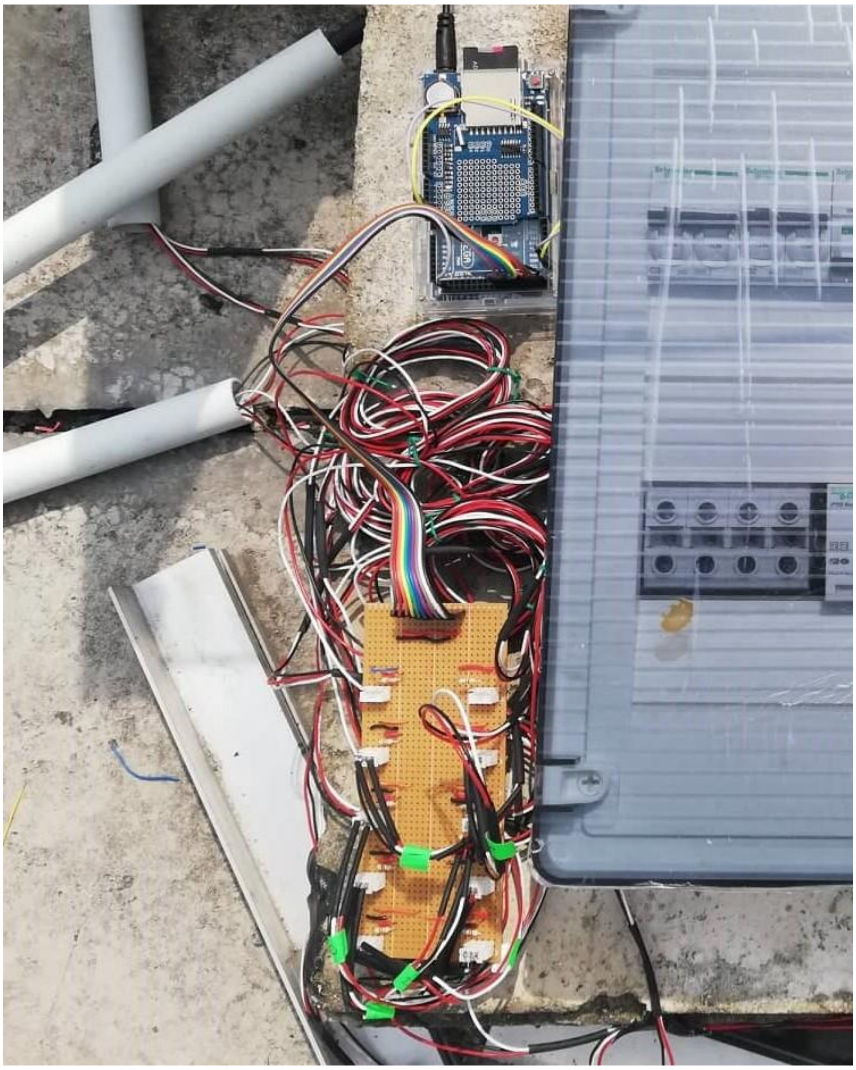

Figure 3.9: Temperature Data Logging System

The Arduino coding used to log the temperature data of each panel is shown in Appendix A. A 16 GB micro-SD card was used as the data logger for collecting and storing the temperature data from Arduino board. After all the connection completed, the temperature sensors are tested before the panels placed on the structure in order to make sure the sensors function well and correctly. The temperature data were used to compensate the temperature effect on the performance of each panel.

### 3.3.4 Performance Analysis and Comparison of Each Panel

The output power and energy generated of each panel that logged in the EMA webserver were studied and recorded. Although the same panels used were the same, but the measurement of each panel would be slightly different. Therefore, the calibration process is needed, it is the process that evaluates and adjusts the precision and accuracy of the measurement equipment.

For this project, the calibration process had been done on the PV panels in order to reduce the bias of the data collected over a range. This process was done by using IV curve tracer under strong solar irradiance, which is higher than 900 W/m$^2$, and the STC power produced by each panel were collected for the adjustment of precision and accuracy of the measurements. Since there is a range of STC power produced from the IV curve tracer, ten data of STC power from each panel, and the average of the ten data was calculated in order to have a better result. After that, a panel was chosen to be the reference panel to calculate the percentage of calibration. In this project, the North panel was chosen as the reference panel. The data collected were multiplied with the percentage of calibration so that the results could be more precise and accurate.

The performance of each panel with various orientations were analysed and compared. The output power performance of each panel was collected in the period of experiment, the performance was compared, and the differences of output power performance on different weather such as cloudy, sunny, rainy day were observed and analysed.

Apart from that, the energy generation of each panel was also collected and compared in the period of experiment. The highest and lowest energy generation of panels were measured every day, and the percentage difference of the energy generated was calculated. The energy generated in a period of one month was sum up in order to find out the optimum orientation of panel in tropical climate, and the percentage difference was also calculated for the total energy generation of each panel so that the performance of panels at different orientations could be showed clearly.

### 3.3.5 Analysis of Diffuse Solar Irradiance

The diffuse component of solar irradiance (DSI) was calculated by using the global horizontal irradiance (GHI) minus the direct normal irradiance (DNI). The DNI was measured by the weather station, and the cosine effect was calculated to get the real DNI on each orientation where the GHI was measured by the panels. The power data from panels were converted to GHI by multiplying with the module's efficiency, temperature coefficient, and divided by the area of the panel. Below shows the method and equations used for calculating the DSI in details.

Before calculating the cosine angle, the solar azimuth angle and altitude angle must be known, and the angles were derived and calculated by using the equations from 3.3 to 3.7.

$$Declination\ angle = \delta = \sin^{-1}(0.39795\cos(0.98563(N-173))) \quad (3.3)$$

$$Hour\ angle = \omega = 15\ (t_s - 12)° \quad (3.4)$$

$$Altitude\ angle = \alpha_s = \sin^{-1}(\sin\delta\sin\varphi + \cos\delta\cos\varphi) \quad (3.5)$$

$$Azimuth\ angle = \gamma_s = \sin^{-1}\left(\frac{-\cos\delta\sin\omega}{\cos\alpha}\right)\ if\ \frac{\sin\delta\cos\varphi - \cos\delta\sin\varphi}{\cos\alpha} > 0 \quad (3.6)$$

$$\gamma_s = 180 - \sin^{-1}\left(\frac{-\cos\delta\sin\omega}{\cos\alpha}\right)\ if\ \frac{\sin\delta\cos\varphi - \cos\delta\sin\varphi}{\cos\alpha} \leq 0 \quad (3.7)$$

In general, the DSI was calculated as shown in the formula:

$$DSI = GHI - DNI\ \cos\theta \quad (3.8)$$

where

DSI = direct solar irradiance, $W/m^2$

GHI = global horizontal irradiance, $W/m^2$

DNI = direct normal irradiance, $W/m^2$

In order to calculate the cosine angle for the DNI, the fixed variables, latitude angle and tilt angle were set as 3 ° and 10 ° respectively.

The Sun's position of axes (E, N, Z), where $\underline{Z}$ is unit vector normal to plan, $\underline{N}$ is unit vector pointing North, and $\underline{E}$ is the unit vector pointing towards East. The vector analysis of solar geometry was used to calculate the cosine angle, a unit vector, $\underline{S}$ is the vector that all times points towards the Sun. The vector is given by:

$$\underline{S} = \cos\alpha_s \sin\gamma_s \, \underline{E} + \cos\alpha_s \cos\gamma_s \, \underline{N} + \sin\alpha_s \, \underline{Z} \tag{3.9}$$

where
$\alpha_s$ = solar altitude angle, °
$\gamma_s$ = solar azimuth angle, °

The panels' directions were identified by the unit vector n, that normal to the panels. The vector is given by:

$$\underline{n} = \sin\beta \sin\gamma \, \underline{E} + \sin\beta \cos\gamma \, \underline{N} + \cos\beta \, \underline{Z} \tag{3.10}$$

where
$\beta$ = tilt angle, °
$\gamma$ = panel azimuth angle, °

The dot product of unit vector $\underline{n}$ and $\underline{S}$ was calculated to find out the cosine angle, the equation is given by:

$$\underline{n} \cdot \underline{S} = \cos\theta = \sin\beta \sin\gamma \cos\alpha_s \sin\gamma_s + \sin\beta \cos\gamma \cos\alpha_s \cos\gamma_s + \cos\beta \sin\alpha_s \tag{3.11}$$

where:
$\cos(\gamma - \gamma_s) = \cos\gamma \cos\gamma_s + \sin\gamma \sin\gamma_s$

$$\therefore \cos\theta = \sin\beta \cos\alpha_s \cos(\gamma - \gamma_s) + \cos\beta \sin\alpha_s \tag{3.12}$$

After calculating the cosine angles, the angles were multiplied with the DNI data from the weather station. The local clock time and the time of weather station must be synchronized in order to perform the correct calculation. The equation of time (EOT) is the different between the local apparent solar time, and the local mean solar time. An approximation for the EOT is given by:

$$EOT = 0.258\cos x - 7.416\sin x - 3.648\cos 2x - 9.228\sin 2x \quad (3.13)$$

where

EOT = equation of time, minutes

$x = \dfrac{360(N-1)}{365.242}$ ,°

N = day number

The equation of the conversion between solar time and local time is given by:

$$LCT = t_s - \frac{EOT}{60} + LC \quad (3.14)$$

where

LCT = local clock time, hours

$LC = \dfrac{Longitude\ of\ standard\ time\ zone\ meridian - local\ longitude}{15}$ , h

## 3.4 Researches on Materials and Equipment

Generally, there are various types of hardware parts and components required for the project. Among all the parts and components used in the project, the research is done on the important and significant parts for the project. The outlines of the research include solar panel, micro inverter, Arduino Mega, and temperature sensor. Other than that, the software, Arduino IDE is required to be programmed for the temperature data collection.

### 3.4.1 Solar Panel

Figure 3.10 shows the solar panel; solar panel is the most important parts that used in this proposed project. There are eight solar panels used in the proposed project and the solar panels used are all identical which the number of cell is 60, and the maximum power, $P_{max}$ is 260 W. The reason that all the solar panels used are identical is to standardize the output power performance from each of the panel so that the analysis will be accurate and easier. Table 3.1 shows the other features of the solar panels.

Figure 3.10: Solar Panel

Table 3.1: Features of Solar Panel

| | **Solar Panel** |
|---|---|
| **Number of Cell** | 60 |
| **Maximum Power, $P_{max}$** | 260 W |
| **Voltage at Maximum Power, $V_{mpp}$** | 30.541 V |
| **Current at Maximum Power, $I_{mpp}$** | 8.525 A |
| **Open Circuit Voltage, $V_{oc}$** | 38.235 V |
| **Maximum System Voltage** | 1000 V |

### 3.4.2 Micro-inverter YC500A

Micro-inverter is a device that normally used in PV system for the conversion from DC to AC. Figure 3.11 shows the micro-inverter YC500A that used in the project.

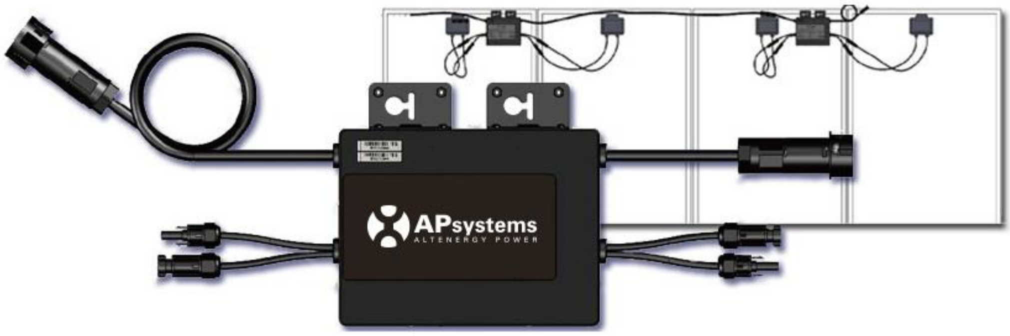


Figure 3.11: Micro-inverter YC500A (APsystems, n.d.)

The APsystems micro-inverters are used in the proposed project where Table 3.2 shows the features of micro-inverter YC500A. This micro-inverter has a higher reliability than the other inverters such as string and centralized inverters. It can operate at the full power for the surrounding temperature below 65 °C. Furthermore, its maximum power point tracking (MPPT) control can maximize the output energy of the PV panels. (APsystems, n.d.)

Besides that, it is easy to be installed. The PV module with various power rate, quantity, type and orientation can also be installed easily. (APsystems, n.d.) This micro-inverter will be a good choice, as the proposed project setup the PV panels in an orthogonal orientation.

Table 3.2: Features of Micro-inverter YC500A (APsystems, n.d.)

| | **Micro-inverter YC500A** |
|---|---|
| **Max. Output Power, $P_{out(max)}$** | 500 W |
| **Max. Input Voltage, $V_{in(max)}$** | 55 V |
| **Operating Voltage Range** | 16 V to 52 V |
| **Peak Efficiency** | 95.5 % |
| **Operating Ambient Temperature Range** | -40 °C to +65 °C |
| **MPPT** | One for each module |

Apart from micro-inverters, it also consists of the energy communication unit (ECU) and the energy monitor and analysis (EMA) web-based monitoring and analysis system.

For the ECU, it is used to collect the statistics of the output performance from each of the micro-inverter and send the real time data to the EMA database. Therefore, a broadband router is needed to connect the ECU for the transfer of data. Besides that, ECU is integrated with the http webserver, which is easy to access, flexible and user-friendly. (APsystems, n.d.) Figure 3.12 shows the ECU used in the proposed project.


Figure 3.12: ECU (APsystems, n.d.)

For the EMA software, the performance of each module will be analysed, reported, and updated to the web server automatically. The users are able to monitor and access to the real time data from anywhere. Therefore, the data logging will be very convenient and simple. Table 3.3 shows the features of EMA software.

Table 3.3: Features of EMA Software (APsystems, n.d.)

| | **EMA software** |
|---|---|
| **Monitoring and Analysis** | Each solar module and micro-inverter |
| **Access Method** | Remotely |
| **Communication** | Real time |

### 3.4.3 Arduino Mega 2560

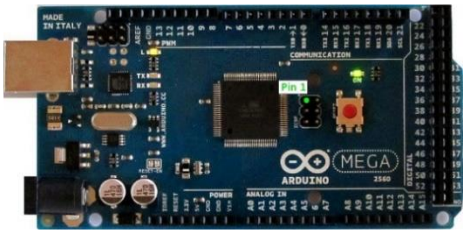

Figure 3.13: Arduino Mega 2560

The Arduino Mega 2560 as shown in Figure 3.13 is a board of micro-controller based on the ATmega 2560. The board can be used to connect to the computer by its USB cable port. Besides that, the board can be powered up by using battery or power jack. (Adnan, 2018) For this proposed project, the method to power up the board is to use the power jack. There are some reasons that Arduino Mega is used in this proposed project like larger memory space, more I/O pins and so on.

Table 3.4: Comparison between Arduino Mega 2560 and Uno ("Review of Arduino Mega 2560," 2011)

| | **Arduino Mega 2560** | **Arduino Uno** |
|---|---|---|
| **Digital I/O** | 54 | 14 |
| **Analog I/O** | 16 | 6 |
| **PWM** | 14 | 6 |
| **Serial** | 4 | 1 |
| **Interrupt Pins** | 5 | 2 |
| **RAM** | 8 | 2 |

For the proposed project, Mega 2560 is a better choice compared to Uno. Table 3.4 shows the comparison between Arduino Mega 2560 and Arduino Uno. Firstly, the input and output pins are the most important things to be considered when choosing the Arduino board. As the Arduino board is used to connect with eight temperature sensors, which the data collected is in analog form, so the analog pins are needed. Therefore, Mega 2560 has the enough analog pins for the sensors but Uno has not enough. Besides, Mega 2560 has more pins left where it allows further improvement or studies to be done in the future. ("Review of Arduino Mega 2560," 2011)

### 3.4.4 Temperature Sensor – DS18B20


Figure 3.14: Temperature Sensor DS18B20

The temperature sensors are used to measure the temperature of solar panels for purpose of analysing temperature effect on the performance of panels. The DS18B20 temperature sensor as shown in Figure 3.14 is used in this project. The features of this sensor are shown in Table 3.5. Other than that, the pin configurations of this sensor are shown in Figure 3.15.

Table 3.5: Features of DS18B20 Temperature Sensor ("DS18B20 (digital temperature sensor) and Arduino," n.d.)

| | |
|---|---|
| **Operating Voltage** | 3.0 V – 5.5 V |
| **Range of Measured Temperature** | -55 °C – 125 °C |

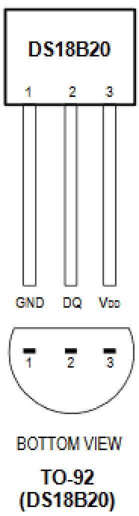


Figure 3.15: Pin Configuration of Temperature Sensor DS18B20

## 3.5 Comparison between Existing Studies with Proposed Project

The comparison of the proposed project with the existing studies is shown in Table 3.6. The comparison consists of number of PV panel used in the study, the time for collecting data, and the location of study.

Table 3.6: Comparison between Existing Studies with Proposed Project

| Studies and Project | Type of Feature | | | |
|---|---|---|---|---|
| | **No. of PV Panel** | **Time for Collecting Data** | **No of Temperature Sensor** | **Location** |
| **1. Orientation Effects on Solar Panel** | 3 | 3 week | 0 | Haramaya University, Ethiopia |
| **2. Temperature Effect on Solar Panel** | 1 | 1 day | 4 | Perlis, Malaysia |
| **3. Tilt Angle Effects on Solar Panel** | 6 | 5 month | 0 | Kerman, Iran |
| **Proposed Project** | 8 | 1 month | 8 | Sg.Long, Selangor, Malaysia |

As shown in the Table 3.6, the number of solar panels used in the proposed project is the highest among all of the existing studies that have been reviewed. The PV panels that used in the first study were only three, which is five less than the proposed project. The higher the number of solar panels is being used in the outdoor experiment, the higher the accuracy, credibility, and reliability of the results obtained and analysed from the study. Therefore, the proposed project is much better than the existing studies.

Besides that, the time for collecting the data of the proposed project is longer than the first and second studies. Not even the time for collecting the data is longer, the data collected will also be more detail and precise. For example, the data collected by the first study, which is the orientation effects on the solar panels, the solar panels were changing the orientation of the panels from 0 ° to 90 ° within a day. This means that the data collected for an angle was just for a short period of time only. For the proposed project, the eight solar panels will be fixes at an orthogonal orientation for a period of one month. Therefore, the results analysed will be more reliable.

Moreover, the temperature sensors used in the proposed project are higher than the other existing studies. Eight sensors are used for the proposed project in order to check the effects of operating temperature to the output performance of the PV system. For the first and third studies, there was no temperature sensors used, which means that they did not consider this factor in their studies. For the second studies, there were only four temperature sensors used, the sensors are still lesser than the sensors used in proposed project although the focus of that study was on temperature factor.

Lastly, the location for studies of the proposed project is different with all of the existing studies. This means that the Sg. Long area did not have this kind of study before and therefore, it is good that running the proposed project so that the areas in or near Sg. Long are able to know the best orientation of placing the solar panels. The orientation of solar panels cannot be following the others places and thumb of rule as the factors like weather, dust, shading, temperature and so on are different from place to place.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

The PV system and the temperature data logging system were setup successfully, and the results are going to be discussed in this chapter. Firstly, the justification of the location for orthogonal structure, which was done for reducing the shading effect on the PV panels, and the shading time were discussed. Besides, the calibration process was done and the percentage difference between panels was calculated. Moreover, the analysis and comparison of energy generation of each panel at various orientations were done and discussed. Lastly, the analysis on the diffuse component of solar irradiance was done and discussed in the last part of this chapter.

## 4.2 Justification for Orthogonal Structure's Location

This subsection will show the sun path charts for all the eight panels used in this project, including the blocking area and time for each panel. Since the space on the rooftop is limited because of the existing weather station, cooling system, building and chiller. Therefore, the blocking area on panels can only be minimized but cannot be fully eliminated. Since the sunrise and sunset time are different from day to day, and thus, the sunrise and sunset time are set to be 7:30 a.m. and 7:30 p.m. respectively for this analysis.

Figure 4.1 shows the sun path chart for North panel. During the morning time, the highest altitude angle that blocked by the building is around 12 °, which means the solar irradiance will be blocked for 51 minutes until 8:21 a.m. Meanwhile, the highest altitude angle blocked by the chiller is around 15 ° for the evening time, thus the solar irradiance will be blocked for 64 minutes from 6:26 p.m. until sunset.

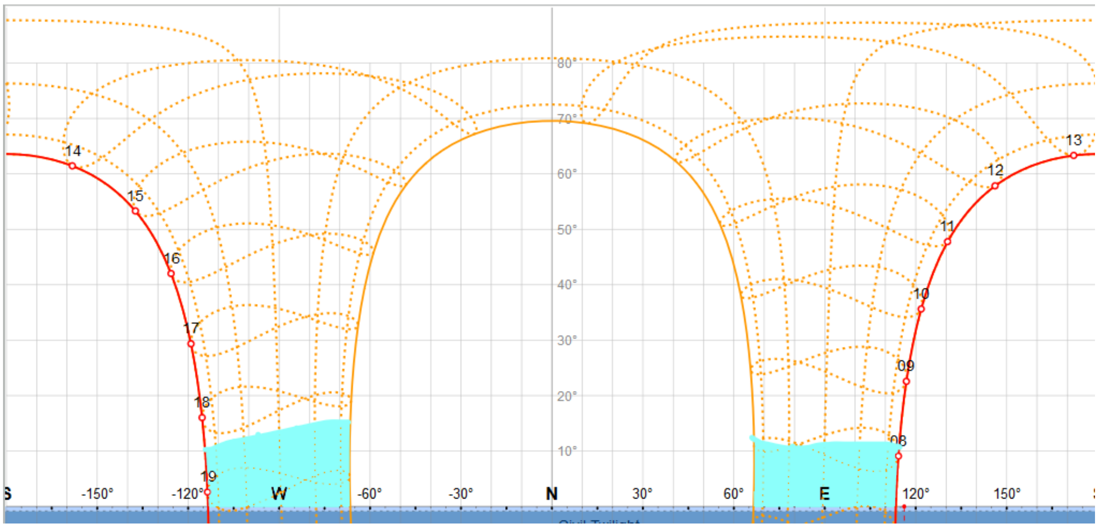


Figure 4.1: Sun Path Chart for North Panel

Figure 4.2 shows the sun path chart for North-East panel. The highest altitude angle that blocked by the building is around 14 ° at the morning, which means the solar irradiance will be blocked until 8:30 a.m. For the evening, the highest altitude angle found is around 12 °, which means the solar irradiance will be blocked from 6:39 p.m. until sunset.

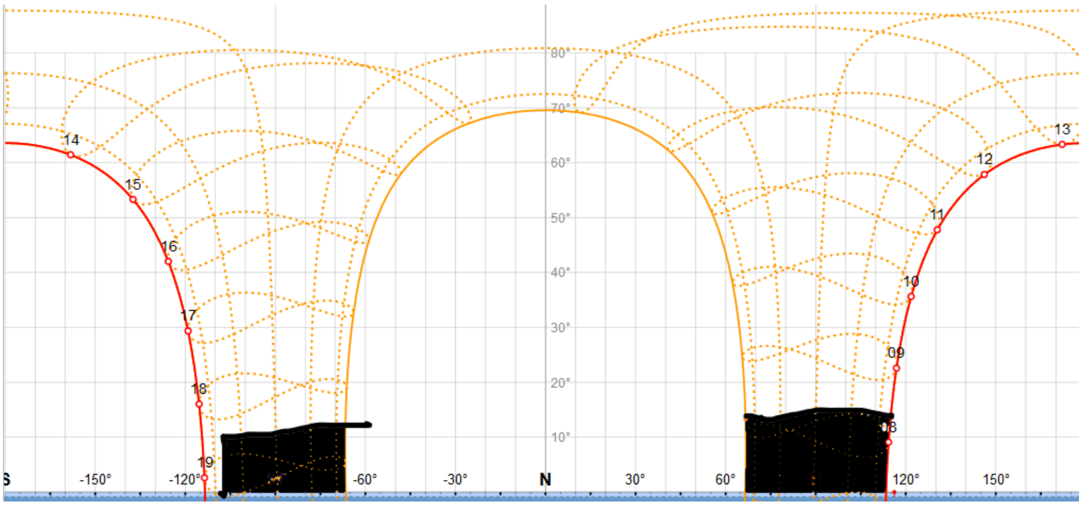


Figure 4.2: Sun Path Chart for North-East Panel

Figure 4.3 shows the sun path chart for the East panel. The highest altitude angle that blocked by the building is around 16 ° at the morning, which means the solar irradiance will be blocked until 8:38 a.m. For the evening, the highest altitude angle measured is around 10 °, which means the solar irradiance will be blocked from 6:47 p.m. until sunset.

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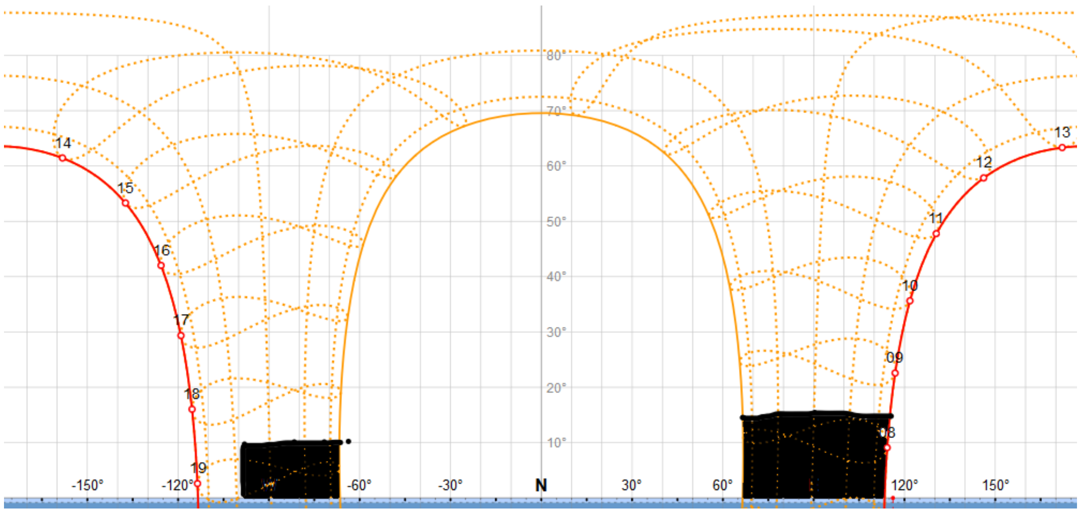


Figure 4.3: Sun Path Chart for East Panel

Figure 4.4 shows the sun path chart for the South-East panel. The highest altitude angle that blocked by the building is around 15 ° at the morning, which means the solar irradiance will be blocked from sunrise until 8:34 a.m. For the evening, the highest altitude angle found is around 17 °, which means the solar irradiance will be blocked from 6: 17 p.m. until sunset.

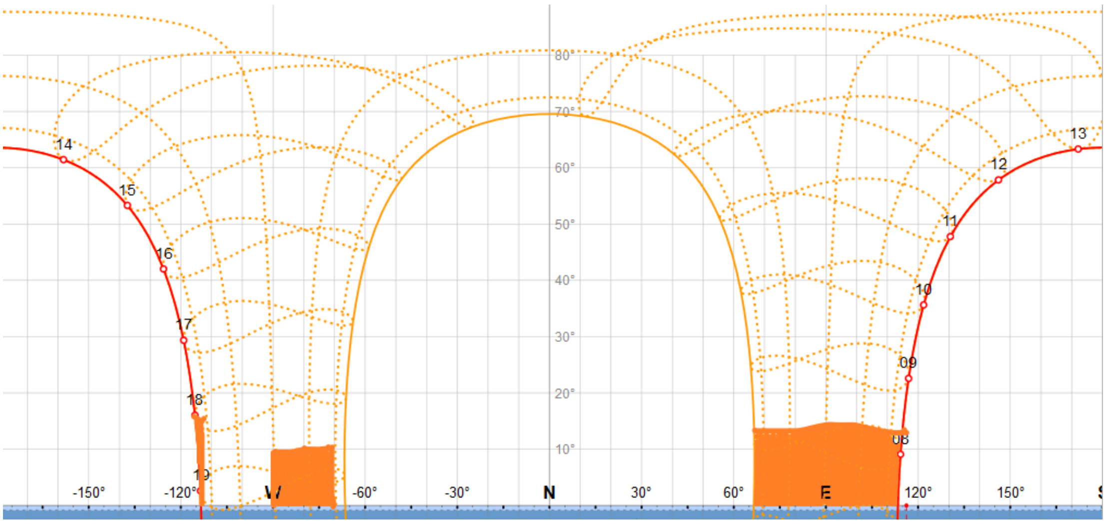


Figure 4.4: Sun Path Chart for South-East Panel

Figure 4.5 shows the sun path chart for the South panel. The highest altitude angle that blocked by the building is around 12 ° at the morning, which means the solar irradiance will be blocked from sunrise until 8:21 a.m. For the evening, the highest altitude angle found is around 26 °, which means the solar irradiance will be blocked from 5: 39 p.m. until sunset.

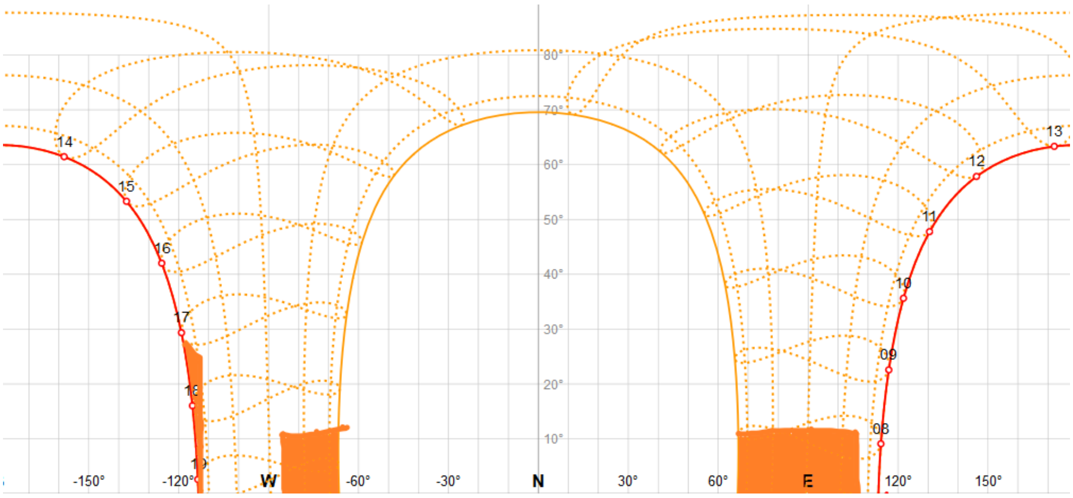


Figure 4.5: Sun Path Chart for South Panel

Figure 4.6 shows the sun path chart for the South-West panel. The highest altitude angle that blocked by the building is around 10 ° at the morning, which means the solar irradiance will be blocked from sunrise until 8:13 a.m. For the evening, the highest altitude angle found is around 15 °, which means the solar irradiance will be blocked from 6:26 p.m.until sunset

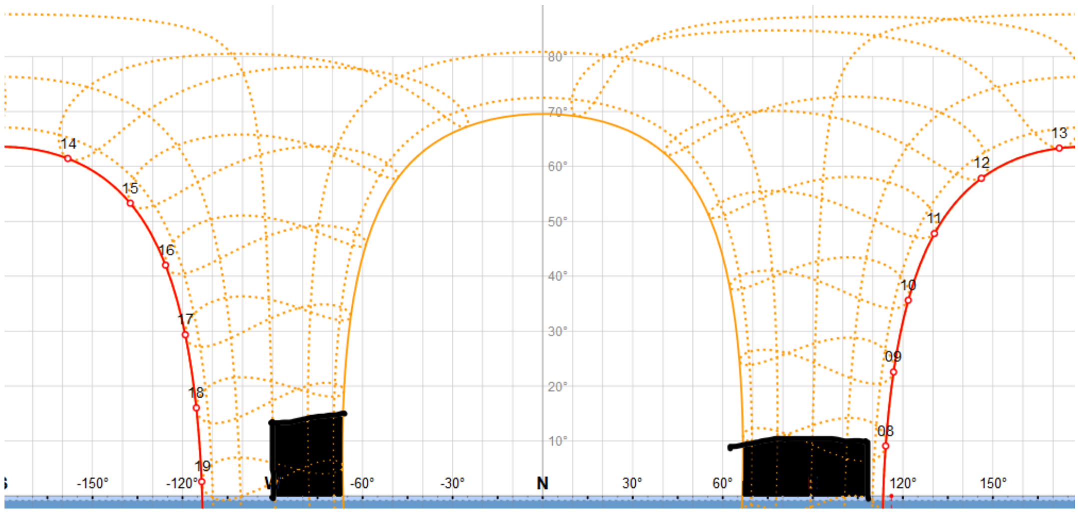


Figure 4.6: Sun Path Chart for South-West Panel

Figure 4.7 shows the sun path chart for the West panel. The highest altitude angle that blocked by the building is around 10 ° at the morning, which means the solar irradiance will be blocked from sunrise until 8:13 a.m. For the evening, the highest altitude angle found is around 17 °, which means the solar irradiance will be blocked from 6: 17 p.m. until sunset.

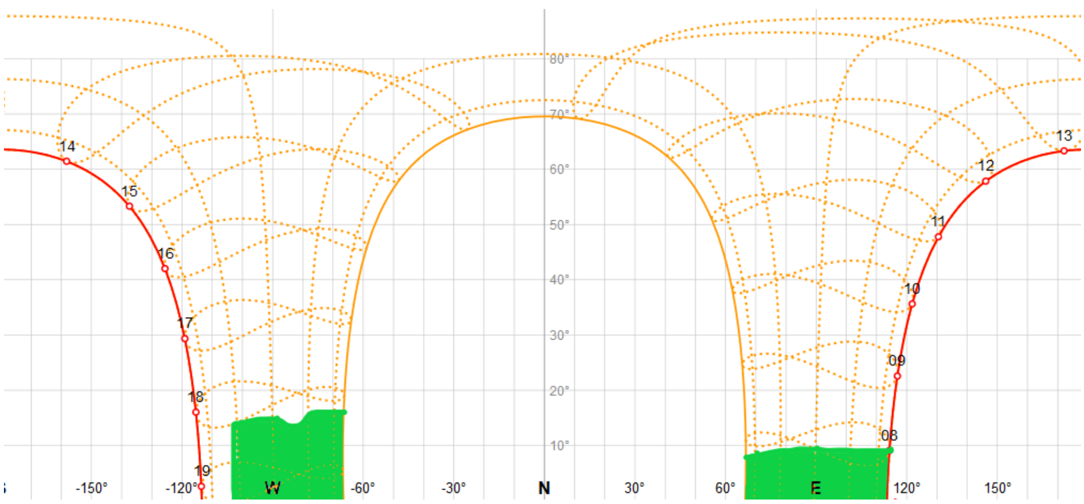


Figure 4.7: Sun Path Chart for West Panel

Figure 4.8 shows the sun path chart for the North-West panel. The highest altitude angle that blocked by the building is around 11 ° at the morning, which means the solar irradiance will be blocked from sunrise until 8:17 a.m. For the evening, the highest altitude angle found is around 17 °, which means the solar irradiance will be blocked from 6: 17 p.m. until sunset.

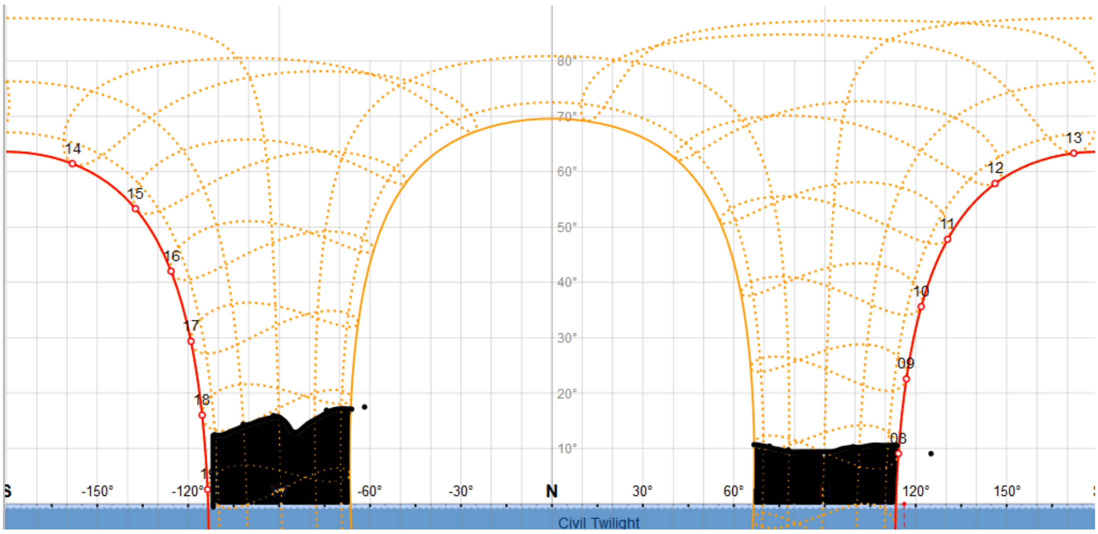


Figure 4.8: Sun Path Chart for North-West Panel

Most of the PV panels will not receive the direct solar irradiance for one hour from the sunrise and one hour before the sunset. Moreover, there are three panels, South-East, West, and North-West panel will be shaded for 73 minutes before the sunset. Since this project is needed to study the performance comparison between PV panels with various orientations, the justification must be fair for all the panels. Therefore, the period for data collection is adjusted so that the accuracy of the analysis can be guaranteed. For this project, the time to collect the data is starting from 8:43 a.m. whereas the data collection is ending by 6:17 p.m., which means that data collected for the first 73 minutes from sunrise and the last 73 minutes before sunset will not be used in the analysis.

## 4.3 Solar Panel Calibration

Table 4.1 shows the measured and calculated calibration data of the PV panels. Since there is a range for the STC power measurement from the IV curve tracer and therefore, the average of STC power is calculated for better accuracy. Besides that, STC power of any panel can be set as a reference for the adjustment of the precision and accuracy of the measurements. For this project, the North panel is chosen as the reference panel for the further calculation, the actual power generated by the solar panels will be multiplied according to the percentage difference relative to North panel as shown in Table 4.1 for the better accuracy of power measurements.

Table 4.1: Calibration for PV Panels

| Panel | Overall average STC power, W | Difference relative to North panel, % |
|---|---|---|
| **North** | 230.3667 | - |
| **North-East** | 243.5769 | + 5.7374 |
| **East** | 227.8786 | - 1.0810 |
| **South-East** | 247.1000 | + 7.2622 |
| **South** | 244.4200 | + 6.0989 |
| **South-West** | 224.8833 | - 2.3830 |
| **West** | 244.8143 | + 6.2682 |
| **North-West** | 225.5630 | - 2.0880 |

## 4.4 Energy Generation in a Period of One Month

Table 4.2 and Graph 4.9 show the energy generation of each panel for a period of one month. The sun position is relatively closer to the South from February to March, and therefore, the panels that faced South would receive the higher solar irradiance during this period. According to the statement above, the South, South-East, and South-West panels would have the higher energy generation compared to the others.

According to Table 4.2, the results measured shows that the East panel generated the highest energy of 33.212 kWh in this period. The energy generation by South, South-East, and South-West were slightly lower, which are 33.029 kWh, 32.918 kWh, and 33.194 kWh respectively, where the North-West panel generated the lowest energy among all, which is only 30.353 kWh.

Table 4.3 shows the percentage difference of the energy generated by each panel. The East panel was set as the reference for calculating the percentage difference. For the overall percentage difference, the energy generated by South-West panel was only less than 0.05 % compared to the East panel, whereas the North-West panel less than 8.61 % compared to East panel. The highest percentage difference was the East and North-West panels, which was up to 17.37 % in a day. This was a huge difference, and this indicates that the orientation of the panels is very important in maximizing the power output.

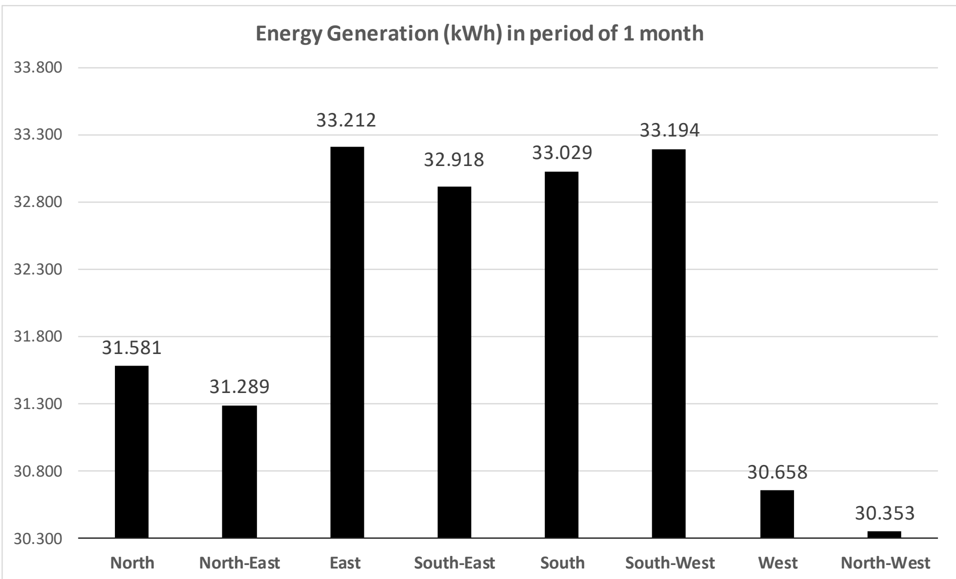


Figure 4.9: Energy Generation of Each Panel in Period of One Month

Table 4.2: Energy Generation for Period of 1 Month

| Date | Energy Generation (kWh) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** |
| **17/2** | 0.983 | 0.968 | 1.025 | 1.031 | 1.043 | 1.061 | 0.954 | 0.950 |
| **18/2** | 0.761 | 0.729 | 0.769 | 0.766 | 0.784 | 0.821 | 0.754 | 0.725 |
| **19/2** | 0.661 | 0.679 | 0.746 | 0.719 | 0.705 | 0.685 | 0.618 | 0.617 |
| **20/2** | 1.003 | 0.987 | 1.045 | 1.039 | 1.059 | 1.099 | 1.019 | 0.992 |
| **21/2** | 1.245 | 1.213 | 1.287 | 1.321 | 1.351 | 1.347 | 1.233 | 1.203 |
| **22/2** | 1.119 | 1.144 | 1.217 | 1.208 | 1.207 | 1.197 | 1.087 | 1.076 |
| **23/2** | 1.164 | 1.174 | 1.270 | 1.265 | 1.265 | 1.242 | 1.146 | 1.140 |
| **24/2** | 1.096 | 1.098 | 1.157 | 1.170 | 1.151 | 1.131 | 1.046 | 1.021 |
| **25/2** | 1.324 | 1.291 | 1.372 | 1.372 | 1.426 | 1.414 | 1.325 | 1.298 |
| **26/2** | 1.162 | 1.163 | 1.248 | 1.235 | 1.225 | 1.229 | 1.116 | 1.087 |
| **27/2** | 1.084 | 1.119 | 1.210 | 1.182 | 1.142 | 1.138 | 1.041 | 1.027 |
| **28/2** | 0.978 | 0.972 | 1.018 | 1.015 | 1.008 | 1.024 | 0.941 | 0.926 |
| **1/3** | 0.764 | 0.756 | 0.830 | 0.813 | 0.800 | 0.781 | 0.705 | 0.702 |
| **2/3** | 1.023 | 1.048 | 1.123 | 1.112 | 1.094 | 1.069 | 0.980 | 0.968 |
| **3/3** | 1.046 | 1.032 | 1.115 | 1.094 | 1.103 | 1.102 | 1.001 | 0.993 |
| **4/3** | 0.954 | 0.912 | 0.974 | 0.975 | 0.967 | 0.999 | 0.927 | 0.901 |
| **5/3** | 1.128 | 1.105 | 1.181 | 1.156 | 1.188 | 1.198 | 1.119 | 1.069 |
| **6/3** | 1.026 | 0.985 | 1.035 | 1.039 | 1.057 | 1.100 | 1.026 | 1.010 |
| **7/3** | 0.884 | 0.886 | 0.949 | 0.941 | 0.922 | 0.894 | 0.810 | 0.815 |
| **8/3** | 1.195 | 1.162 | 1.234 | 1.231 | 1.233 | 1.243 | 1.149 | 1.134 |
| **9/3** | 1.111 | 1.128 | 1.176 | 1.159 | 1.162 | 1.169 | 1.073 | 1.082 |
| **10/3** | 1.224 | 1.199 | 1.284 | 1.241 | 1.251 | 1.262 | 1.176 | 1.173 |
| **11/3** | 1.006 | 1.010 | 1.050 | 1.034 | 1.036 | 1.050 | 0.964 | 0.984 |
| **12/3** | 1.213 | 1.209 | 1.275 | 1.251 | 1.261 | 1.291 | 1.202 | 1.200 |
| **13/3** | 1.033 | 1.057 | 1.122 | 1.100 | 1.091 | 1.076 | 0.996 | 0.998 |
| **14/3** | 1.317 | 1.285 | 1.334 | 1.316 | 1.330 | 1.360 | 1.287 | 1.269 |
| **15/3** | 1.308 | 1.280 | 1.360 | 1.338 | 1.360 | 1.358 | 1.273 | 1.268 |
| **16/3** | 1.408 | 1.382 | 1.438 | 1.421 | 1.435 | 1.462 | 1.361 | 1.391 |
| **17/3** | 1.361 | 1.317 | 1.368 | 1.375 | 1.371 | 1.394 | 1.327 | 1.334 |
| **Sum** | 31.581 | 31.289 | 33.212 | 32.918 | 33.029 | 33.194 | 30.658 | 30.353 |

Table 4.3: Percentage Difference of Energy of Each Panel

| Date | Percentage Difference (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | N | NE | E | SE | S | SW | W | NW |
| **17/2** | -4.16 | -5.57 | - | 0.59 | 1.77 | 3.43 | -6.94 | -7.32 |
| **18/2** | -1.09 | -5.24 | - | -0.44 | 1.94 | 6.67 | -2.00 | -5.81 |
| **19/2** | -11.40 | -9.07 | - | -3.63 | -5.57 | -8.19 | -17.23 | -17.37 |
| **20/2** | -4.01 | -5.56 | - | -0.60 | 1.39 | 5.19 | -2.48 | -5.07 |
| **21/2** | -3.31 | -5.81 | - | 2.65 | 4.94 | 4.60 | -4.19 | -6.55 |
| **22/2** | -8.05 | -6.00 | - | -0.78 | -0.89 | -1.63 | -10.74 | -11.64 |
| **23/2** | -8.33 | -7.51 | - | -0.35 | -0.36 | -2.20 | -9.71 | -10.21 |
| **24/2** | -5.30 | -5.07 | - | 1.13 | -0.52 | -2.24 | -9.63 | -11.73 |
| **25/2** | -3.48 | -5.87 | - | 0.01 | 3.99 | 3.06 | -3.42 | -5.34 |
| **26/2** | -6.84 | -6.76 | - | -1.03 | -1.81 | -1.51 | -10.55 | -12.85 |
| **27/2** | -10.44 | -7.57 | - | -2.36 | -5.63 | -5.99 | -13.97 | -15.17 |
| **28/2** | -3.91 | -4.56 | - | -0.35 | -0.95 | 0.61 | -7.56 | -9.03 |
| **1/3** | -8.04 | -9.00 | - | -2.05 | -3.62 | -5.99 | -15.08 | -15.43 |
| **2/3** | -8.84 | -6.64 | - | -0.98 | -2.59 | -4.76 | -12.73 | -13.78 |
| **3/3** | -6.12 | -7.46 | - | -1.88 | -1.01 | -1.18 | -10.22 | -10.91 |
| **4/3** | -2.09 | -6.44 | - | 0.02 | -0.71 | 2.57 | -4.85 | -7.58 |
| **5/3** | -4.46 | -6.46 | - | -2.15 | 0.60 | 1.47 | -5.22 | -9.49 |
| **6/3** | -0.94 | -4.84 | - | 0.39 | 2.08 | 6.22 | -0.86 | -2.47 |
| **7/3** | -6.78 | -6.59 | - | -0.83 | -2.86 | -5.79 | -14.58 | -14.09 |
| **8/3** | -3.17 | -5.81 | - | -0.21 | -0.08 | 0.71 | -6.85 | -8.07 |
| **9/3** | -5.52 | -4.10 | - | -1.40 | -1.16 | -0.60 | -8.76 | -8.01 |
| **10/3** | -4.69 | -6.60 | - | -3.40 | -2.56 | -1.74 | -8.41 | -8.66 |
| **11/3** | -4.19 | -3.81 | - | -1.51 | -1.37 | 0.02 | -8.17 | -6.33 |
| **12/3** | -4.89 | -5.16 | - | -1.90 | -1.08 | 1.25 | -5.70 | -5.85 |
| **13/3** | -7.90 | -5.79 | - | -1.94 | -2.77 | -4.04 | -11.17 | -11.02 |
| **14/3** | -1.24 | -3.64 | - | -1.33 | -0.24 | 1.99 | -3.53 | -4.82 |
| **15/3** | -3.83 | -5.88 | - | -1.57 | 0.00 | -0.16 | -6.34 | -6.76 |
| **16/3** | -2.11 | -3.90 | - | -1.20 | -0.21 | 1.64 | -5.38 | -3.28 |
| **17/3** | -0.53 | -3.73 | - | 0.51 | 0.20 | 1.90 | -3.01 | -2.47 |
| **Sum** | -4.91 | -5.79 | - | 0.89 | -0.55 | -0.05 | -7.69 | -8.61 |

The practical results found are different from the theoretical results due to the weather in tropical climate. For example, the weather on 2019-03-16 was a clear sunny day, there was no cloud, and no raining. As shown in Figure 4.10, the East panel generated the highest power in the morning time but it also generated the lowest power after the noontime. On the other hand, the South-West panel generated the highest power after the noontime. After adding up the power generated in whole day, the power generated by the South-West panel was higher the East panel. Therefore, the South-West panel energy generated (1.462 kWh) was 0.024 kWh higher than the East panel energy generated (1.438 kWh) as shown in Table 4.2.

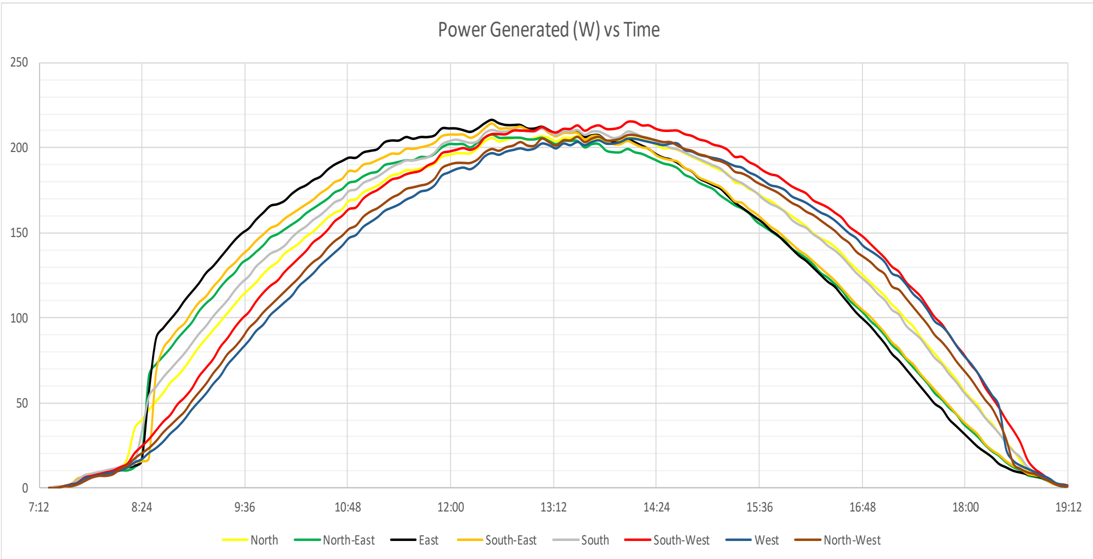

Figure 4.10: Power Generated by Each Panel on 2019-03-16

However, the weather in tropical climate is always rainy, hot and humid. For example, the weather on 2019-02-24 was a cloudy and rainy day, and the rainfall was happened after noontime. As shown in Figure 4.11, the East panel generated the highest power in the morning period. The South-West panel was generated the highest power after the noontime, but the solar irradiance within that period was shaded by the cloud, and the rain happened. Therefore, the overall energy generated by the East panel was the highest on that day. The East panel energy generated (1.157 kWh) was 0.026 kWh higher than the East panel energy generated (1.131 kWh) as shown in Table 4.2.

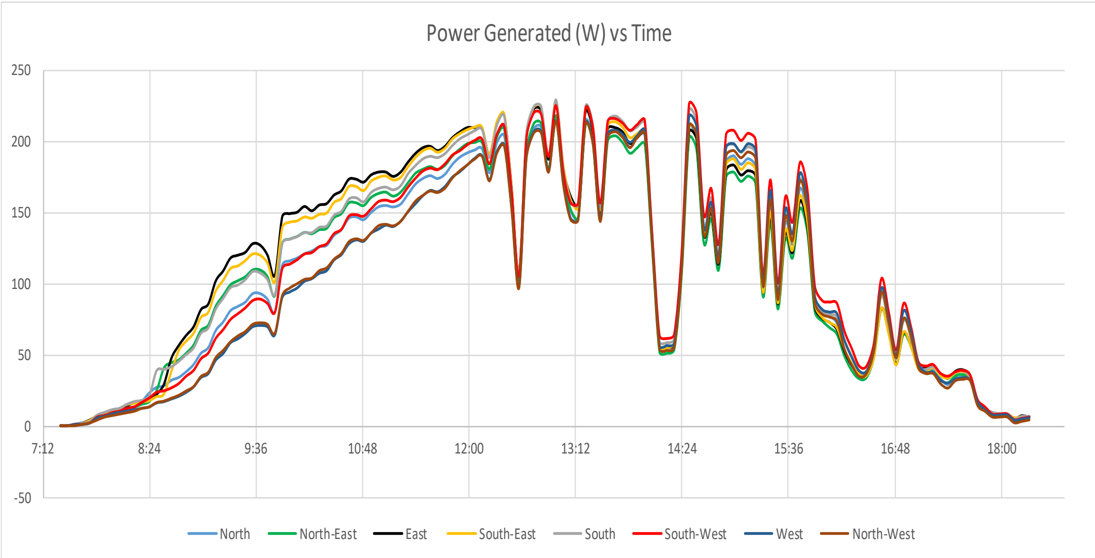


Figure 4.11: Power Generated by Each Panel on 2019-02-24

The afternoon rainfall was always happened from February to March, and especially March is the third wettest month of the whole year. Since the rainfall likely, to happen after the noontime, and therefore, the solar irradiance in the morning time was higher compared to the noontime. Therefore, this is the reason that the East panel had the highest energy generation within this period.

## 4.5 Diffuse Component of Solar Irradiance

Diffuse solar irradiance (DSI) is the irradiance that scattered by the molecules and particles in the atmosphere, and the irradiance still reach the surface of Earth. When the weather is a clear sunny day, the DSI would only consist about 15 % of the total insolation. On the other hand, when the atmospheric conditions such as clouds, dust, and other pollutions, the percentage of DSI would increase, and it would go up to 100 % of the solar irradiance when the weather is extremely overcast.

The characteristics of the weather in tropical climate are always cloudy, rainy, humid, and the air pollutions like haze are always happened in the tropical climate. Therefore, the percentage of DSI significant and it is also important in ensuring the power output is maximized. If the DSI is isotropic in tropical climate, then the factor to consider when installing the panels is to obtain the maximum direct normal irradiance (DNI). However, if the DSI is anisotropic in tropical climate, then the DSI is also needed to take into account when doing the installation.

Table 4.4 and Figure 4.12 show the DSI of each panel for a period of 22 days. As shown in Table 4.4, within the period of study, the DSI was found to be anisotropic in tropical climate, where the South-West oriented panel received the highest DSI every day, and the total DSI measured for South-West panel was 2156979 W/m$^2$. On the other hand, the North-East oriented panel received the lowest DSI in this period, the total DSI measured for North-East panel was only 492970 W/m$^2$.

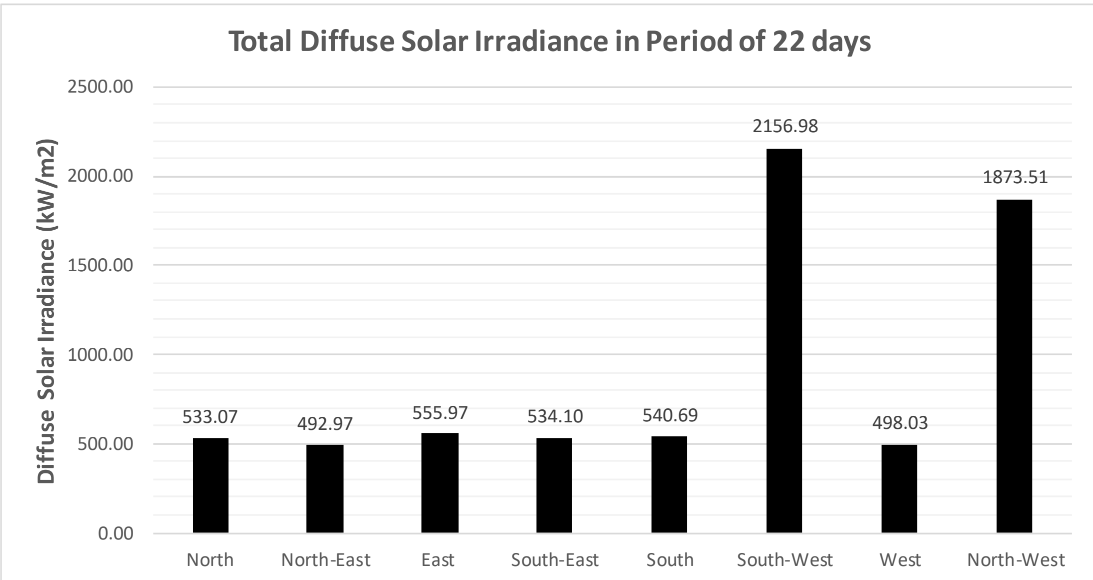


Figure 4.12: Diffuse Solar Irradiance of Each Panel in Period of 21 Days

Table 4.4: Diffuse Solar Irradiance in 22 days

| **Date** | **Diffuse Solar Irradiance (W/m$^2$)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** |
| **17/2** | 36703 | 34867 | 38419 | 37955 | 38656 | 110500 | 35940 | 93604 |
| **18/2** | 35517 | 34072 | 36640 | 36006 | 36572 | 90140 | 34811 | 78069 |
| **19/2** | 22830 | 23011 | 25340 | 24839 | 24460 | 70008 | 21910 | 60421 |
| **20/2** | 27089 | 25062 | 27349 | 26882 | 27543 | 104152 | 26447 | 89298 |
| **21/2** | 25854 | 23458 | 26289 | 25883 | 26857 | 120671 | 24622 | 100698 |
| **22/2** | 20556 | 18386 | 21668 | 20975 | 21222 | 104134 | 18461 | 87295 |
| **2/3** | 27863 | 25761 | 28886 | 27729 | 27982 | 101522 | 25919 | 85162 |
| **3/3** | 30522 | 28515 | 31890 | 30883 | 31200 | 106073 | 28725 | 83676 |
| **4/3** | 36051 | 33949 | 36910 | 35811 | 36446 | 102854 | 34620 | 88462 |
| **5/3** | 38142 | 36228 | 39708 | 38704 | 39138 | 120625 | 36889 | 105774 |
| **6/3** | 25825 | 23991 | 26873 | 25636 | 25639 | 101064 | 23934 | 88945 |
| **7/3** | 24926 | 24034 | 27063 | 25854 | 25791 | 86981 | 23155 | 76110 |
| **8/3** | 25388 | 23609 | 27059 | 25637 | 25847 | 112775 | 23350 | 99932 |
| **10/3** | 23652 | 21873 | 25068 | 24064 | 23941 | 112899 | 21102 | 100164 |
| **11/3** | 29178 | 27646 | 30317 | 29193 | 29079 | 100628 | 27220 | 91164 |
| **12/3** | 30796 | 29102 | 32257 | 31111 | 31629 | 99678 | 29794 | 90522 |
| **13/3** | 23435 | 21845 | 24975 | 23646 | 23814 | 98592 | 21736 | 87566 |
| **14/3** | 17098 | 14405 | 17299 | 15839 | 16315 | 111205 | 15036 | 98007 |
| **15/3** | 15159 | 12645 | 15877 | 14593 | 14971 | 113025 | 13289 | 99017 |
| **16/3** | 4533 | 1489 | 4206 | 2523 | 2914 | 79257 | 1862 | 72280 |
| **17/3** | 11957 | 9023 | 11876 | 10338 | 10678 | 110196 | 9207 | 97348 |
| **Sum** | 533071 | 492970 | 555970 | 534103 | 540695 | 2156979 | 498027 | 1873510 |

Table 4.5 shows the percentage difference of the DSI of each panel. The South-West panel was set as the reference for calculating percentage difference. For the overall percentage difference, DSI received by North-East panel was less than 77.15 % compared to the South-West panel whereas North-West panel was only less than 13.14 %. The highest percentage difference was South-West and North-East panels, which was up to 98.12 % in 2019-03-16. This was a huge difference, and this indicates that DSI is very important and it needed to be considered when installing PV system.

Table 4.5: Percentage Difference of DSI of Each Panel

| Date | Percentage Difference (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** |
| **17/2** | -66.78 | -68.45 | -65.23 | -65.65 | -65.02 | - | -67.48 | -15.29 |
| **18/2** | -60.60 | -62.20 | -59.35 | -60.06 | -59.43 | - | -61.38 | -13.39 |
| **19/2** | -67.39 | -67.13 | -63.80 | -64.52 | -65.06 | - | -68.70 | -13.69 |
| **20/2** | -73.99 | -75.94 | -73.74 | -74.19 | -73.56 | - | -74.61 | -14.26 |
| **21/2** | -78.57 | -80.56 | -78.21 | -78.55 | -77.74 | - | -79.60 | -16.55 |
| **22/2** | -80.26 | -82.34 | -79.19 | -79.86 | -79.62 | - | -82.27 | -16.17 |
| **2/3** | -72.55 | -74.63 | -71.55 | -72.69 | -72.44 | - | -74.47 | -16.12 |
| **3/3** | -71.23 | -73.12 | -69.94 | -70.88 | -70.59 | - | -72.92 | -21.12 |
| **4/3** | -64.95 | -66.99 | -64.11 | -65.18 | -64.57 | - | -66.34 | -13.99 |
| **5/3** | -68.38 | -69.97 | -67.08 | -67.91 | -67.55 | - | -69.42 | -12.31 |
| **6/3** | -74.45 | -76.26 | -73.41 | -74.63 | -74.63 | - | -76.32 | -11.99 |
| **7/3** | -71.34 | -72.37 | -68.89 | -70.28 | -70.35 | - | -73.38 | -12.50 |
| **8/3** | -77.49 | -79.07 | -76.01 | -77.27 | -77.08 | - | -79.30 | -11.39 |
| **10/3** | -79.05 | -80.63 | -77.80 | -78.69 | -78.79 | - | -81.31 | -11.28 |
| **11/3** | -71.00 | -72.53 | -69.87 | -70.99 | -71.10 | - | -72.95 | -9.41 |
| **12/3** | -69.10 | -70.80 | -67.64 | -68.79 | -68.27 | - | -70.11 | -9.19 |
| **13/3** | -76.23 | -77.84 | -74.67 | -76.02 | -75.85 | - | -77.95 | -11.18 |
| **14/3** | -84.62 | -87.05 | -84.44 | -85.76 | -85.33 | - | -86.48 | -11.87 |
| **15/3** | -86.59 | -88.81 | -85.95 | -87.09 | -86.75 | - | -88.24 | -12.39 |
| **16/3** | -94.28 | -98.12 | -94.69 | -96.82 | -96.32 | - | -97.65 | -8.80 |
| **17/3** | -89.15 | -91.81 | -89.22 | -90.62 | -90.31 | - | -91.65 | -11.66 |
| **Sum** | -75.29 | -77.15 | -74.22 | -75.24 | -74.93 | - | -76.91 | -13.14 |

There are three major type of weather in tropical climate, which are cloudy, rainy, and clear sunny day. Therefore, the data of DSI received by panels in these three different types of weather will be shown in below:

For the cloudy day, Figure 4.13 shows the DSI received by each panel on 2019-02-17. As shown in Figure 4.13, the amount of DSI received by each panel was different, which means that the DSI is anisotropic in tropical climate. Since it was a cloudy day, the DSI received by panels was relatively higher compared to the other days. The panel oriented to the South-West direction received the highest DSI among the others orientation, whereas the North-East panel received the lowest DSI.

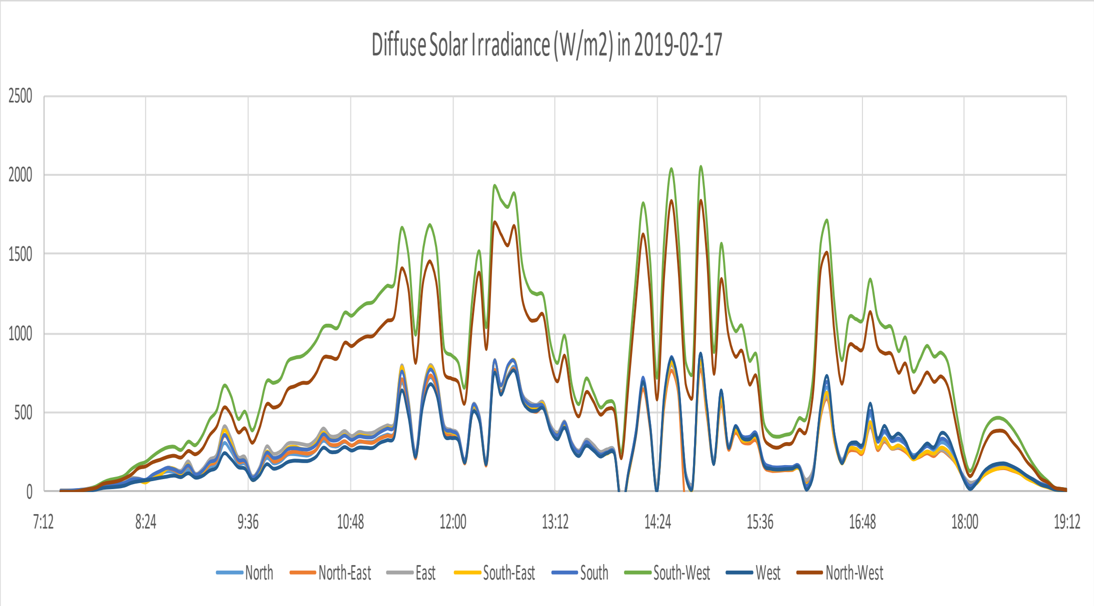

Figure 4.13: Diffuse Solar Irradiance on Each panel on 2019-02-17

For the rainy day, Figure 4.14 shows the DSI received by each panel on 2019-02-19. As shown in Figure 4.14, the amount of DSI received was low because there was no solar irradiance during raining period. The South-West oriented panel received the highest DSI whereas the West oriented panel received the lowest DSI on that day.

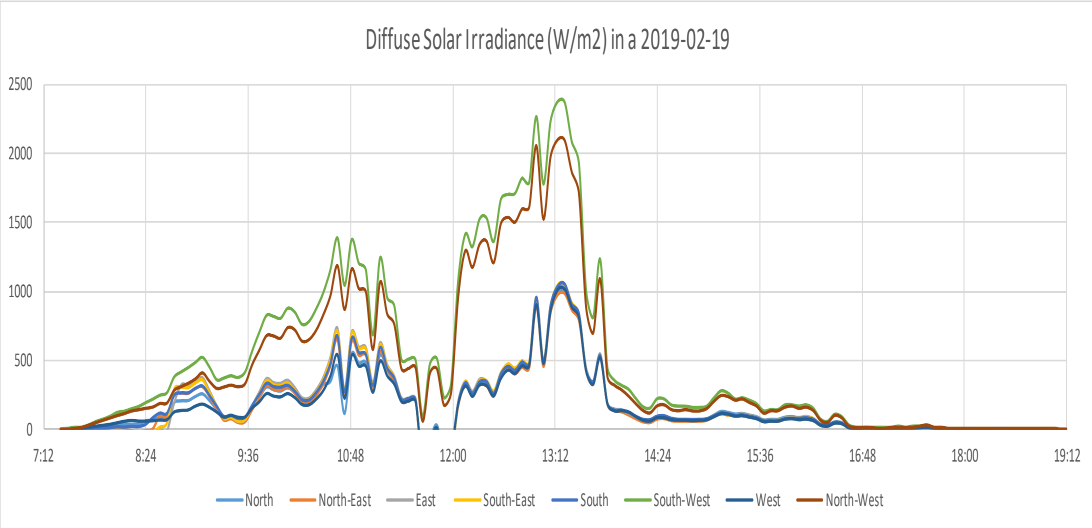


Figure 4.14: Diffuse Solar Irradiance on Each panel on 2019-02-19

For the clear sunny day, Figure 4.15 shows the DSI received by each panel on 2019-03-16. As shown in Figure 4.15, the amount of DSI received was very low compared to the other days, the DSI received on that day was close to zero since the DSI in clear sunny day is low. The South-West oriented panel received the highest DSI among the others orientation whereas the North-East panel received the lowest DSI.

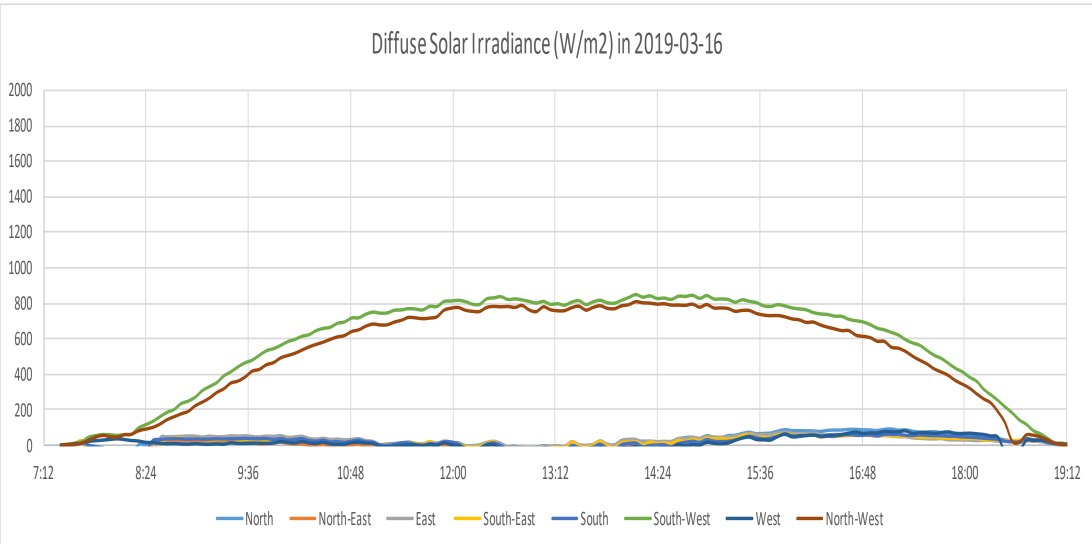


Figure 4.15: Diffuse Solar Irradiance on Each panel on 2019-03-16

# CHAPTER 5

# CONCLUSION AND RECOMMNEDATIONS

## 5.1 Conclusion

The objectives of this study were achieved. The PV system and the temperature measurement system at various orientations on the rooftop was setup and installed. Besides, the data logging systems to collect the performance of each solar panel through micro-inverter as well as the module temperature for a period of one month were setup. Moreover, the power and energy generated for different oriented solar panel were analysed and compared.

The hypothesis was accepted; the output performance of the PV system is highly related to the orientations of the PV panels. The output performance could be maximized by placing the panels at the optimum orientation

The optimum orientation for the installation of PV panels in the period of one month from February to March is the East direction in tropical climate. The orientation of panel will affect the power output greatly according to the results, the highest percentage difference is between the East and North-West panel. If installing the panel at North-West orientation would reduce the performance up to 17.37 %. Therefore, the PV system should have installed in the East orientation during the period from February to March.

Apart from that, the diffuse solar irradiance is found to be anisotropic in tropical climate within the study period of 22 days. According to the results measured and calculated, the panel faced South-West orientation received the highest diffuse solar irradiance whereas the panel faced North-East orientation received the lowest diffuse solar irradiance.

## 5.2 Suggestions and Recommendations for Future Enhancement

This study on the performance comparison of PV panels at different orientations produced the desired outcome and achieved the objectives of the project. However, there are some further works, and suggestions can be done to improve the PV system in the future in order to provide and produce even more accurate and precise results. Following are the suggestions that can be implemented in the project.

Firstly, the albedo, which means the diffuse reflection of solar radiation should be eliminated. The albedo could be reduced and eliminated by putting some material which is poor in reflecting the sunlight and good in absorbing the sunlight such as grass, soil, or asphalt that having the lower albedo percentage than the current concrete. On the other hand, the dark appearing materials also reduce the albedo like the black cotton material, black cloth and more. After reducing or eliminating the albedo, the energy generated from different orientations would be more accurate since the albedo is different at different places.

Besides that, the study should be continuing for a longer period with at least one year. As the optimum orientations that found from this study was from February to March, but it could not be the optimum orientations in a period of one year. Since the installation of PV system of the industries will be fixed after they setup the whole system, and therefore, the optimum orientation which could maximize the yearly power output should be obtained and measured.

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# APPENDICES

## APPENDIX A: Arduino Source Code

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

#define ONE_WIRE_BUS_1 22 //Data wire (North) is plugged into pin 22
#define ONE_WIRE_BUS_2 24 //Data wire (North-East) is plugged into pin 24
#define ONE_WIRE_BUS_3 26 //Data wire (East) is plugged into pin 26
#define ONE_WIRE_BUS_4 28 //Data wire (South-East) is plugged into pin 28
#define ONE_WIRE_BUS_5 30 //Data wire (South) is plugged into pin 30
#define ONE_WIRE_BUS_6 32 //Data wire (South-West) is plugged into pin 32
#define ONE_WIRE_BUS_7 34 //Data wire (West) is plugged into pin 34
#define ONE_WIRE_BUS_8 36 //Data wire (North-West) is plugged into pin 36

//Setup a oneWire instance to communicate with any oneWire devices
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);

//Pass our oneWire reference to Dallas Temperature
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);

#define LOG_INTERVAL 1000
#define SYNC_INTERVAL 1000

uint32_t syncTime = 0;

#define ECHO_TO_SERIAL 1
#define WAIT_TO_START 0

//Digital pins connected to LEDs
#define redLED 3
#define greenLED 4

RTC_DS1307 RTC;

//For data logging shield, digital pin 10 for SD CS line
const int chipSelect = 10;

//Logging file
File logfile;

void error(char const*str) //turn on red LED if error
{
  Serial.print("Error: ");
  Serial.println(str);
  digitalWrite(redLED, HIGH);
  while(1);
```

```
}

void setup() {
  //Start serial port
  Serial.begin(9600);
  Serial.println("Dallas Temperature IC Control Library Demo");

  //use debugging LEDs
  pinMode(redLED, OUTPUT);
  pinMode(greenLED,OUTPUT);

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

  //Initialize SD card
  Serial.print("initializing SD card...");
  pinMode(SS, OUTPUT);

  //Check whether card is initialized
  if(!SD.begin(10,11,12,13))
  {
    error("Card failed");
  }
  Serial.println("Card initialized");

  //Create new file when power restart
  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))
    {
      logfile = SD.open(filename, FILE_WRITE);
      break;
    }
  }

  if(!logfile)
  {
    error("Could not create file!");
  }

  Serial.print("Logging to: ");
  Serial.print(filename);
  Serial.print("\n");

//Connect to RTC
  Wire.begin();
  if(!RTC.begin())
  {
    logfile.println("RTC failed");

   #if ECHO_TO_SERIAL
   Serial.println("RTC failed");
   #endif
  }

  logfile.println("ms, stamp, datetime, temp 1, temp 2, temp 3, temp 4, temp 5, temp 6,
temp 7, temp 8"); //write titles in the log file

  #if ECHO_TO_SERIAL
```

```
  Serial.println("ms, stamp, datetime       ->  temp 1, temp 2, temp 3, temp 4, temp 5, temp 6, temp 7, temp 8");
  #endif

  //Start up library
  sensors_1.begin();
  sensors_2.begin();
  sensors_3.begin();
  sensors_4.begin();
  sensors_5.begin();
  sensors_6.begin();
  sensors_7.begin();
  sensors_8.begin();
}

void loop() {
  DateTime now;

  //delay for reading
  delay((LOG_INTERVAL - 1) - (millis() % LOG_INTERVAL));

  digitalWrite(greenLED, HIGH);

  //log ms since starting
  uint32_t m = millis();
  logfile.print(m);
  logfile.print(", ");

  #if ECHO_TO_SERIAL
  Serial.print(m);
  Serial.print(", ");
  #endif
```

```
now = RTC.now(); // local time

//log time
logfile.print(now.unixtime());
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());
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

//send command to get temperature reading
sensors_1.requestTemperatures();
sensors_2.requestTemperatures();
sensors_3.requestTemperatures();
sensors_4.requestTemperatures();
sensors_5.requestTemperatures();
sensors_6.requestTemperatures();
sensors_7.requestTemperatures();
sensors_8.requestTemperatures();

//Can have more than one DS18B20 on the same bus
// 0 refers to the first IC on the wire
float temp1 = sensors_1.getTempCByIndex(0);
float temp2 = sensors_2.getTempCByIndex(0);
float temp3 = sensors_3.getTempCByIndex(0);
float temp4 = sensors_4.getTempCByIndex(0);
float temp5 = sensors_5.getTempCByIndex(0);
float temp6 = sensors_6.getTempCByIndex(0);
float temp7 = sensors_7.getTempCByIndex(0);
float temp8 = sensors_8.getTempCByIndex(0);

//log temperature
logfile.print(", ");
logfile.print(temp1);
logfile.print(", ");
logfile.print(temp2);
logfile.print(", ");
logfile.print(temp3);
logfile.print(", ");
```

```
logfile.print(temp4);
logfile.print(", ");
logfile.print(temp5);
logfile.print(", ");
logfile.print(temp6);
logfile.print(", ");
logfile.print(temp7);
logfile.print(", ");
logfile.print(temp8);
logfile.print("\n");

#if ECHO_TO_SERIAL
Serial.print(" -> ");
Serial.print(temp1);
Serial.print(", ");
Serial.print(temp2);
Serial.print(", ");
Serial.print(temp3);
Serial.print(", ");
Serial.print(temp4);
Serial.print(", ");
Serial.print(temp5);
Serial.print(", ");
Serial.print(temp6);
Serial.print(", ");
Serial.print(temp7);
Serial.print(", ");
Serial.println(temp8);
#endif // ECHO_TO_SERIAL

// 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(redLED, HIGH);
  logfile.flush();
  digitalWrite(redLED, LOW);
}
```