THE STUDY OF COOLING EFFECT ON PHOTOVOLTAIC USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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This report is submitted in fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

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2019

DECLARATION

I declare that this project report entitled "The study of cooling effect on photovoltaic using Computational Fluid Dynamics(CFD)" is the result of my own work except as cited in the references

Signature : ……………………..

Name : ……………………..

Date : ……………………..

APPROVAL

I hereby declare that I have read this project and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:	………………………
Name of Supervisor	:	………………………
Date	:	………………………

DEDICATION

الحمد لله رب العالمين

My family.

ABSTRACT

The temperature of photovoltaic (PV) panels is an important parameter in the conversion efficiency of solar radiation to electricity. PV cells generally can convert up to 20% of solar radiation to electricity and the rest is generated into heat which increases the panel temperature causing a drop in the performance. Various methods have been used by researches in order to reduce the panel temperature and still being cost effective. One of the cost-effective methods is by using natural convection. The purpose of this study is to study the cooling effect on solar PV by using ANSYS CFD simulation. The solar panel is simulated under two different condition where it is assumed there's no cooling with constant ambient temperature and the other one with air cooling with vary ambient temperature. The simulation is analyzed under transient state to simulate the PV performance during 10 a.m. to 4 p.m. in real time. The results show that the maximum efficiency of panel with air cooling is 15.90% while the panel with no cooling is 14.33% thus making the panel more efficient and productive when being cooled. It was shown that the presence of natural convection would reduce the temperature and increase the efficiency of PV. However, this would require a higher wind velocity for a better result as seen from the result obtained when the air velocity ranges between 2 m/s to 5 m/s.

ABSTRAK

Suhu panel fotovoltaik (PV) adalah parameter penting dalam kecekapan penukaran sinaran suria kepada elektrik. Sel-sel PV secara umumnya boleh menukar sehingga 20% radiasi solar ke elektrik dan selebihnya dijana menjadi haba yang meningkatkan suhu panel menyebabkan kejatuhan prestasi. Pelbagai kaedah telah digunakan oleh penyelidik untuk mengurangkan suhu panel dan masih kos efektif. Salah satu cara yang kos efektif adalah dengan menggunakan perolakan semula jadi. Tujuan kajian ini adalah untuk mengkaji kesan penyejukan pada PV solar dengan menggunakan simulasi ANSYS CFD. Panel solar disimulasikan di bawah dua keadaan yang berbeza di mana ia diandaikan tiada penyejukan dengan suhu ambien yang berterusan dan yang lain dengan penyejukan udara dengan suhu ambien yang berbeza. Simulasi dianalisis di bawah keadaan sementara untuk mensimulasikan prestasi PV pada 10 pagi hingga 4 petang. dalam masa nyata. Keputusan menunjukkan bahawa kecekapan maksimum panel dengan penyejukan udara adalah 15.90% manakala panel tanpa penyejukan adalah 14.33% dengan itu membuat panel lebih cekap dan produktif apabila didinginkan. Telah ditunjukkan bahawa kehadiran konveksi semulajadi akan mengurangkan suhu dan meningkatkan kecekapan PV. Walau bagaimanapun, ianya memerlukan halaju angin yang lebih tinggi untuk hasil yang lebih baik seperti yang dilihat dari hasil yang diperoleh apabila halaju angin berkisar antara 2 m/s hingga 5 m/ s.

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LIST OF ABBREVIATIONS

PV	Photovoltaics
CFD	Computational Fluid Dynamics
STC	Standard Test Conditions
ANSYS	Analysis System
TRNSYS	Transient System Simulation

LIST OF SYMBOLS

h	Convective heat transfer coefficient
η_{ref}	Maximum PV efficiency tested with reference temperature
η_{cell}	PV cell efficiency
β	Temperature coefficient of power
T_{cell}	Temperature of PV module cell
T_{ref}	Reference temperature of PV module
I_{STC}	Solar irradiance under STC

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In the last decades, the increasing global demand for electricity which resulting on the increase of political and environmental problems related to the fossil fuels are the main drawbacks of this energy source. A way to overcome this problem and minimizing the negative impacts of energy production and consumption on the environment is by switching to renewable energy sources; one of it is the sun. The conversion of sunlight into electricity called as solar power is done by using photovoltaic (PV) technology. This technology is one of the cleanest (does not produce pollutants) and the easiest sources to be obtained compare to fossil fuels.

In general, PV is a method which absorb the light transfer from the sun with the help of semiconductors material and convert it into electricity. Semiconductors are materials which become electrically conductive when supplied with light or heat but operate as insulators at low temperatures. Example of solar PV is shown in Figure 1.1.

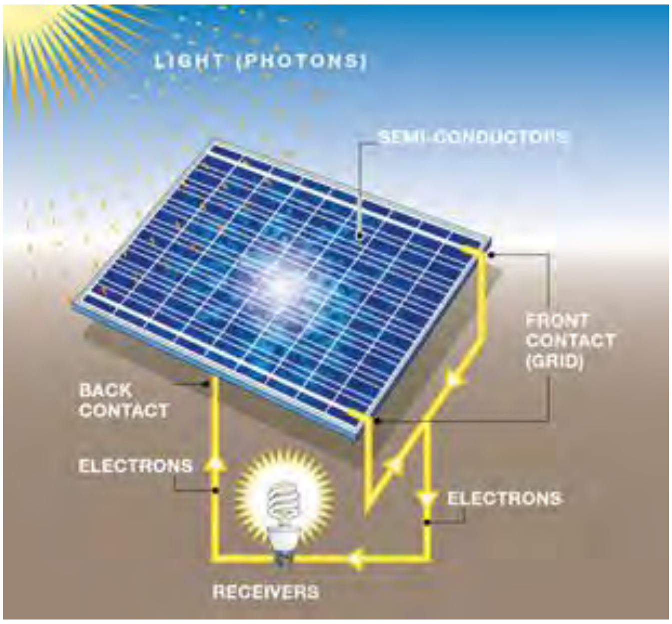


Figure 1.1: Schematic showing PV power source [1]

Even though this clean technology has free energy source and has made tremendous improvement in the past years, but it also can be expensive in many ways. Solar researchers are still trying to come out with the way to increase the performance of the PV panel while minimizing the modifications cost.

It is known that the performance of PV panel is affected by numerous factors and one of it is the temperature. The relation between these two are inversely proportional, as the temperature increases the efficiency of the solar panel decrease and vice versa. With the exposure of high temperature to the PV panel in a long period of time can cause degradation on its electrical power output. The incident solar radiation absorbed by the PV can be up to 80% but only a small amount of it is converted into electricity as the remainder energy increase the cells temperature [2]. Each solar cell is tested under the Standard Test Condition (STC) which the temperature is at 25 ºC with the irradiance of 1000 W/m^2. PV cell generates the maximum power in these conditions [3,4]. Some researches claim that maximum power generated varies almost linearly with the operating temperature of PV cells [5,6]. But in real operating conditions, it is hard to obtain these conditions with the ambient temperature and the irradiance always changes throughout the day [7,8]. In Figure 1.2, it shows that when temperature rises the current produced become slightly increase but the voltage is also reduced causing a drop on the power generated by the PV.

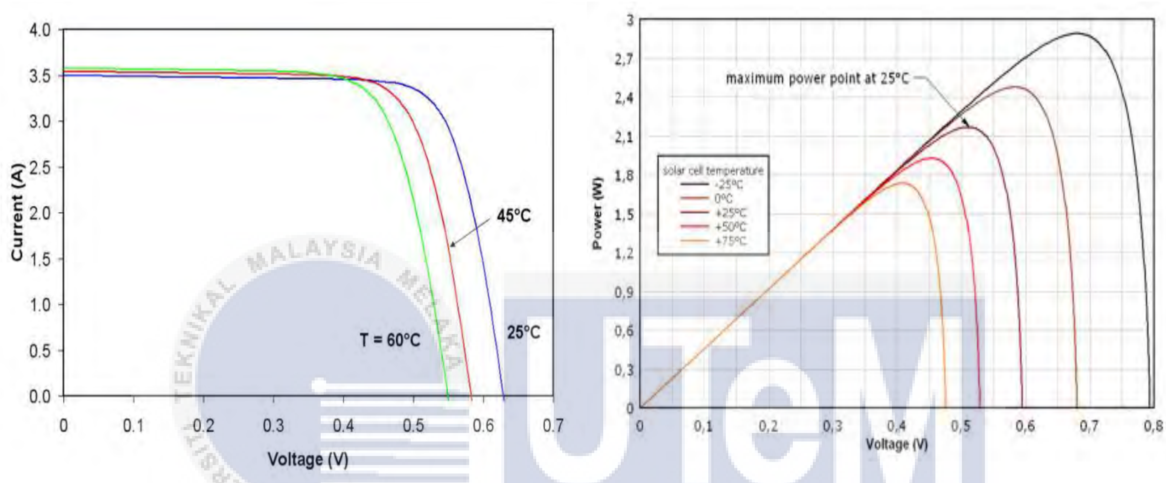


Figure 1.2: I-V and P-V curves of a typical PV module [2]

1.2 PROBLEM STATEMENT

The operating temperature of PV cells has a big impact on its performance. The maximum output power production is reduced when the temperature of PV cells elevated. An increase in efficiency is important to the development of solar PV, as it would save money while providing greater amounts of energy and increase the lifespan of it. Finding the best method to cool down the solar panel in Malaysia weather and climate which is usually hot while saving the cost of improvement is crucial in this country economic state.

1.3 OBJECTIVES

The objective of this project are as follows:

1. To study the effect of air cooling on the temperature and efficiency of solar PV using ANSYS.
2. To study the performance of solar PV under different wind velocity by using ANSYS.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. The analysis is studied only on polycrystalline solar panel.
2. The results of this analysis are only focusing towards the temperature and efficiency of solar PV.
3. The simulations of this study using 3D analysis on ANSYS in transient state.
4. Cooling effect from air ranging from 2 m/s to 5 m/s.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will describe briefly on the heat transfer of solar PV and the cooling system of solar PV. Solar PV can be cooled by using passive and active cooling methods which uses air or water as the coolant. These cooling methods have been carried out by many researches and it produces good results on optimising the PV performance. This chapter further presents some of the existing work regarding the implementation of these methods of cooling the PV cells carried out by other researches.

2.2 HEAT TRANSFER

Generally, the process of solar PV is the conversion of solar radiation into electricity. Because of the panels are not totally efficient, most of the energy absorbed are wasted as heat. By adapting convection, conduction and radiation, the heat can be dissipated as shown in figure below.

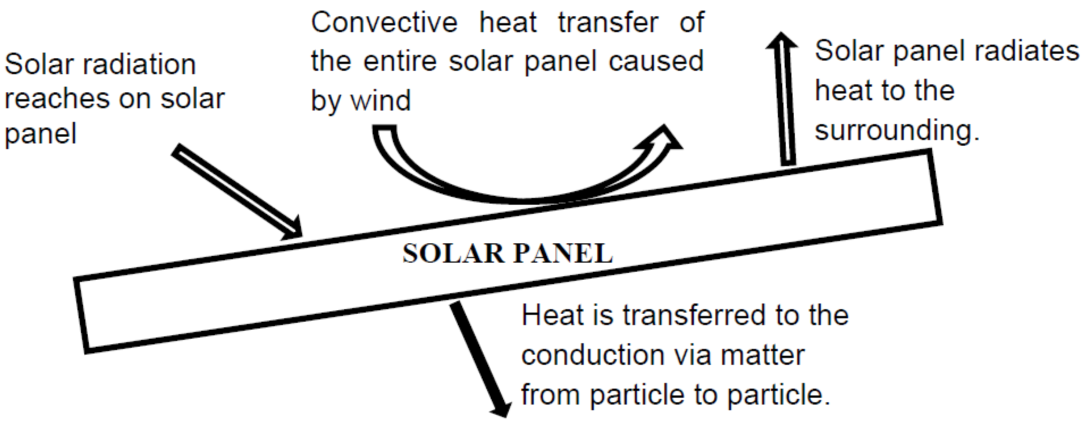


Figure 2.1: The heat transfer of a conventional solar panel.

2.2.1 Convection

Heat transfer within mixed portion of fluid is by convection. The fluid's movement can be caused by density differences resulting from temperature differences such as natural convection (or free convection) or by mechanical means such as forced convection. The fluid movement increases the heat transfer, as it brings hotter and cooler fluid into contact and initiates higher conduction rates at a greater number of sites in a fluid. Therefore, the heat transfer rate through a fluid by convection is higher than conduction [9].

Convective heat transfer is described by correlations between parameters without dimensions such as the Nusselt, Reynolds and Prandtl numbers in order to determine value of heat transfer coefficient, h in Newton's law of cooling:

$$Q = hA_s(T_s - T_f) \tag{2.1}$$

where

h = convective heat transfer coefficient, W/m^2. °C

A_s = heat transfer surface area, m^2

T_s = surface temperature, °C

T_f = fluid temperature sufficiently far from surface, °C

2.2.2 Conduction

Conduction is the transfer of heat from one part of the substance to another part of the same substance or in physical contact with it from one substance to another. For the PV panel, energy is absorbed by the cell and heat is carried to the back and front of the panel [9]. Fourier's law of heat conduction state that:

$$Q = -kA\frac{dt}{dx} \tag{2.2}$$

where

Q = heat flow, kJ/kg

k = thermal conductivity of material, W/m^2. °C

A = area of the section at right angles

dt/dx = temperature gradient

2.2.3 Radiation

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the electronic configuration changes in the atoms or molecules. In contrast to conduction and convection, the radiation transfer of energy does not require the presence of an intermediate medium [9]. Stefan-Boltzmann law state that:

$$Q = \frac{\sigma A(T_1^4 + T_2^4)}{(\varepsilon_1)^{-1} + (\varepsilon_2)^{-1} - 1} \tag{2.3}$$

where

σ = Stefan-Boltzmann constant

A = surface area, m^2

$T_{1,2}$ = surface temperature, K

$\varepsilon_{1,2}$ = surface emissivity

2.3 SYSTEM OVERVIEW

This system consists of a set of photoelectric cells, also called photocells or solar cells. These are electronic devices made of silicon, the second most abundant substance in the Earth, which size ranges between 1 and 10 cm of diameter, and that can transform light energy (photons) into electrical energy (electrons) by the photovoltaic effect. It is important to notice, that it accepts both direct and diffuse radiation and can generate electricity even on cloudy days. These cells are manufactured of a material which benefits from the photoelectric effect: they absorb photons of the sunlight and emit electrons. When the sunlight strikes the surface of the photovoltaic cell, electrons are released from an atom. Electrons, excited by the light, move through the silicon as shown in figure below. When these free electrons are captured, the result is an electric direct current that can be use as electricity from a power between 1W and 2W.

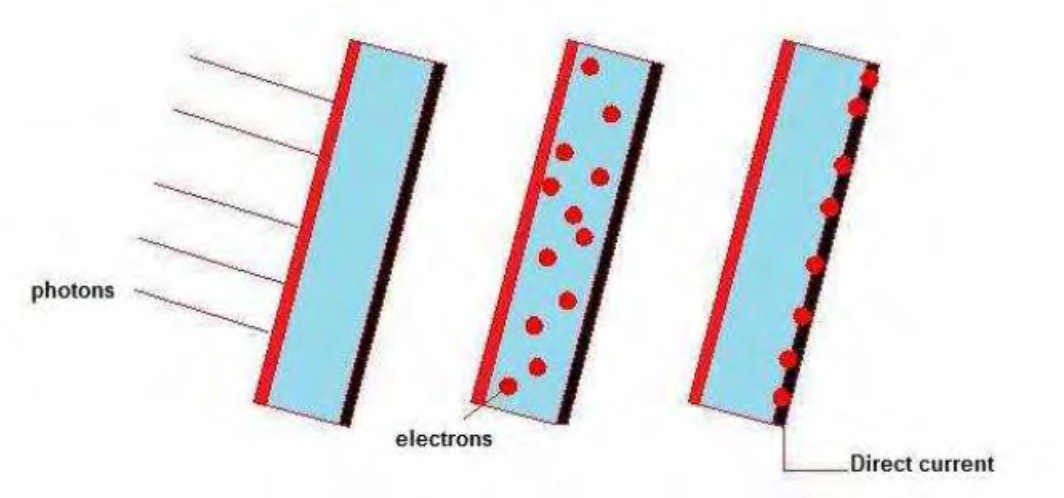
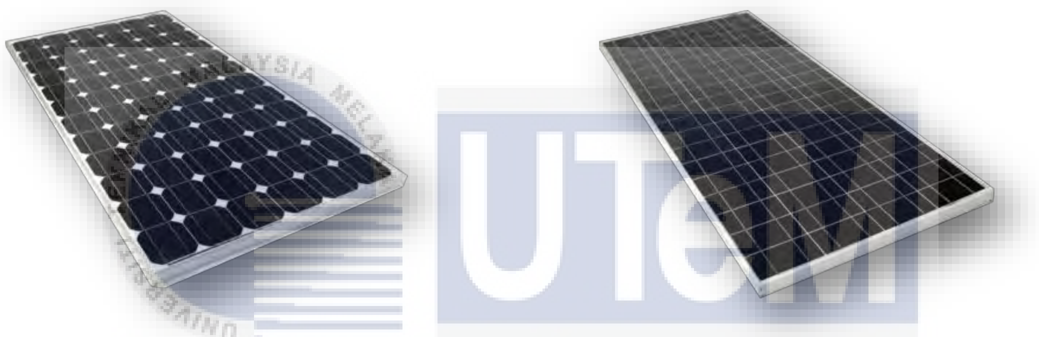


Figure 2.2: Photovoltaic effect [10]

PV cells are usually made of crystalline silicon (Si). Circular PV cells are embedded into a plastic sheet to make a panel. It is known that the performance of PV cells is affected by irradiance, module temperature, and solar spectrum distribution [11,12]. This is due to the energy being converted from light energy in the photons to electrical energy. At the molecular level, the electrons become excited due to a high amount of thermal energy. This ends up dominating the electrical properties of the semi-conductor used in the solar panel. The temperature affects the voltage and current in the PV generator. While atmospheric temperature tends to have a small effect on the cell's operating temperature, the solar irradiance and wind speed both have a large effect [13].

There are three kinds of innovation used in solar cells, these are monocrystalline (Mono-Si), polycrystalline (Poly-Si) and thin film amorphous. Mono-Si and Poly-Si are the most commonly used solar. These two solar can be easily be identify by its appearance as shown in Figure 2.3. The performance of these solar cells is quite similar compare to thin film which is less efficient. Mono-Si is the most developed technologies of the three. Monocrystalline solar panels are made from the highest-grade silicon making it have the highest efficiency rates. This solar panel generate the highest power output and only require a small amount of space compared to the other types. The only downside of using this type of solar is the production cost which is rather expensive. In recent years the usage of Poly-Si solar have become more common because the production of polycrystalline silicon is cheaper and simpler but, the efficiency of this solar panel is slightly lower than the Mono-Si solar panel [14,15]. However, this small margin is usually neglected in the industry due to the cost difference.



(a) (b)

Figure 2.3: (a) Monocrystalline solar panel (b) Polycrystalline solar panel [13].

2.4 EFFECT OF TEMPERATURE ON PV CELLS

Temperature can affect the PV cells in a negative way due to the negative temperature coefficient of crystalline silicon. This temperature coefficient is estimated to be -0.5%/K [16]. This causes a drop on the cells efficiency which is usually around 12% under the reference temperature of 25°C. It has been shown that a decrease in the temperature of the solar panel can cause a 2% increase in the efficiency of the PV cells, when the carrier fluid has a mass flow rate of 0.01 kg/s [17]. An increase in efficiency is vital to the development of solar panels, as it would save money while providing greater amounts of energy. PV cells have the potential to be extremely efficient. Even in the worst-case scenario, a PV cell has an efficiency limit of 28.9% [18]. Figure 2.4 shows the relationship of efficiency versus the module temperature. As can be seen, the conversion efficiency drops as the module temperature increases [19].

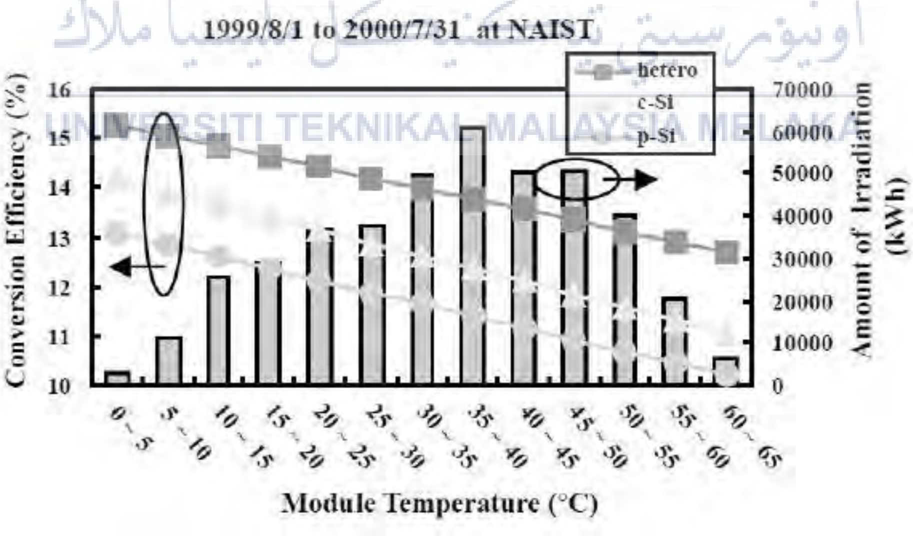


Figure 2.4: Variation of Efficiency as a Function of Module Temperature [19]

The high temperature of PV cells can also be affected by solar irradiance. A PV cells generally can convert solar radiation to only up to 20% of the energy absorbed where the remaining waste heat generated will increase the cells temperature which leads to the drop in its electrical efficiency [20,21]. It is important to perform an energy balance of the system to analyse the efficiency of the PV cells with different operating temperature since the radiation absorbed is converted to electrical energy as well as thermal energy.

2.5 REVIEW OF SOLAR PV COOLING

The efficiency of solar PV decreases as its temperature increases. The performance varies with temperature changes which affect the power generated by the cells. Some studies [5,13] claimed that the operating temperature varies linearly with the maximum power generated. The performance usually drops with an average of 0.45% for every degree of temperature raise from 25 °C. This can be seen usually on the middle of a hot day where the efficiency supposedly the highest due to high solar radiation. Only up to 20% of the solar radiation converted to electrical energy where the rest will increase the panel temperature. Therefore, cooling the PV panels is essential to gain the maximum power generation and to increase the lifetime of solar. There're numbers of research going, focusing on cooling the solar panel using active and passive cooling which utilise air and water as the coolant. In general, passive cooling achieved by utilising natural conduction and convection. This approach doesn't rely on external power supply or power generated by the solar. In the case of active cooling, it maximises the cooling effect on solar panel with the help of additional mechanical systems however to accomplish it require energy from external power supply or from the panel itself. But, if the energy output from the solar panel itself surpass the energy input to run the active cooling system, it will be very beneficial to use this technique.

2.6 WATER COOLING

2.6.1 Active Cooling System

Active cooling system is considered as a system that continuously consume power by a pump to cool the PV module. This system can produce more power and more accessible thermal energy compare to passive cooling system, but the power consumption still needs to be considered when using this system. Odeh and Behnia [22] carried out an experimental and analysis study to improve efficiency and reduce the rate of thermal degradation of a PV module by reducing its surface temperature. The cooling process is done by spraying water using a pump with constant flow rate of 0.85/s on the upper surface of the panel. The system output showed an increased about 15% due to heat loss by convection when the method is adopted. The experimental setup involved using PV modules with 60W maximum power connected with variable resistance to obtain the I-V characteristics curve of the module. Figure 2.5 shows the difference in power output between two temperature tested with constant radiation at 1000W/m^2. The simulation study on this experiment were carried out to study the long-term performance of the system by using Transient System Simulation (TRNSYS) software. The results indicate that the system's performance increase about 5% during dry and warm seasons throughout the year. Krauter [23] experimented with the same technique in a PV façade. Small diameter nozzles and DC water pump are used in the experimental setup. This result an increase of 10.3% on the power generated. The application of this technique has three main advantages: a decreased in cell temperature, an increase in incident radiation due to water radiation refraction and continued surface cleaning by water flow. The only downside to it, is the power required to circulate the water by the pump.

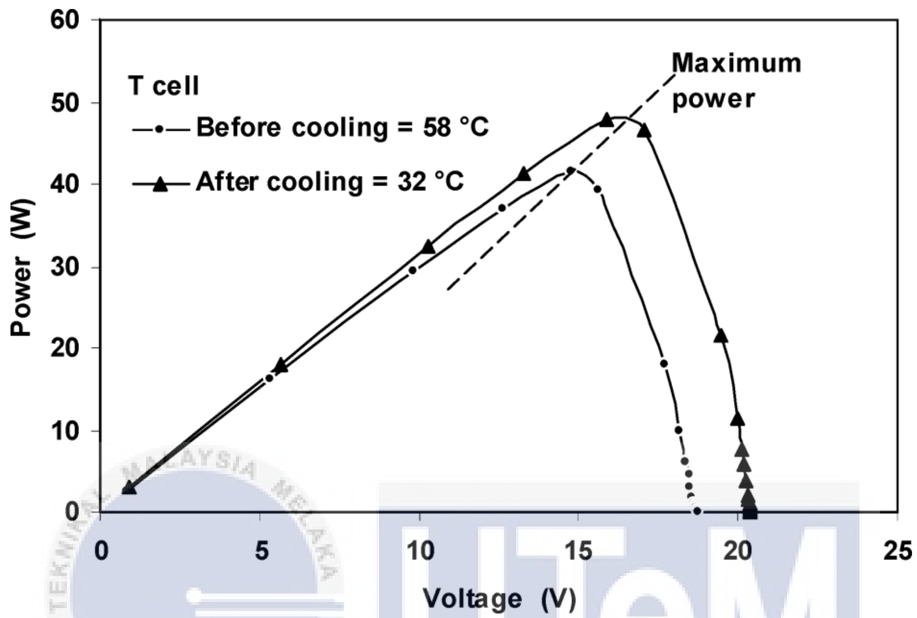


Figure 2.5: The effect of water cooling on P-V characteristics curve of the PV module at 1000W/m^2 radiation [22]

Irwan et. al. [24] conducted a similar experiment to increase the electrical efficiency of the PV module with different setup where it was carried out indoor by using vary number of halogen lamp bulbs acts as natural sunlight with different solar radiation. Using a DC water pump to spray water on the front surface on the panel, resulting an increase on the power output by 9% to 22% when the surface temperature decreases in value of 5°C to 23°C. This technique is advantageous to decrease cell temperature, increase radiation due to refraction on water surface and continued surface cleaning [22]. However, the downside of this system is the power consumed by the pump to circulate the water. Syafiqah et. al. [25] presented an analytical study on performance of PV panel with water cooling system using ANSYS. The flow rate of the cooling water on the panel surface is 0.0556 kg/s and it consumed around 2.16W generated by the PV making the efficiency to increase by 3%. Bahaidarah et. al. [26] incorporated a heat exchanger at the rear surface of the PV module, resulting a drop on the module temperature by 20% and manage to increase its efficiency by 9%. The experimental setup includes monocrystalline panel and water pump with different flow rates that is regulated with a flow-meter. The cooling water is stored in a water tank which is connected to the PV system. The experimental results are then compared with numerical analysis using EES (Engineering Equation Solver) software. There's a good correlation between the experimental and analytical result as shown in figure below.

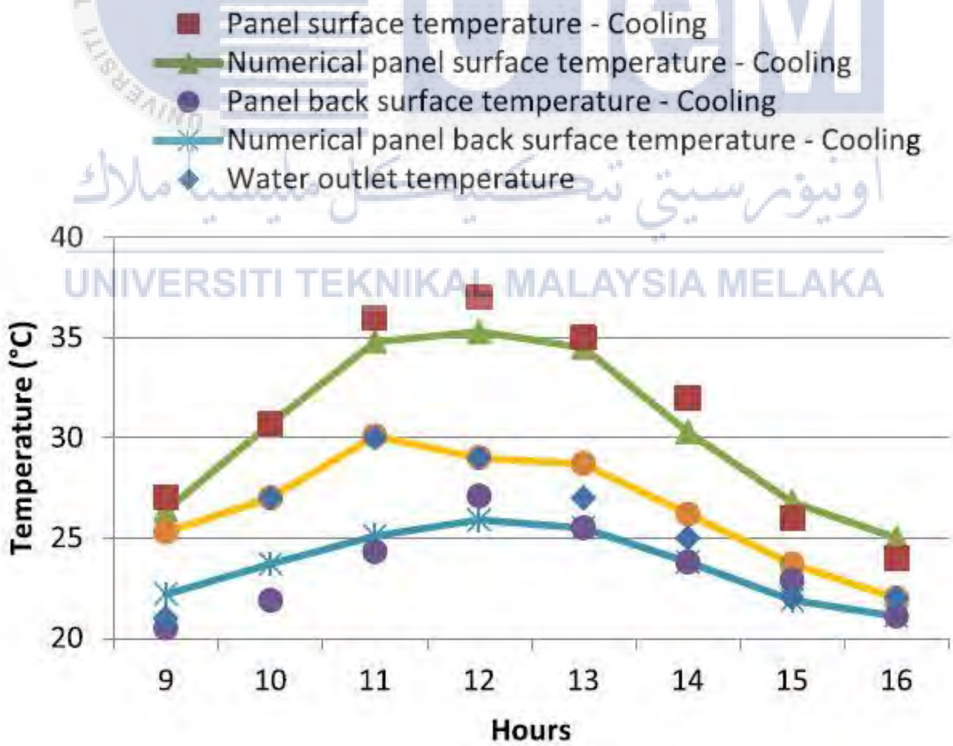


Figure 2.6: Comparison of experimental and numerical data with water cooling [26]

Hosseini et. al. [27] combined the cooling method of a PV system consisting of a thin film of water running on the front side of the panel with additional system to utilise the hot water produced by the system. This system yielded high power output and electrical efficiency and lowered the surface temperature and reflection losses compared to the conventional PV system. Raval et. al. [28] also validate that the irradiance's refraction while striking the surface through the water was helpful. The authors presented the result with an experiment and CFD analysis for PV panel with water flowing on the surface. The overall efficiency increased from 6% to 40% by the cooling system.

2.6.2 Passive Cooling System

Another way to cool the PV panels without consuming any power produced is by using passive water cooling as it doesn't involve any energy input. This system is well investigated by many researches. Rosa-Clot et. al. [29] proposed a water submission technique to reduce the solar panel temperature. The authors have obtained four months of experiments with silicone PV panels in still water. For comparison of results, a referent PV panel exposed to air was also used. The water depth ranged from 4 cm to 40 cm and specific results are presented in Figure 2.7 regarding the relative efficiency of the PV panel. Results for various silicone-based PV market technologies were obtained. According to the results reported, the average operating temperatures of the referent PV panels were between 70°C and 80°C, while the submerged PV panels had average operating temperatures of about 30°C. The average increase in efficiency being around 11% and for a solar irradiation level of approximately 800W/m^2, peak power output increased from 19W to 29W. However, it was also found that the solar panel efficiency will degrade once the it was submerged in the water at 40 cm deep due to insignificant sunlight refraction and refraction in the water.

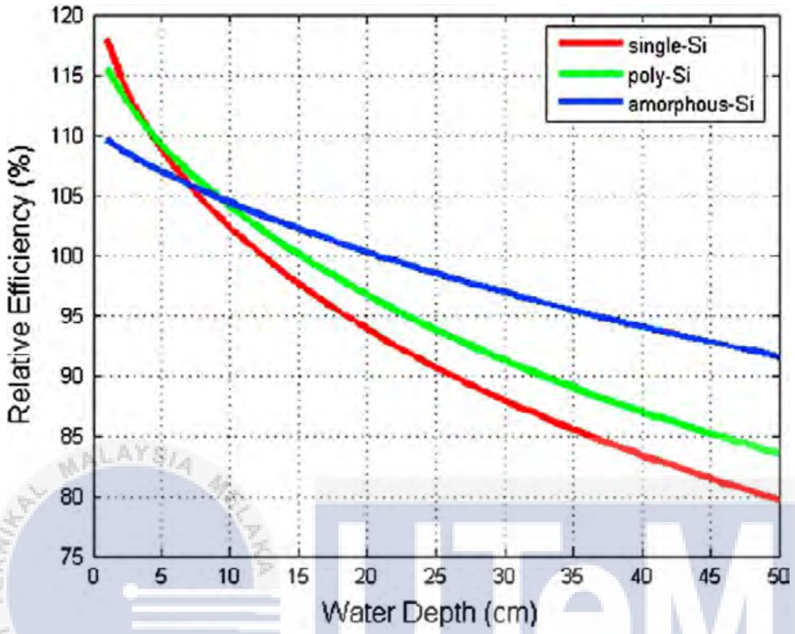


Figure 2.7: Variation of PV efficiency with water depth [29]

In a research work by Alami [30], the author used a layer of synthetic clay on the back of the module and allowed a thin film of water to evaporate, resulting the module surface temperature to drop. This led to an increase of output voltage up to 19.4% and the output power by 19.1%. Wu and Xiong [31] used rainwater as cooling media to reduce the temperature of the cells. The rainwater is stored in a tank and distributed on the surface of the cells. The results showed that the cells temperature reduction reaches 19°C and 8.3% increase on the average electrical generated.

In another study, Musthafa [32] attached water absorption sponge on the rear side of the PV panel and maintain wet condition by circulation of drop by drop water through sponge to reduce the panel temperature. The temperature dropped up to 10°C with the efficiency of the solar cells increases by 20% during operating time. Chandrasekar et.al [33] used cotton wick combined with water on the rear side of the panel to reduce and maintain uniform temperature across the panel. The PV panel used in this paper made up of single crystalline silicon cells connected in series with 20V and 50Wp of rated voltage and power respectively. The research showed that by using this method, the temperature pf the PV panel able to be reduced by 20°C and managed to obtain 10.4% increase on the maximum efficiency as shown in Figure 2.8.

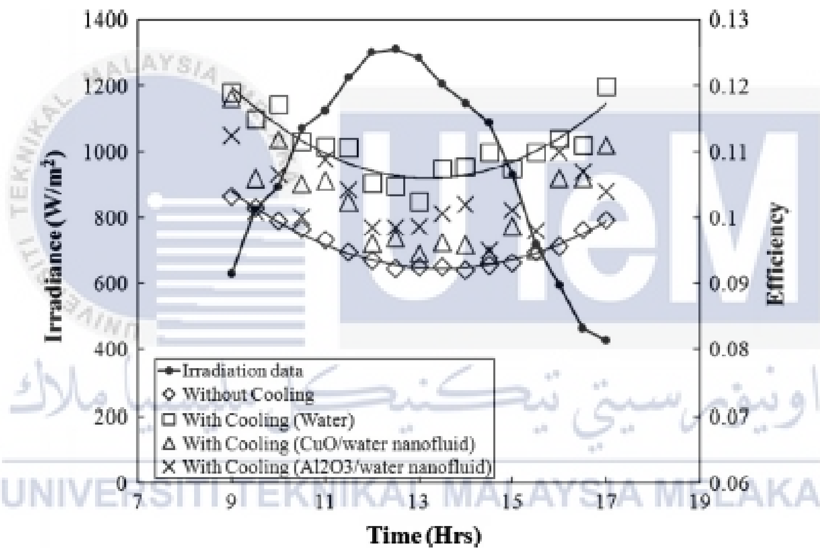


Figure 2.8: Efficiency of PV panel variation under different operating conditions [33]

2.7 AIR COOLING

2.7.1 Active cooling system

Active cooling help in enhancing output power generated by solar PV and it is also known to consume power continuously to reduce PV panel temperature. Most active air cooling is done by adding a mechanical system to increase the wind speed to reduce the temperature and increase the efficiency of solar PV. Syafiqah et. al. [34] studied the performance of solar PV by attaching DC fans on the back of solar panel. The experimental setup includes a 100 W monocrystalline PV panel with different number of DC fans attached at the back of the panel. The results showed that by using two DC fans is the most optimum setup to increase the efficiency of solar panel while minimising the power used by the DC fans. In other study performed by the same author [35], confirmed that by using active air cooling can reduce the temperature of the panel as shown in figure below.

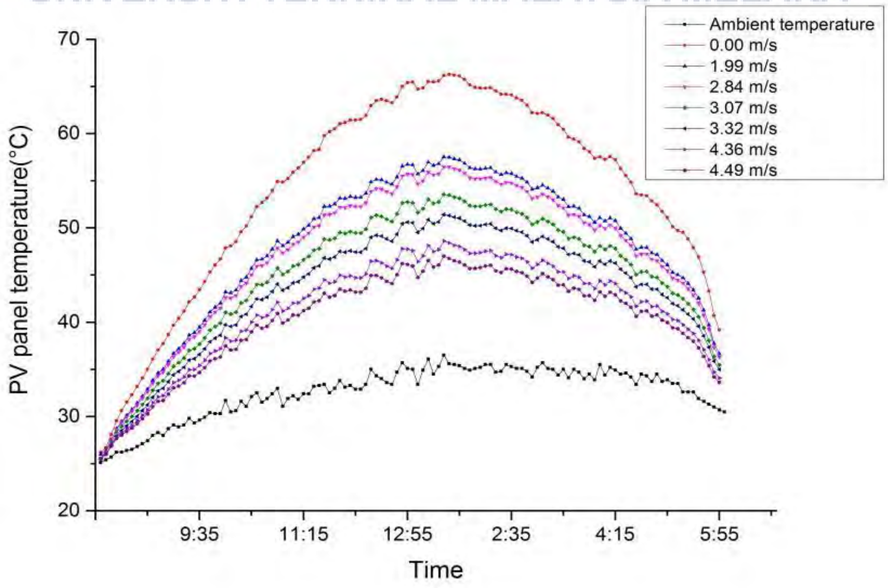


Figure 2.9: PV panel temperature with different DC fan speed [35]

Tina et. al. [36] validated the results by conducting a numerical analysis that able to study the PV panel temperature as a function of ambient temperature, humidity, wind velocity and direction, and solar irradiance. Bhattacharya et. al. [37] analysed the effect of wind speed and ambient temperature on the performance of a monocrystalline solar PV. The results showed in this paper, validate the correlation between efficiency and wind speed as shown in Figure 2.10.

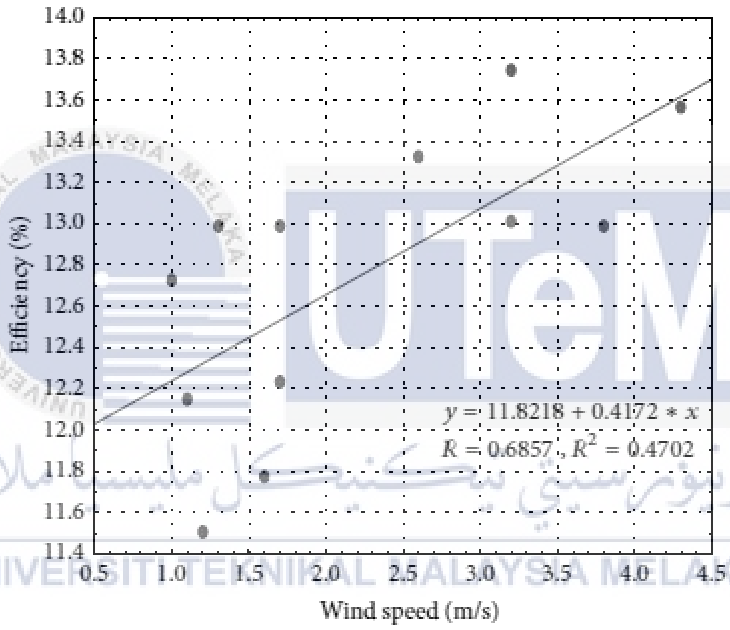


Figure 2.10: Average value of efficiency with different wind speed [37]

In another study, Tonui and Tripanagnostopolous [38] showed that efficiency of PV panel decreases as the temperature of PV panel increases. With the help of forced air cooling could help reducing the panel temperature. However, it has a limited thermal efficiency due to low density, small thermal conductivity and capacity of air. The temperature profiles of the PV panel, channel back and air are presented in the results which showed the relationship of the electrical and thermal efficiencies of the system as shown in figure below.

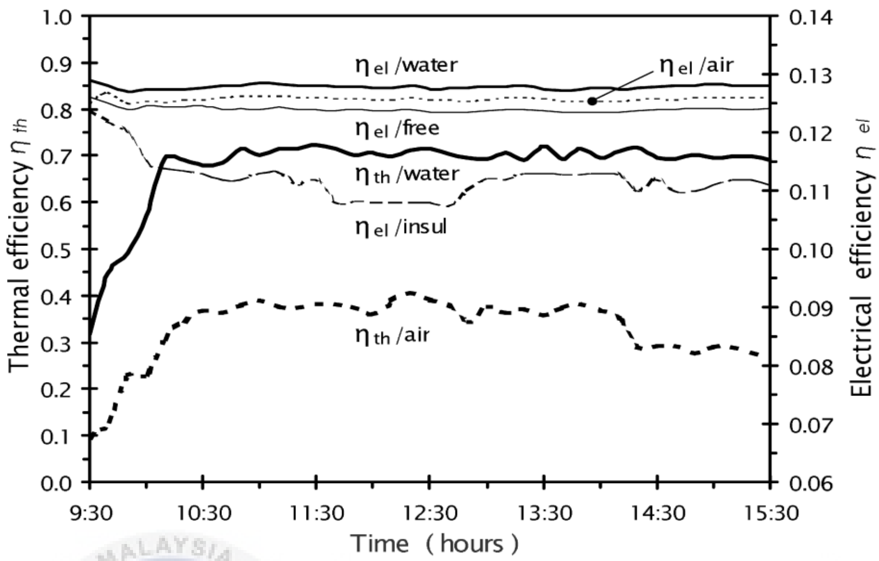
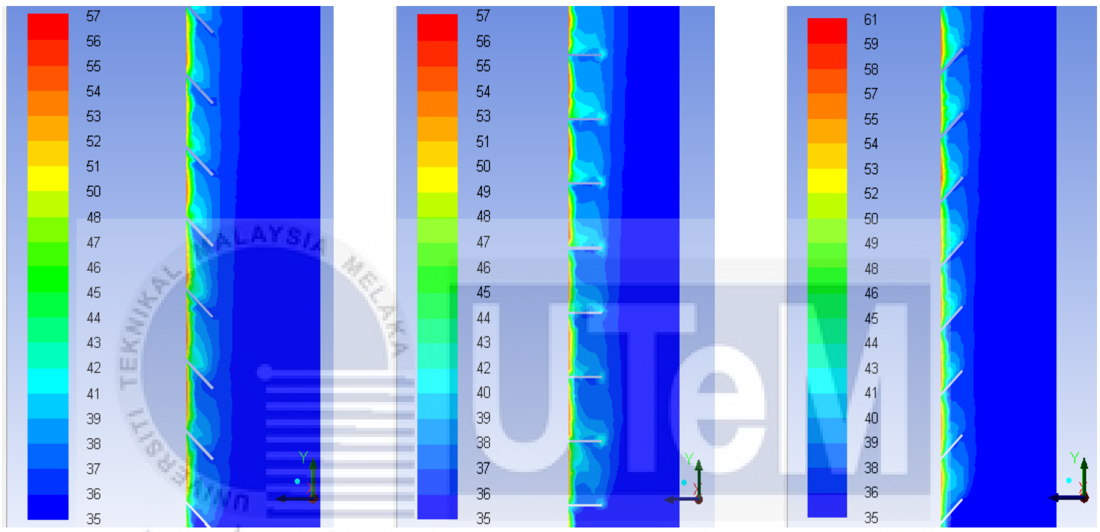


Figure 2.11: Results comparisons between multiple PV setup with the efficiency [38]

2.7.2 Passive cooling system

Air passive cooling including conductive cooling, is the cheapest way to cool a PV channel. This method is less popular than other method considering the heat extraction by the air itself is less efficient. Popovici et. al. [39] presented a numerical study on reducing the temperature of PV panels to increase the efficiency by using air cooled heat sink. The cooling design presented in this paper involved air flow on the back side of the PV module. On the studied case the temperature of PV panel reaches 56 °C and produce maximum power 86% of the nominal one. When using heat sink, the average temperature of the PC decreases at least by 10 °C with the maximum power produced 90% of the nominal one.

The experimental setup involved three models with different angle of ribs and different ribs height attached on the back of the PV module. The airflow is set at 1.5 m/s with solar radiation of 500 W/m^2. Low convective heat transfer was assumed at the outer surface and the convective heat transfer coefficient was assumed to be 8 W/m^2.K. The results indicate that when using ribs with 0.03 m height and 45° the heat transfer is much better compared to the other set-up as shown in Figure 2.12. Figure 2.13 shows the average temperature of PV vary with different ribs height and angle.



(a) (b) (c)

Figure 2.12: Temperature spectra for different ribs angle at a) 45°, b) 90°, c) 135° [39]

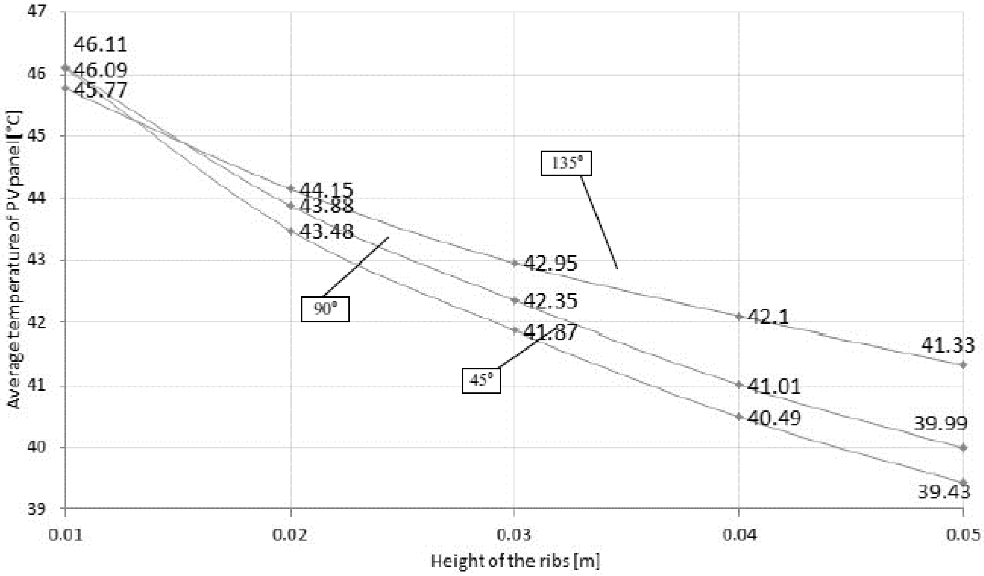


Figure 2.13: Variation of PV panel temperature depending on the rib's height and angle [39]

An analytical study was carried out by Leow et. al. [40] using ANSYS to investigate the performance of solar PV based on different wind velocity. The simulation was carried out with the wind velocity in the range of 0 m/s up to 6.95 m/s under 35 °C ambient temperature and 1000 W/m^2 solar radiation. The result of this study shows that the wind velocity has an impact on the solar panel temperature due to the cooling effect provided to the solar surface by the wind velocity. Figure 2.14 shows the highest temperature that generated by the solar panel models under different wind velocity. The statement correlates with the findings by Sabri and Benzirar [41] that when the wind velocity increases the solar panel temperature decreased and power generated increased. This is because of heat from the solar panel dissipate more from high wind velocity.

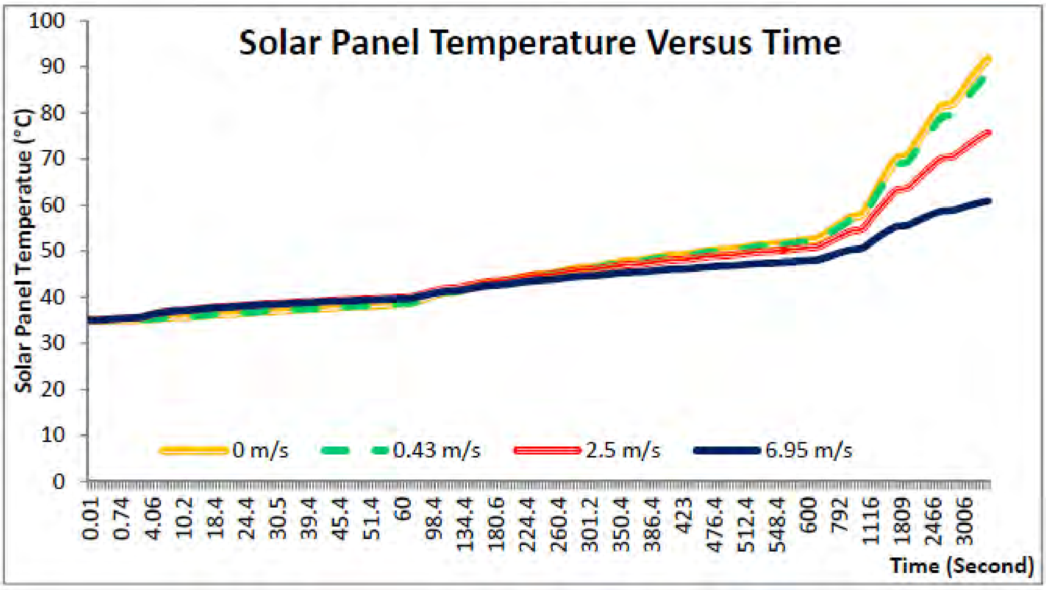


Figure 2.14: Solar panel temperature versus time under different wind velocity [40]

In other study by Yang et. al. [42], an experimental model is constructed to validate the numerical analysis on the impact of wind velocity on the performance of solar array. The experiment was carried out with the wind speed ranging between 2 to 8 m/s with irradiance valued between 200 to 1000 W/m^2. The result showed that by increasing the wind velocity will improve the power generated by the PV system. Cuce et. al. [43] conducted an experiment related to the implementation of passive cooling technique. The paper studied the effect of using aluminium heat sink on the performance of solar PV. A solar simulator was constructed with aluminium heat sink attached on the rear of the PV panel in order to increase the heat rejection. The experiment This result in an increase 20% on PV panel output at 800 W/m^2 solar radiation with an increase of electrical efficiency by 1% depends on the solar radiation.

2.7.3 Literature Review Summary

Table 2.1: Summary of research work performed for thermal regulations of PV panels

PV type	Technique	PV cell temperature	PV performance	Reference
Water Cooling				
Multi-crystalline	Experimental and Simulation	32 °C	Increase 5% during dry and warm seasons	[22]
Crystalline silicon	Experimental	Up to 22 °C reduction	10.3% power increase	[23]
-	Experimental	Decreases in value 5 °C to 23 °C	Increases by 9% to 22%	[24]
-	Simulation	-	Efficiency increases by 3%	[25]
Mono-crystalline	Experimental	Drop by 20%	Increases by 9%	[26]
-	Experimental	Temperature decreases	Yield high power output	[27]
-	Experimental and Simulation	Between 30 °C to 40 °C	Overall energy efficiency increases about 36%	[28]
Crystalline silicon	Experimental	30 °C	Power output increases by 10W	[29]
-	Experimental	-	Increase output voltage to 19.4% and power output by 19.1%	[30]
-	Experimental	Reduction up to 19 °C	Average electrical generated increase 8.3%	[31]

PV type	Technique	PV cell temperature	PV performance	Reference
-	Experimental	Dropped by 10 °C	Efficiency increase by 10%	[32]
Single crystalline silicon	Experimental	Reduction of 20 °C	10.4% efficiency increase	[33]
Air Cooling				
Mono-crystalline	Simulation	Dropped to 48 °C with 4 DC fans	Power output increases to 67W with optimisation	[34]
-	Simulation	53.6 °C with fan speed of 3.07 m/s	Net power saving of 3%	[35]
-	Numerical analysis	-	-	[36]
Mono-crystalline	Experiment	-	-	[37]
PV-T collector	Experiment	-	-	[38]
-	Simulation	Reduced at least 10 °C	Power produced increased by 2%	[39]
Mono-crystalline	Simulation	Maximum temperature reaches 60 °C	-	[40]
-	Experimental	-	Power generated increases with wind velocity	[42]
-	Experimental	-	20% increase of power output	[43]

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will describe the methodology in conducting this project. This includes the process of designing the solar PV cooling system using CAD software and the process of analysing the data using ANSYS. The analysis will be conducted by developing a solar PV cooling system in order to study the temperature behaviour of the panel. Once the analysis is completed, the results will be compared to the past research in order to support the data. If not, the analysis will be carried out again. Figure 3.1 summarized the methodology of this project

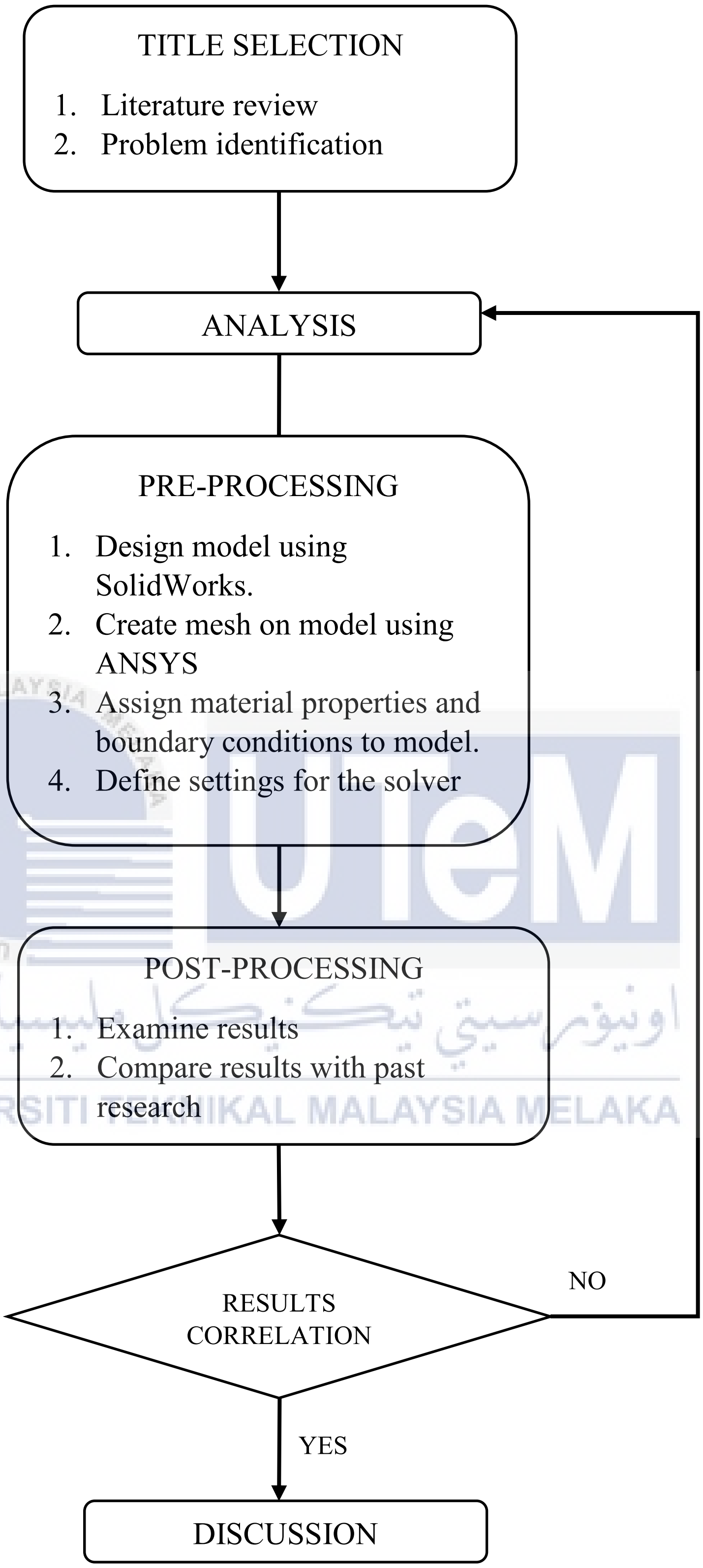


Figure 3.1: Flowchart of the methodology

3.2 SOFTWARE AND METHOD

3.2.1 SolidWorks 2017

SolidWorks 2017 is a computer-aided design (CAD) software that will be used to design the solar panel. In order to create the model of a solar panel, the geometry model of the solar panel based on Kyocera KU270-6MCA polycrystalline PV module. In this case, a panel with the dimension of 1662mm x 990mm is created as shown in Figure 3.2. Shown in Figure 3.3 is the panel model consists of 5 layers such as a glass cover, Ethylene Vinyl Acetate (EVA), solar cells, second layer of EVA and tedlar. Table 3.1 shows the properties of each layer in the solar panel.

Table 3.1: Material properties of each layer of PV panel [44]

Material	Thickness (mm)	Thermal Conductivity (W/m °C)	Specific Heat Capacity (J/kg °C)	Density (kg/m^3)
Glass Cover	3.0	0.98	500	3000
EVA	0.5	0.35	2090	960
Solar Cell	0.4	148.00	677	2330
Tedlar	0.1	0.36	1250	1200

Figure 3.2: Model of solar panel

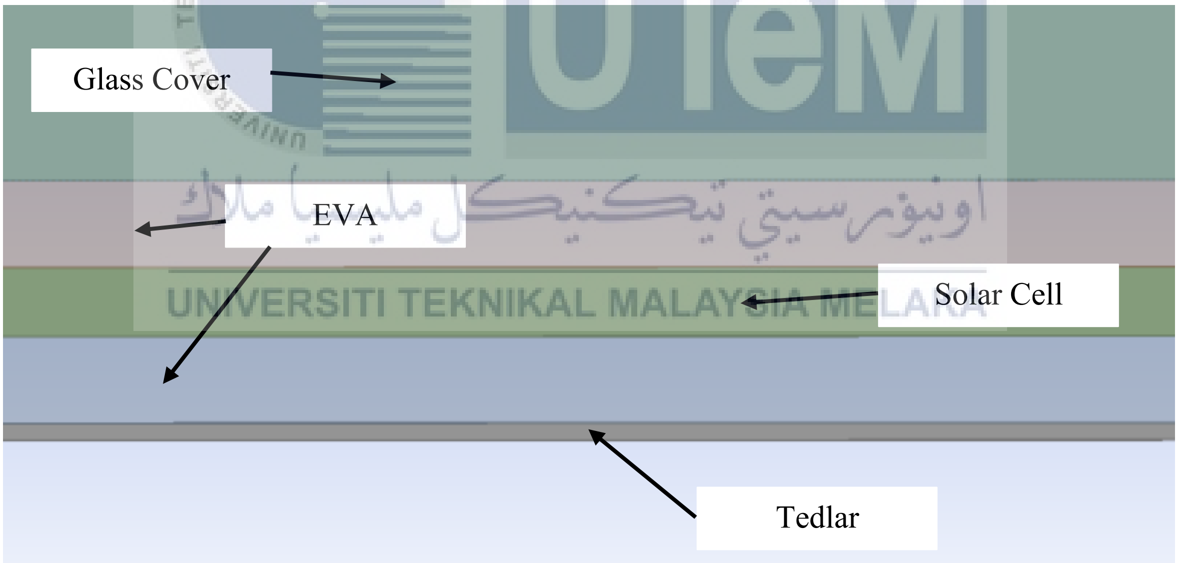


Figure 3.3: Layers of solar panel

3.2.2 Data Collection

The data collection process can be carried out easily as the data can be obtained on the internet and research journals. The most important data for this project is the amount of irradiance at Melaka [45]. Melaka was chosen as the solar radiation at this state is acceptable to be used in simulation. Table 3.2 shows the average hourly environment condition in Melaka taken on a day in March. The model's initial temperature is set at 35 °C, where it is the average daily ambient temperature recorded in Malaysia [46].

Table 3.2: Average hourly environment condition in Melaka [45]

Hours	Irradiance, I (W/m^2)	Wind Velocity (m/s)	Ambient Temperature (°C)
0800	16	1.9	24.7
0900	116	2.1	25.1
1000	227	2.9	26.3
1100	414	3.5	27.5
1200	831	4.8	29.3
1300	1007	3.7	31.0
1400	1088	3.7	32.1
1500	902	3.3	32.7
1600	791	3.3	33.4
1700	534	3.2	33.4
1800	387	3.3	33.6

3.2.3 ANSYS Software

To get the analytical results, ANSYS will be used to analyse the temperature distribution throughout the solar panel. ANSYS is a computer software that perform computer simulation for various cases (e.g., thermal analysis, fluid flow, rigid dynamic, etc.). These programs can be accessed from ANSYS Workbench, which work as the main connecting point between them. The sub-program that will be used are ANSYS Transient Thermal, Steady-State and FLUENT.

3.2.3.1 Model Setup

The first step is to create a computational domain for fluid as shown in Figure 3.4. The selection of domain size is respected to the panel width, Wp = 0.99m. The height of the panel and the width of the domain is H = W = 7Wp, while the length of the fluid domain is L = 9Wp, which the length from the inlet to the panel is 3Wp. The model is defined with suitable named selection of each region as shown in Figure 3.5.

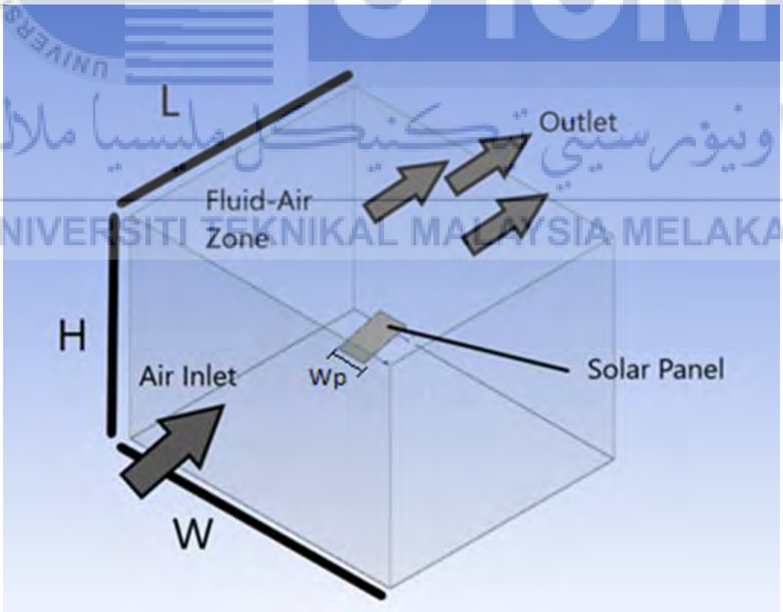


Figure 3.4: Air domain geometry

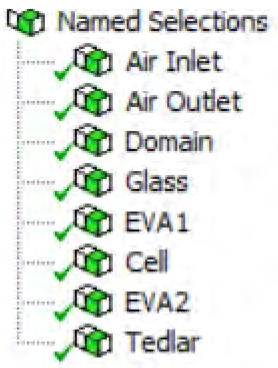


Figure 3.5: Named selection of region

3.2.3.2 Meshing

After importing the geometry to ANSYS software, the model will be meshed beforehand in order to start the analysis. The accuracy of the result depends on the type of mesh and the elements size used. Meshing process was satisfy until it produces a good quality mesh. The meshing of the air domain and solar panel is shown in Figure 3.6 and Figure 3.7.

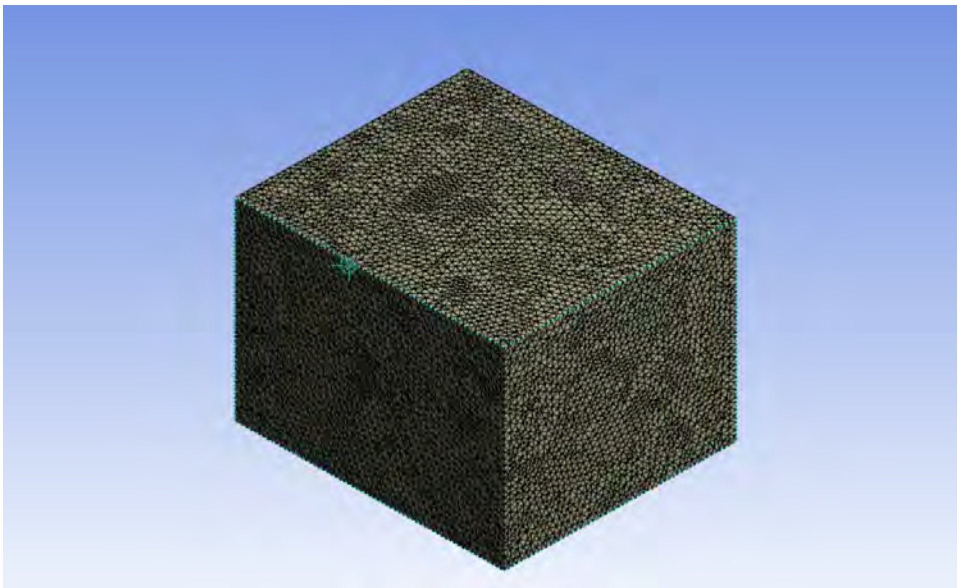


Figure 3.6: Meshing of air domain

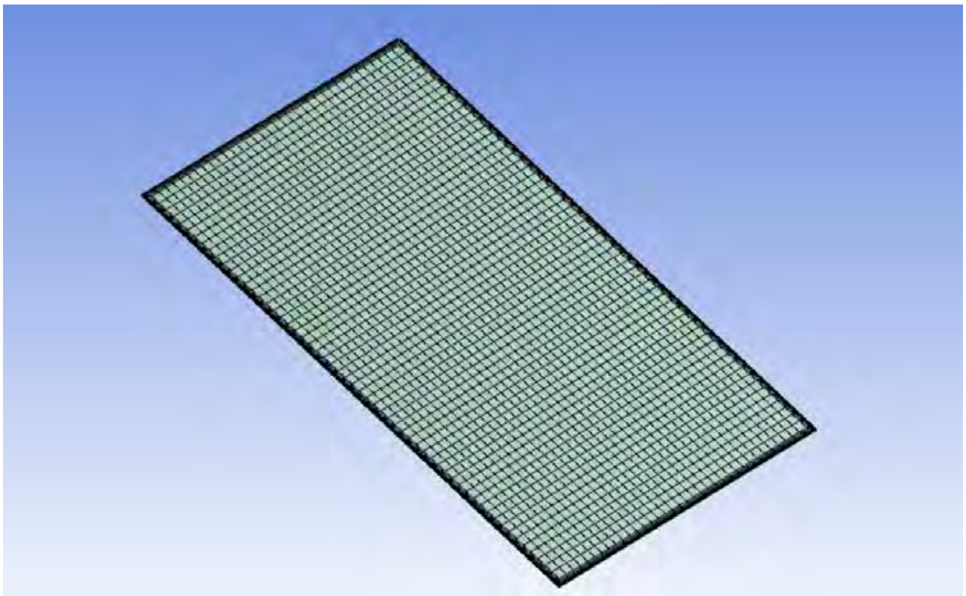


Figure 3.7: Meshing of solar panel

3.2.3.3 Grid Independence Test

Grid independence test or grid convergence is the term used to describe the improvement of results by using successively smaller cell sizes. The test is carried out first in order to ensure the results are not affected by mesh size. The test is tested with different relevance; coarse, medium and fine and it is conducted under irradiance of 1000 W/m^2 with ambient temperature of 30 °C. The results are shown in figure below.

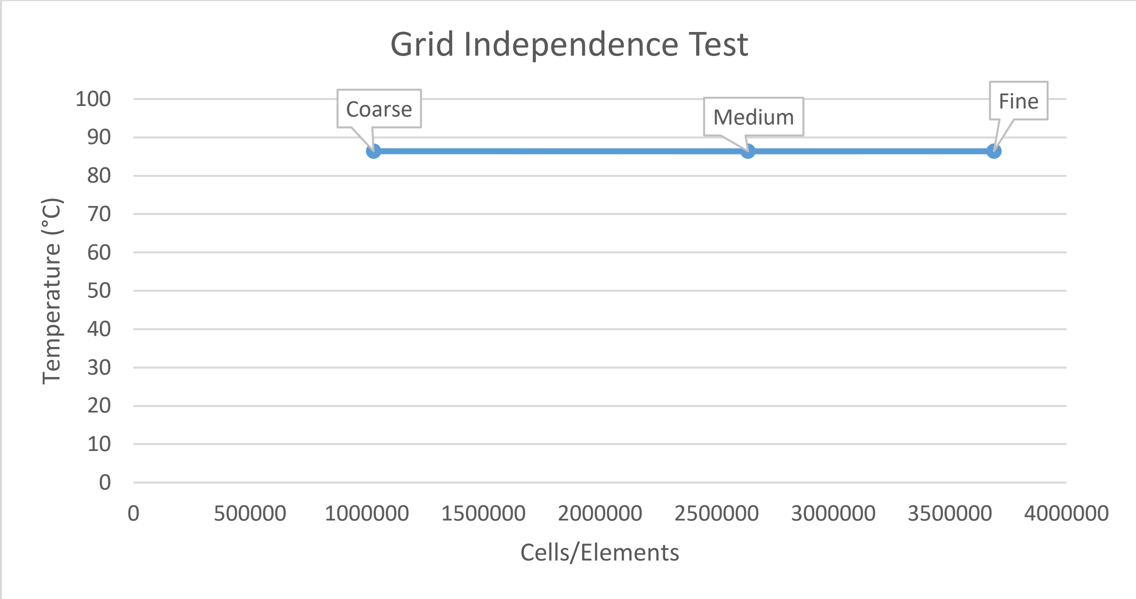


Figure 3.8: Graph of grid independence test

The three test shows a good agreement considering the different number of cells. Since there isn't much difference on the average temperature, this simulation is run using medium mesh to save computational time.

3.2.3.4 Setup and Solution's Calculation

Fluent is then opened to start the setup and calculation. First, the panel was set to tilt at 15° angle as most of the solar panel in Malaysia was set to tilt between 0° to 15° and the gravity option is activated. The "Energy Equation" is turned on so that heat transfer throughout the panel can be calculated. The cell zone conditions of each body are defined with its own material properties as shown in Figure 3.9.

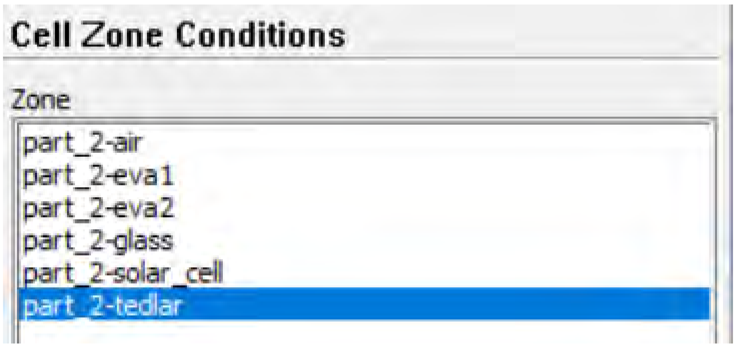


Figure 3.9: Cell zone conditions of each body

After finished setting up the boundary conditions for each body accordingly with the appropriate setup as shown in Figure 3.10, the solution is then initialised and run until the solution is converged. This process is repeated for each simulation until proper results is obtained.

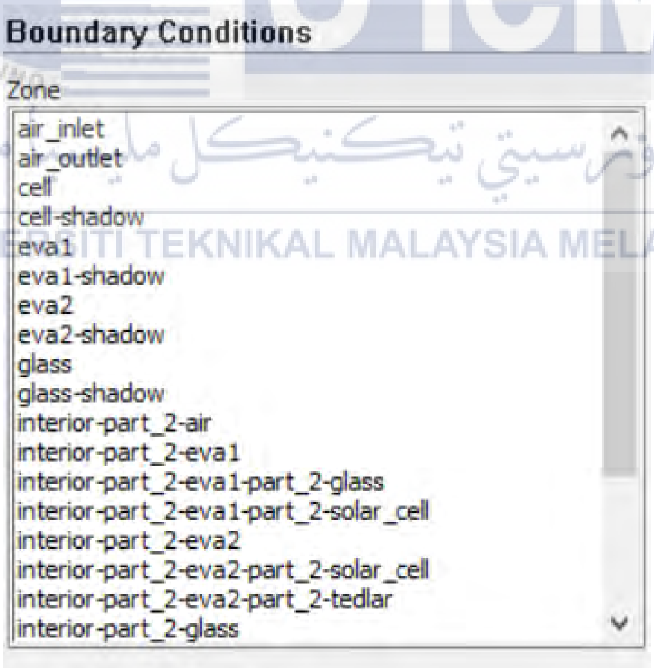


Figure 3.10: Boundary conditions of each region

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results from the analysis will be presented here. All the data is presented in the form of tables and figures for a better understanding. There's also some comparison made with past research that related with this study to validate the results obtained.

4.2 RESULTS AND DISCUSSION

The solar panel is simulated under two conditions, which one of it is assumed that there is no wind flow across the panel means it was exposed to solar radiation without cooling and with a constant value of ambient temperature, 30°C while the other simulation is set up with proper environmental conditions as in Table 3.2. The results of both simulations are then compared to see the effect of cooling on the solar panel.

4.2.1 Temperature of solar panel back surface

The first analysis is focusing towards the effect of cooling on the back surface of PV panel. Table 4.1 and Figure 4.1 shows the data for the temperature of PV panel when exposed to the sun radiation between 10 a.m. to 4 p.m. which is the suitable time for PV panel to perform efficiently.

Based on the results, the highest temperature of PV panel the highest when the irradiance reached 1088 W/m^2 at 2pm. The temperature can reach approximately up to 116°C when there is no cooling load applied whereas when there is cooling load the temperature only reaches up to 57°C as seen in Table 4.1 and Figure 4.1. Figure 4.2 shows the difference of temperature distribution between both simulations.

Table 4.1: Average back surface temperature of PV for 6 hours

Time (Hrs)	Average Temperature (°C)	
	No Cooling	With Cooling
1000	56.5736	32.5985
1100	63.5740	36.6391
1200	81.1906	43.7611
1300	107.7646	52.9193
1400	116.3235	57.1595
1500	113.6525	55.7535
1600	115.6532	54.3094

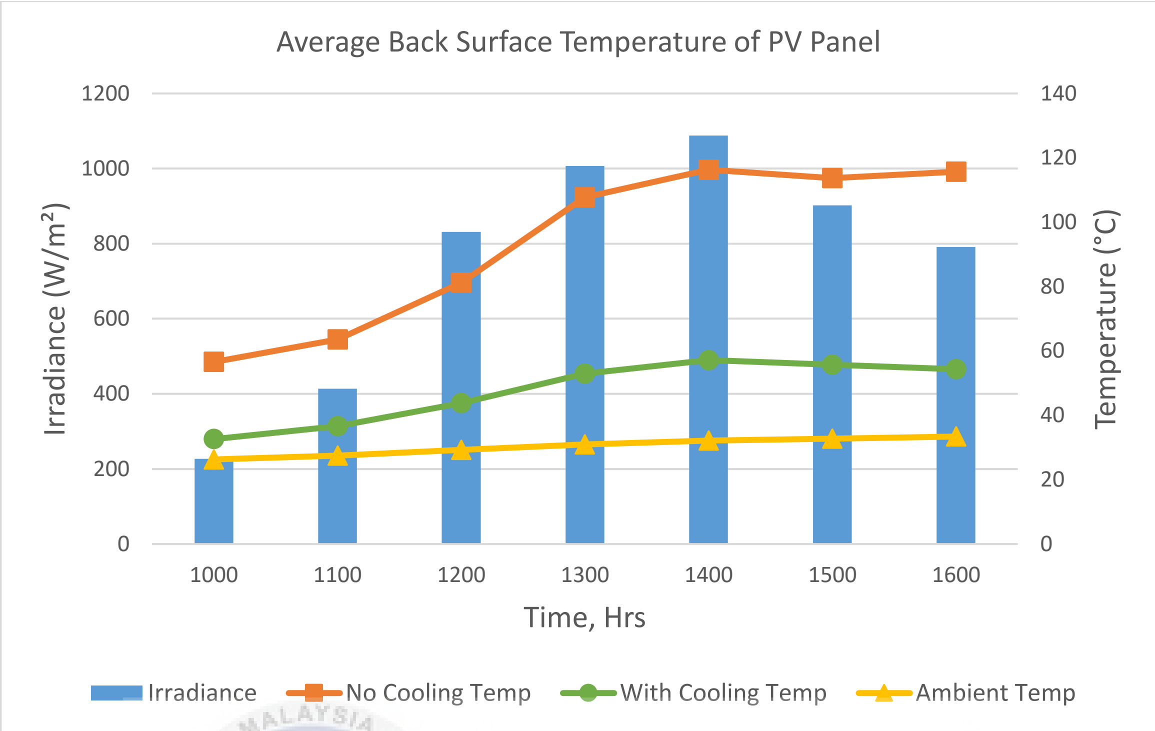
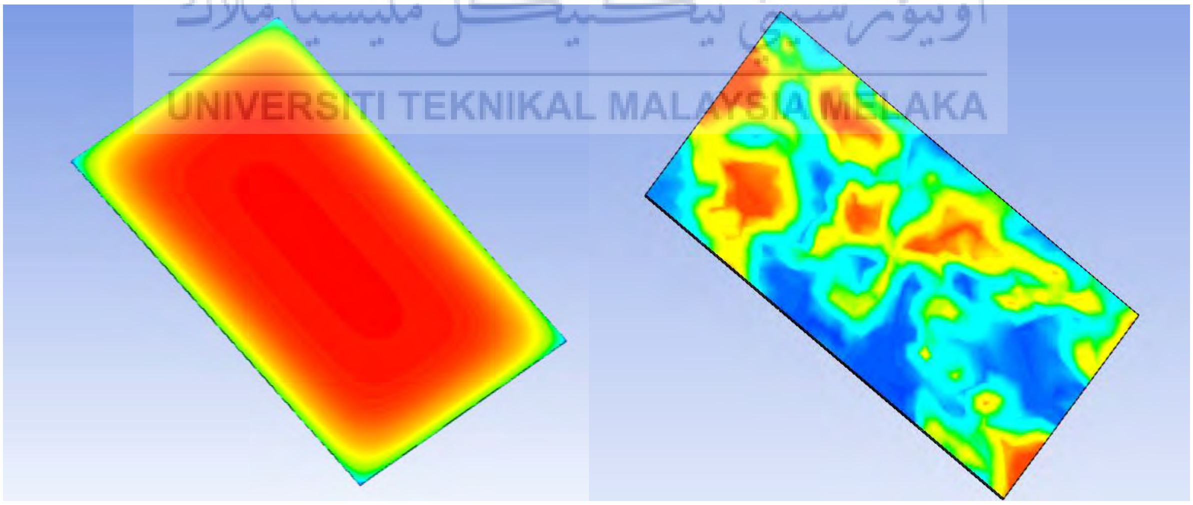


Figure 4.1: Back surface temperature of PV panel



(a) (b)

Figure 4.2: Temperature distribution of PV panel a) no cooling, b) with cooling

4.2.2 Efficiency of Solar PV

Irradiance, ambient temperature, wind velocity as well as the PV temperature, affects the performance of PV module. From the temperatures obtained by the simulation and the solar panel manufacturer data sheet as seen in Table 4.2, the value of efficiency can be obtained by using Eq. (4.1) and Eq. (4.2) [47].

$$\eta_{cell} = \eta_{ref}\left[1 - \beta\left(T_{cell} - T_{ref}\right)\right] \tag{4.1}$$

$$\eta_{ref} = \frac{P_{max,STC}}{A_{PV} \times I_{STC}} \tag{4.2}$$

Where η_{ref} is the maximum efficiency of the PV cells when tested with reference temperature, T_{ref} and solar irradiance under STC, I_{STC} which is usually 25°C and 1000W/m^2 respectively.

Table 4.2 PV Properties [48]

Properties	Data
Type	Polycrystalline
Surface area of PV, A_{PV}	1.65m^2
Maximum power of module, $P_{Max,STC}$	270
Temperature coefficient, β	-0.46 %/°C

After being calculated by using Microsoft Excel, a line graph of the efficiency of PV for both simulation is generated from the tabulated data in Table 4.3. According to Figure

4.3, the efficiency dropped as the surface temperature increases correlate with the theory from the literature review. In Figure 4.4, it can be seen that the efficiency slightly increases after 2pm due to the irradiance intensity changes over time. The efficiency during peak irradiance at 2pm for simulation with cooling approximately 14% while the efficiency without cooling shown a big difference of -4%.

Table 4.3: Average efficiency of PV

Time (Hrs)	Average Efficiency	
	No Cooling	With Cooling
1000	0.1433	0.1590
1100	0.1387	0.1564
1200	0.1271	0.1517
1300	0.1097	0.1457
1400	0.1041	0.1429
1500	0.1058	0.1438
1600	0.1045	0.1448

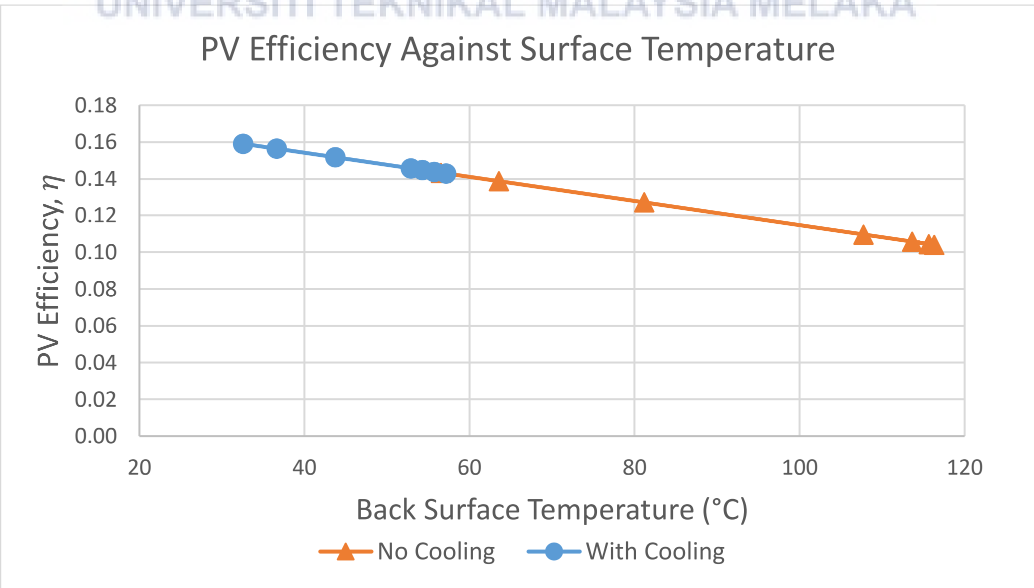


Figure 4.3: Efficiency of PV against back surface temperature

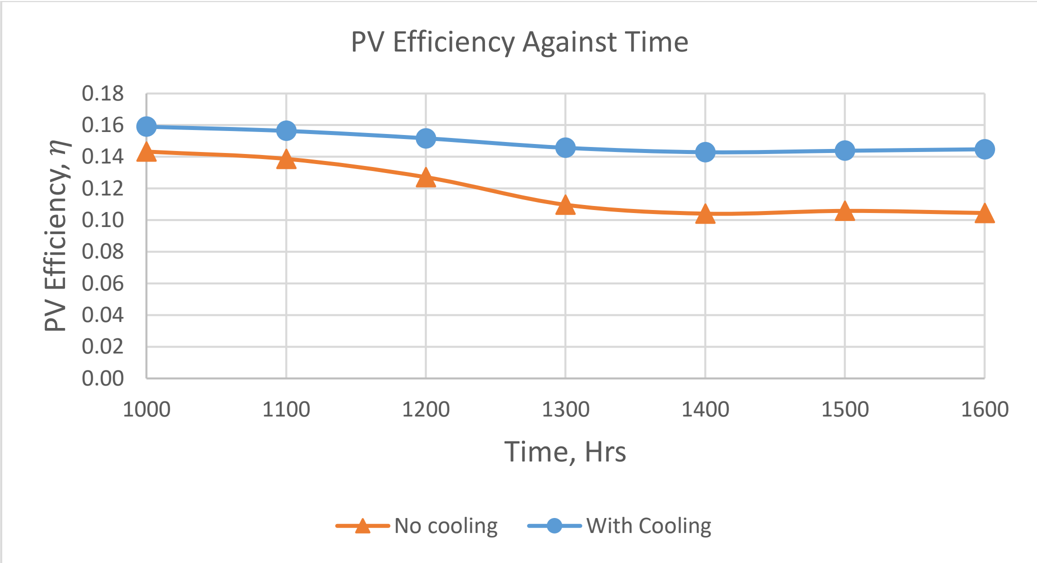


Figure 4.4: Efficiency of PV along the simulated transient time

4.2.3 Performance of PV under different wind velocity

Long exposure to solar radiation and high temperature causes the solar panel to be overheating making it less efficienct. The solar panel is tested under wind velocity range between 2m/s to 5m/s during peak irradiance at 2pm. Table 4.4 show the average efficiency of solar PV when applied different wind velocity in the course of one hour (represent in second as seen in Figure 4.5). From the result, it can be seen that with 2 m/s, 3 m/s, 3.7 m/s and 5 m/s of wind velocity, the efficiency of the panel is approximately 13.6%, 14.1%, 14.3% and 14.6% respectively.

Table 4.4: Average efficiency of PV at 2pm under different wind velocity

Wind Velocity (m/s)	Average Efficiency
2	0.1360
3	0.1408
3.7	0.1429
5	0.1458

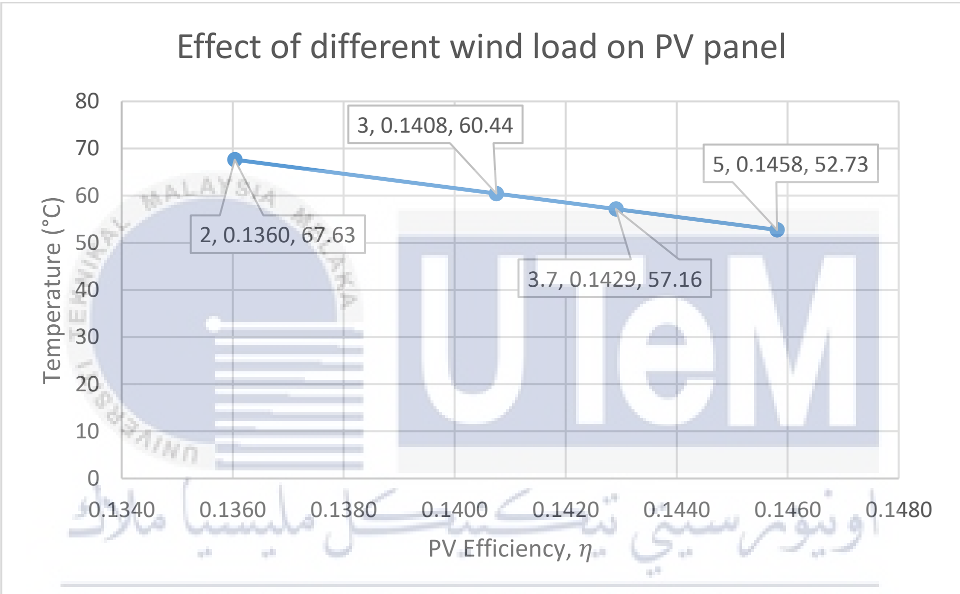
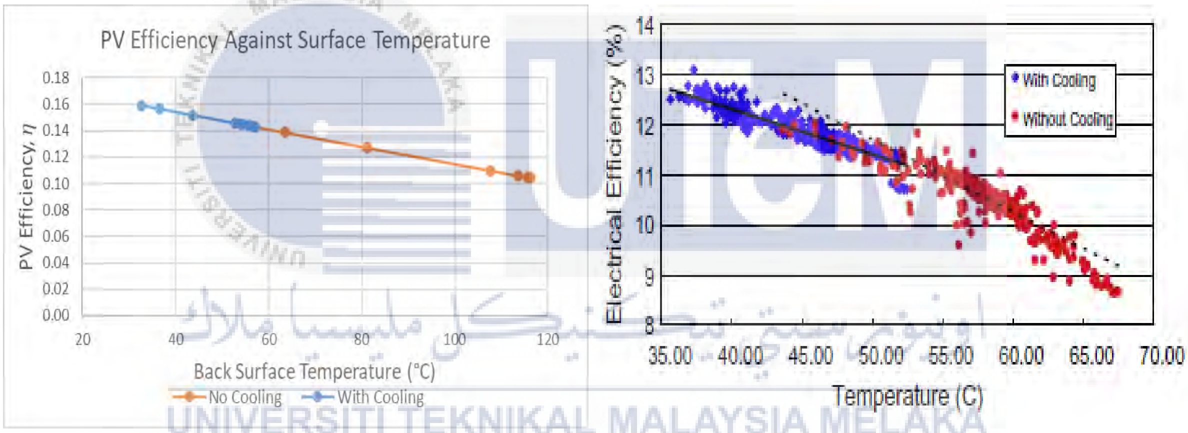


Figure 4.5: Efficiency of PV at 2pm under different wind velocity

4.3 VALIDATION

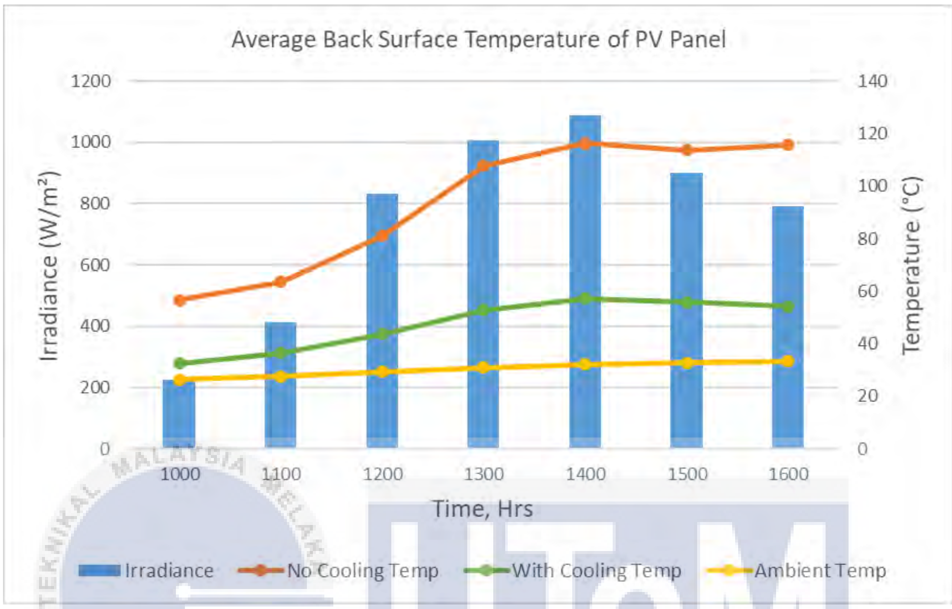
Based on Figure 4.6, it shows that both research have an almost similar trend on the efficiency obtained where the efficiency decreases as temperature increases. However, this research have a difference about 3% lower from the previous research due to Teo et.al [49] conduct their research by experiment which took all environment factor into account whereas this research only conducted by simulation which some of the environment factor is neglected. Beside the previous research conducted the experiment with a full solar PV set-up whereas this research only simulated on the solar panel.



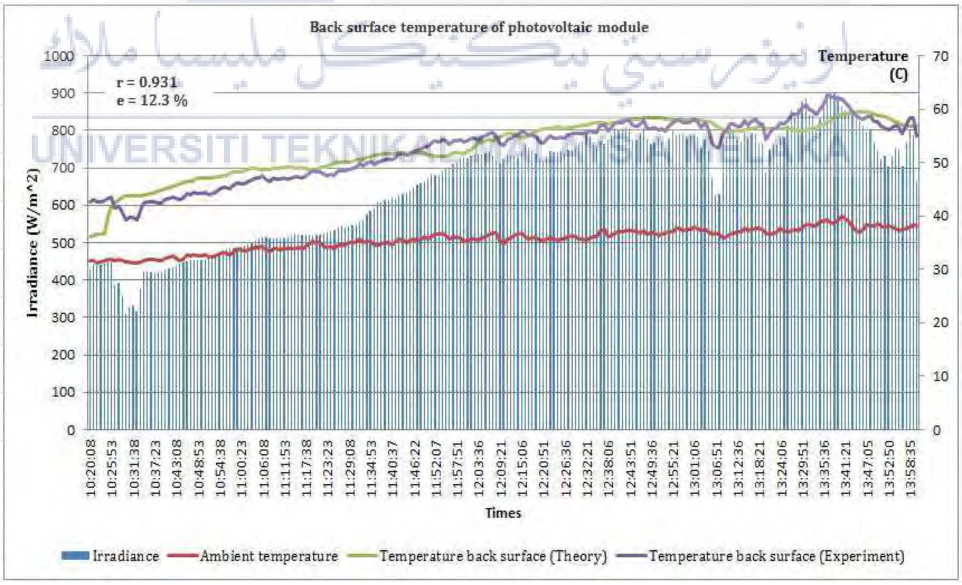
(a) (b)

Figure 4.6: Comparison of efficiency a) this research and b) previous research [49]

Based on Figure 4.7, the comparison of back surface temperature result between this research and previous research by Rosli et.al [50] slightly correlate with each other. The difference in value is due to the experiment carried out on the previous research and simulation of this research are tested on different day, meaning that the environment condition will be different. This simulation could be more accurate if it simulated on the same condition as the previous research.



(a)



(b)

Figure 4.7: Comparison of back surface temperature a) this research b) previous research [50]

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This work has presented CFD simulation using ANSYS on passive cooling by natural convection of air and also without cooling towards the solar panel. From the simulation, it has been found that temperature of solar PV affect the performance of PV. Then from this simulations, the efficiency of solar PV when back surface temperature changes also have been presented.

Both of the simulations is compared with each other to show the difference and the advantages of cooling load on solar panel. The back surface temperature of PV when no cooling and with cooling during peak irradiance approximately 116 °C and 57 °C respectively showing a great difference between it. Based on this result, efficiency of PV cell is obtained by calculation. The theoretical efficiency of PV cell with no cooling during peak irradiance approximately around 10% whereas it valued around 14% when cooling load is applied showing an increase of 4% where this value is consider big in solar industries. As conclusion, PV with cooling shows a better performance compared to the PV without cooling.

It was shown that the presence of natural convection would reduce the temperature and increase the efficiency of PV. However, this would require a higher wind velocity for a better result as seen from the result obtained when the velocity ranges between 2 m/s to 5 m/s.

5.2 RECOMMENDATION

From this study, it has shown some recommendation that can be made that would improve the cooling effect on the solar panel at the same time will improve the performance of solar PV. Since the solar panel used in this simulation is bare panel with natural convection, the cooling effect is not fully utilised. Instead of using this, one of the ways to improve the performance and utilise the natural convection, is by adding heat sink to the panel. Heat sink with ribs will have a big influence in reducing the temperature of the panel while increasing the efficiency.

From the simulations, it is expected that panel with higher wind velocity have a better performance compared to the panel with lower wind velocity. However, it would be hard to get a consistent high wind velocity in Malaysia. To overcome this, other cooling technique that can be introduced to the system is active air cooling or forced air circulation. By adding fans or blower to the solar panel, a consistent air speed can be assured to increase the performance of the solar panel.

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APPENDIX A

Gantt Chart for PSM 1

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
FYP Title Selection	1	2	1	2	100%
Identifying Problem Statement	3	2	3	2	100%
Identifying Objective	3	2	3	2	100%
Identifying Scope of Project	3	2	3	2	100%
Literature Review	5	3	5	3	100%
Simulation Preparation	5	4	5	4	100%
Methodology	9	2	9	2	100%
Expected Results	11	3	11	3	100%
Report	14	2	14	2	100%

APPENDIX B

Gantt Chart for PSM 2

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	WEEKS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANSYS Simulation	1	10	1	10	100%															
Identifying Simulation Error	3	2	3	2	100%															
Data Collection	3	2	3	2	100%															
Progress Report	8	1	8	1	100%															
Result and Discussion	9	4	9	4	100%															
Draft Final Report	13	2	13	2	100%															

APPENDIX C

Kyocera Manufacturer Data Sheet (Solar Panel Model)

ELECTRICAL SPECIFICATIONS

Standard Test Conditions (STC) *STC=1000 W/M² irradiance, 25°C module temperature, AM 1.5 spectrum**		
	KU270-6MCA	
P_{max}	270	W
V_{mp}	31.0	V
I_{mp}	8.71	A
V_{oc}	38.3	V
I_{sc}	9.43	A
$P_{tolerance}$	+3/-0	%
Nominal Operating Cell Temperature Conditions (NOCT) *NOCT=800 W/M² irradiance, 20°C ambient temperature, AM 1.5 spectrum**		
T_{NOCT}	45	°C
P_{max}	194	W
V_{mp}	27.9	V
I_{mp}	6.96	A
V_{oc}	35.1	V
I_{sc}	7.63	A
PTC	242.7	W
Temperature Coefficients		
P_{max}	-0.46	%/°C
V_{mp}	-0.49	%/°C
I_{mp}	0.02	%/°C
V_{oc}	-0.36	%/°C
I_{sc}	0.06	%/°C
Operating Temp	-40 to +90	°C
System Design		
Series Fuse Rating		15 A
Maximum DC System Voltage (UL)		1000 V
Hailstone Impact		in (25mm) @ 51mp (23m/s)

*Subject to simulator measurement uncertainty of +/- 3%.
KYOCERA reserves the right to modify these specifications without notice.

WARNING: Read the instruction manual in its entirety prior to handling, installing & operating Kyocera Solar modules.

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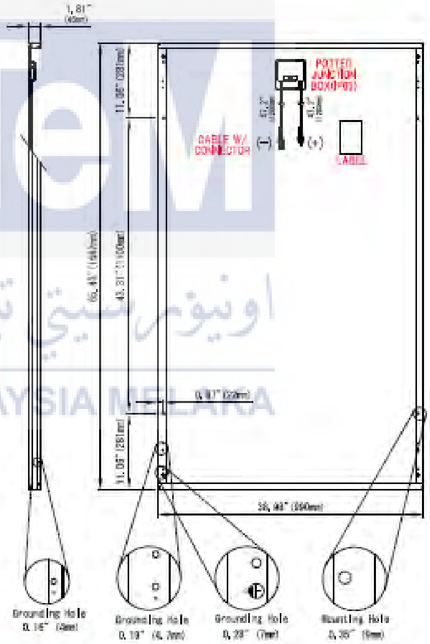
MODULE CHARACTERISTICS

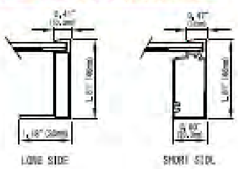
Cells per module:	60 (6 x 10)
Dimensions: *length/width/height*	65.43in/38.98in/1.81in (1662mm/990mm/46mm)
Weight:	41.9lbs (19.0kg)

PACKAGING SPECIFICATIONS

Modules per pallet:	20
Pallets per 53' container:	36
Pallet box dimensions: *length/width/height*	66in/40in/47in (1675mm/1005mm/1175mm)
Pallet box weight:	950lbs (430kg)



FRAME CROSS SECTION DIAGRAM



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