# EXPERIMENTAL INVESTIGATION OF A PHOTOVOLTAIC PANEL WITH ALUMINIUM COOLING FINS UNDER NATURAL CONVECTION”

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**EXPERIMENTAL INVESTIGATION OF A PHOTOVOLTAIC PANEL WITH ALUMINIUM COOLING FINS UNDER NATURAL CONVECTION"**

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**in partial fulfilment of the requirements for the degree of**
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**2024**

## DECLARATION

I declare that this thesis entitled "EXPERIMENTAL INVESTIGATION OF A PHOTOVOLTAIC PANEL WITH ALUMINIUM COOLING FINS UNDER NATURAL CONVECTION" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :

Name : Aldrich bin Ateng

Date : 17 June 2024

**APPROVAL**

I hereby declare that I have checked this report entitled "Experimental investigation of a photovoltaic panel with aluminium cooling fins under natural convection", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Electrical Engineering with Honours

Signature :

Supervisor Name : Dr. Ahmad Aizan bin Zulkefle

Date : 17 June 2024

**DEDICATIONS**

To my beloved mother and father

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I would like to express my sincere appreciation to all those who contributed to the successful completion of the experimental investigation of a photovoltaic panel with aluminium cooling fins under natural convection.

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# ABSTRACT

The purpose of this experimental inquiry is to explore the impact that cooling fins made of aluminium have on the efficiency of a solar panel that is working under circumstances of natural convection. In light of the ever-increasing need for energy sources that are not only efficient but also environmentally friendly, it is becoming more vital to enhance the efficiency of solar panels. The experiment used a specific solar panel that was outfitted with aluminium cooling fins that were positioned in a strategic way in order to enhance the effectiveness of natural convection. This was done in order to increase the efficiency of natural processes. In order to determine whether or not cooling fins made of aluminium are beneficial in enhancing the efficiency of solar panels that are operating under natural convection circumstances, the goal of this research is to inquire about their performance. The field is significantly advanced as a result of this kind of study. These results may have implications for the development and use of cooling solutions for solar energy systems. It is conceivable that these discoveries will have significant implications.

# *ABSTRAK*

Tujuan siasatan eksperimen ini adalah untuk meneroka kesan sirip penyejuk yang diperbuat daripada aluminium terhadap kecekapan panel solar yang berfungsi dalam keadaan perolakan semula jadi. Memandangkan keperluan yang semakin meningkat untuk sumber tenaga yang bukan sahaja cekap tetapi juga mesra alam, ia menjadi lebih penting untuk meningkatkan kecekapan panel solar. Eksperimen ini menggunakan panel solar khusus yang dilengkapi dengan sirip penyejuk aluminium yang diletakkan dengan cara yang strategik untuk meningkatkan keberkesanan perolakan semula jadi. Ini dilakukan untuk meningkatkan kecekapan proses semula jadi. Untuk menentukan sama ada sirip penyejuk yang diperbuat daripada aluminium bermanfaat atau tidak dalam meningkatkan kecekapan panel solar yang beroperasi di bawah keadaan perolakan semula jadi, matlamat penyelidikan ini adalah untuk bertanya tentang prestasinya. Bidang ini sangat maju hasil daripada kajian seperti ini. Keputusan ini mungkin mempunyai implikasi untuk pembangunan dan penggunaan penyelesaian penyejukan untuk sistem tenaga suria. Dapat dibayangkan bahawa penemuan ini akan mempunyai implikasi yang ketara.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| PV | - | Photovoltaic |
| Si | - | Silicon |
| CdTe | - | Cadmium telluride |
| CIGS | - | copper indium gallium selenide |
| GaAs | - | gallium arsenide |
| a-Si | - | amorphous silicon |
| Φ | - | finning factor |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

One important component of the worldwide movement toward renewable energy is solar power, which is collected using photovoltaic (PV) panels. Improving the effectiveness of photovoltaic panels is becoming critical due to the rising need for renewable energy. High operating temperatures limit efficiency and may cause long-term damage to these panels, which has a major impact on their performance. So, efficient cooling systems are very necessary to keep everything running at peak performance. The photovoltaic (PV) sector is now using both active and passive cooling measures currently. For the purpose of this experiment, we decided to make use of indirect cooling systems. The utilization of natural convection is what is meant by the term "passive cooling system." The use of aluminium, which is well-known for its high thermal conductivity, and cost-effectiveness, has emerged as a potentially useful material for improving the natural convection cooling performance of photovoltaic panels. Aluminium cooling fins have the capacity to effectively disperse heat, which would result in an improvement in the overall performance of photovoltaic panels. During the course of this experimental investigation, the primary objective is to evaluate the impact that solar panels equipped with aluminium cooling fins have on their thermal performance as well as efficiency while operating in natural convection environments. The purpose of this study is to provide valuable information to the design and installation of photovoltaic panel cooling systems, with the ultimate goal of strengthening the practicality and durability of solar energy in the long term.

## 1.2 Motivation

Photovoltaic (PV) panels have significant difficulties in operating efficiently at high temperatures, which is why this research is necessary. Reduced performance, lower efficiency, and rapid depreciation of PV panels are all symptoms of high working temperatures. The increasing need for renewable and sustainable energy has made it critical to find ways to make solar power systems as efficient and dependable as possible. In order to solve temperature-related problems, this research is investigating passive cooling methods, with an emphasis on using aluminium cooling fins. The study's overarching goal is to improve solar power generating efficiency by reducing the negative impacts of high temperatures. Improving thermal management may increase the lifetime of PV panels, which in turn decreases the frequency of maintenance or replacements and aligns with sustainability objectives, which is a crucial factor in considering the environmental effect. To further shed light on realistic and budget-friendly ways to improve PV panel performance in real-world settings, the study aims to evaluate passive cooling systems' cost-effectiveness. Improving energy collecting and making strides toward more dependable solar power systems are the ultimate objectives.

## 1.3 Problem Statement

The use photovoltaic (PV) panels become popular as a renewable energy source. The drawback of the PV is that when the temperature rises, the efficiency of the PV will drop accordingly. Even though Malaysia has a large number of solar resources, the efficiency of photovoltaic (PV) panels can be greatly lowered due to rising operating temperatures. This is especially true when the ambient temperature is high, which is extremely common in the region. Under natural convection circumstances, the purpose of this experiment is to explore the effect that aluminium cooling fins have on the thermal performance of photovoltaic (PV) panels. By optimizing the design of cooling fins and evaluating their overall performance in real-world operating situations, the study intends to improve both the efficiency and durability of the cooling fins. During the experiment, both regular and customized photovoltaic panels will be monitored for their power production, temperature distribution, and efficiency.

## 1.4 Objective

1) To design cooling fins using SOLIDWORKS.
2) To analyze the performance of cooling fins using SOLIDWORKS.
3) To analyze the effect of irradiance on PV panel with and without cooling fins

## 1.5 Scope of project

The experiment is to fully study how aluminium cooling fins affect the performance of a 20W maximum power polycrystalline solar panel when it is exposed to natural convection. Aluminium fins will be carefully put on the back of the panel to see if they can help get rid of heat and make the whole system work better. This experiment will be done outside to make it more like the real world. It will include exact temperature readings, power output, and a comparison with another panel without any aluminium cooling fins. This experiment will both includes electrical and mechanical parts. For the electrical part, this experiment will need to evaluate the performance of output (power), efficiency, and any changes occurring during the experiment. As for mechanical part, it will cover for designing the cooling fins, and investigate the changes of temperature of cooling fins using simulation (SOLIDWORKS) when heat applied.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The technology known as solar cells converts the energy that the sun produces into electricity. Solar cells were first developed in the early 1800s. They have progressed farther since then, and three generations have been born out of it all. Earlier generations of semiconductors relied on silicon (Si) in its many crystalline forms [1]. Solar cells from the first generation are the most efficient of all the generations that came before them. The second iteration of solar cells relied on thin-film technology, which is famous for its lightweight and thin profile [1]. The lightweight and bendable nature of these cells is a major plus. The second generation of solar cells is made using semi-conductors such as cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). New dye-sensitized solar cells are the third generation of photovoltaic cells. The production process for these cells is based on low-cost, environmentally friendly basic materials. Generation three solar cells have the lowest efficiency compared to generations before them [2]. Out of all the varieties of solar cells on the market today, first generation cells see the greatest use. This is because they are the most efficient and cost-effective option.



Photovoltaics enable users to produce power in a reliable and environmentally friendly manner. This is a notable breakthrough in the domain of energy [3]. Solar cells are the components used in the construction of solar systems. These cells are the devices that directly convert light energy into electricity. Solar cells are often called thus because they typically rely on sunlight as their primary light source. Solar cells are often employed due to this rationale. The word "photovoltaic" is derived from the combination of "photo," which pertains to light, and "voltaic," which specifically describes the process of generating electricity. When combined, these two words create the new noun. The photovoltaic process may be defined as the direct conversion of sunlight into electricity. Another often used abbreviation for photovoltaics is PV, derived from the term photovoltaics [4].

In this section, we will go over why this project is being carried out. Multiple studies have shown that solar panels lose some of their efficiency when their temperature rises. Two options exist for dealing with this issue. To begin with, there is the active cooling system, which makes use of increased power resistance in order to power the cooling components, including pumps and fans. Secondly, there is a passive cooling system that operates without the need for any extra energy. Because of this, an aluminium cooling fin system will be used as part of the passive cooling system to disperse heat via natural convection.

## 2.2 Types of PV panels

### 2.2.1 Monocrystalline

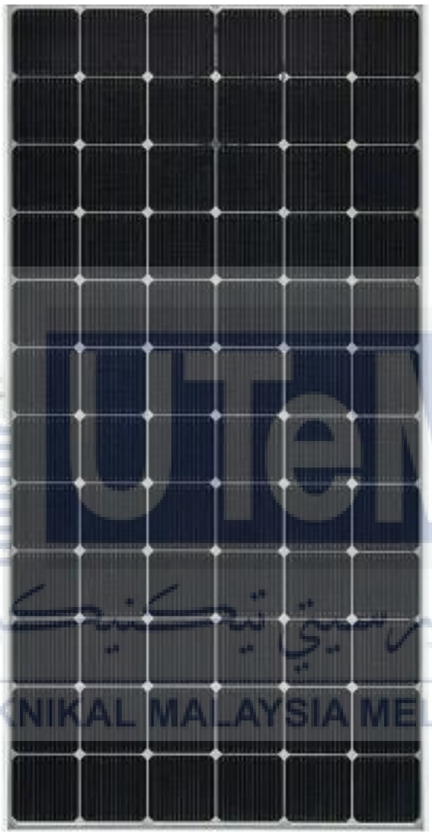




Figure 1.1 Monocrystalline module

Monocrystalline solar panels operate as photovoltaic cells and are composed of a single silicon component. By virtue of their junction box and electrical connections, these cells can convert solar energy into electrical power that can be utilised [5]. Monocrystalline solar panels are highly regarded for their remarkable efficiency, durability, and remarkably low cost.

The process of fabricating monocrystalline solar cells involves the slicing of a single silicon chip into thin wafers, which are then organised in rectangular arrays. Electrical connections are affixed to the lower and upper extremities of the cells, which are subsequently linked to a junction box and wires to constitute a fully functional panel suitable for rooftop or pole installation.

In comparison to alternative solar cell types, monocrystalline solar panels exhibit a superior efficacy that enables them to generate an additional 20% of energy per square foot. Moreover, their minimal maintenance requirements and remarkable durability render them highly favoured in commercial and residential settings. One drawback of monocrystalline solar panels is their relatively higher cost in comparison to alternative variations. Furthermore, their limited dimensions result from their construction from a single silicon unit, which requires the addition of panels and, consequently, more space for larger installations [5].

Monocrystalline solar panels are generally favoured for a variety of applications due to their longevity and efficiency, which generate a high return on investment. With proper installation and maintenance, it is anticipated that these solar cells will function as a reliable energy source for a substantial duration [6].

### 2.2.2 Polycrystalline



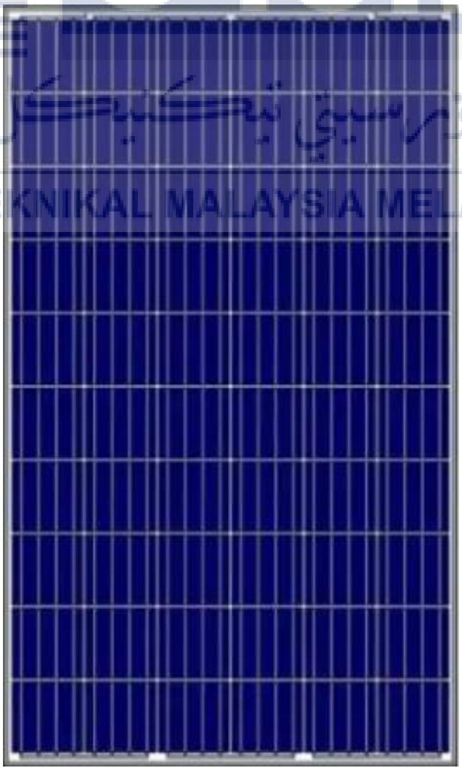


Figure 1.2 Polycrystalline module

Solar cells that use many silicon crystals in a single construction are called polycrystalline or multicrystalline solar panels. In order to create polycrystalline solar panel wafers, it is necessary to fuse together many pieces of silicon. The method of making polycrystalline solar cells involves letting the silicon cool in a vat on the panel rather than in a separate container. To make sure the cells grow to their full potential, this process is carried out. A mosaic design (a pattern resembling a mosaic) is purposefully shown on the surface of these solar panels [7]. Their square shape and brilliant blue colour are because of their composition of many polycrystalline silicon atoms. The high concentration of silicon crystals in each polycrystalline panel cell is responsible for the low mobility of electrons inside the panel.

The solar panels are fabricated utilizing a variety of photovoltaic cells. The cellular functionality of the device is facilitated by the inclusion of silicon crystals within each individual cell. Electrons acquire energy through the absorption of incident photons at the PN junction, a region characterized by the interface between N-type and P-type materials [7]. This facilitates the movement of electrons, resulting in the generation of an electric current. The origin of this phenomenon can be attributed to the photons emitted by the sun. In the context of this scale, materials classified as P-type exhibit a deficit of electrons, whereas materials categorized as N-type possess an abundance of electrons. A correlation exists between the photovoltaic cells and the two electrodes. The electrode situated on the upper surface consists of minuscule wires, whereas the electrode positioned on the lower surface is a conductor resembling foil.

### 2.2.3 Thin film

Figure 1.3 Thin film module

Thin-film solar panels are characterized by the configuration of photovoltaic (PV) materials in the form of thin layers, which facilitates the conversion of solar energy into electrical power [8]. In general, the thickness of these strata is limited to a few micrometers. These coatings possess the capability to be applied onto various substrates, such as metal, plastic, and glass, which makes them exceptionally well-suited for applications that are limited in space. Thin-film solar panels demonstrate enhanced attributes in relation to flexibility and weight reduction when contrasted with traditional crystalline silicon solar panels. These improvements enable the seamless implementation of thin-film solar panels in a wide range of geographical locations. Furthermore, these alternatives are considerably more cost-effective, making them an appealing option for individuals who are mindful of their budget but still wish to utilize sustainable energy sources.

On the contrary to traditional photovoltaic (PV) panels which are exclusively composed of silicon substrates, thin-film solar panels are produced utilizing a variety of materials such as gallium arsenide (GaAs), copper indium gallium selenide (CIGS), and amorphous silicon (a-Si). However, in regards to their functioning mechanisms, thin-film solar panels demonstrate no noticeable differences compared to traditional solar panels.

Analogous to silicon wafers, the semiconductor material that is deposited onto the substrate converts light energy into electrical energy via the photovoltaic phenomenon. The growing adoption of flexible thin film solar panels may be partially ascribed to the ease of their production [9].

A resolution that is more financially efficient for clients and users, as evidenced by increased revenue generation and sales, and increased profits for manufacturers and vendors, is one in which expenses are decreased. At present, the utilization of thin film solar technology is primarily limited to commercial sectors in both Europe and the United States, with limited accessibility. Furthermore, the implementation of these nimble modules has demonstrated efficacy in the advancement of portable solar energy solutions and products [8].

## 2.3 Comparison between solar panels

Sunlight is converted into energy using three basic kinds of photovoltaic technologies: thin-film, polycrystalline, and monocrystalline solar panels. Each kind has pros and cons of its own, and the decision between them is based on several variables including cost, application, and efficiency [10]. These three categories are contrasted here:

Table 2.3.1 Comparison between Monocrystalline, Polycrystalline, and Thin film



| Factors / Types | Efficiency | Cost | Material | Temp. coefficient | Installation |
|---|---|---|---|---|---|
| **Monocrystalline** | 17%-22% | Highest | Single crystal silicon | -0.3%/°C | Residential/ Commercial |
| **Polycrystalline** | 15%-17% | Mid | Multiple crystals silicon | -0.5%/°C | Residential/ Commercial |
| **Thin film** | 10%-13% | Lowest | Amorphous silicon, cadmium telluride. Copper indium gallium selenide | -0.2%/°C | Large scale (Industrial) |

## 2.4 Environmental factors affecting PV efficiency

The PV modules must be placed in the open air and exposed directly to sunlight. Hence, the climatic conditions significantly impact the performance and efficiency of the PV module. The main factors that significantly influence the outcome are sun irradiation and temperature.

### 2.4.1 Solar irradiance

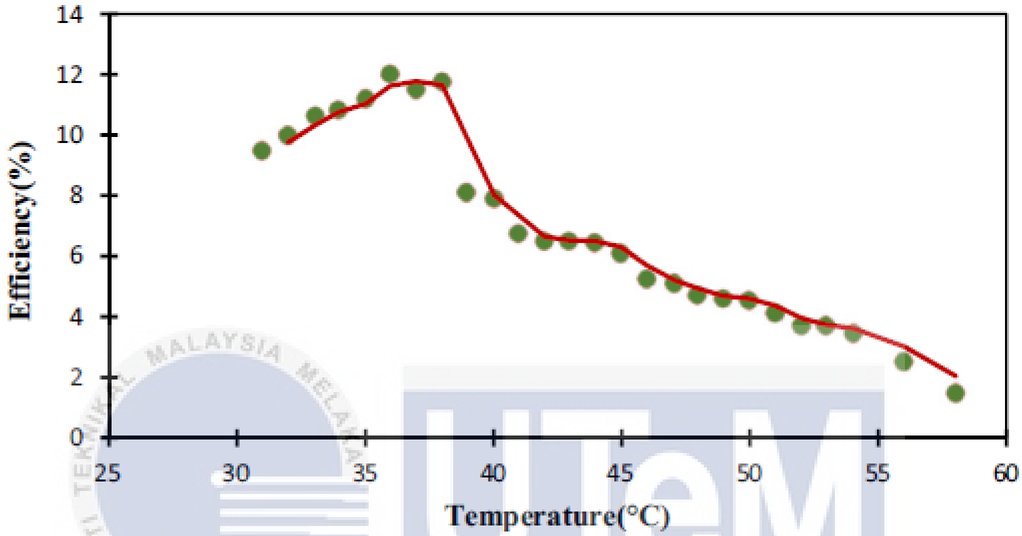



Figure 2.4.1.1 Efficiency vs Temperature

The output of PV panels is greatly influenced by solar power, which is subject to significant variability due to the unpredictable nature of solar irradiance [11]. The level of irradiance typically fluctuates because of various factors such as weather conditions, seasonal shifts, geographical location, the time of day, and the position of the sun in the sky [12]. The factor that is principally responsible for the fluctuating irradiance value is overcast conditions [13].

### 2.4.2 Temperature

The level of efficiency in electricity generation is significantly influenced by the temperature of the modules within a PV panel. One consequence of an increase in module temperature is a decline in electrical efficacy. 80% of solar energy is converted to heat and only 20% is converted to electricity by the PV modules [14]. The temperature at which the solar cell is functioning has a significant impact on the efficiency of monocrystalline silicon solar cells. The efficiency of the solar cell is reduced by 3.13% when it is exposed to 1000 W/m2 of irradiation without being cooled, and this occurs when the operating temperature is 56°C [15]. As the temperature of the module increases from 43°C to 47°C, the rate of temperature growth is affected by the wind speed, which results in a loss of efficiency of 5% [16]. Because of lack of cooling, the electrical efficiency of solar cells drops by 0.03%–0.05% for every 1°C rise in temperature cells experience.

### 2.4.3 Dust/Shading

In situations when dust, water vapour, air molecules, and other contaminants in the environment prevent sunlight from reaching the photovoltaic panel, the efficiency of photovoltaic modules is reduced accordingly. It is possible for dust particles in the air to scatter sunlight because they are bigger than the wavelength of the incoming solar beam. This reduces the amount of solar irradiation that is received [17]. Dust may also accumulate on the surface of the PV module, forming a thick coating. Changing the optical characteristics of a dust layer may result in increased light reflection and absorption, as well as a reduction in surface transmissibility, which ultimately leads to increased PV module output. The buildup of dust is determined by environmental variables such as the speed of the wind, the humidity, the amount of rainfall, the source of dust particles, the kind of dust particles, the technology of the PV module, and the surface cover of the PV module [18]. In environments with high levels of humidity, these particles have the ability to be absorbed by water vapour, which leads to the creation of mud that is both adhesive and sticky to the surfaces. It has been shown via research that a dust collecting period of 45 days leads to a 20% decrease in the overall transmittance of the glass cover. There is a direct correlation between the quantity of dust that is deposited and the amount of rainfall that occurs [19]. In some areas, the density of dust may decrease as a result of factors such as wind, rainfall, and other environmental characteristics [20].

The blockage that prevents light from reaching the photovoltaic panel is referred to as shading. As a result of the shadowing effect, the PV power output was dropped [21]. Hard shading, soft shading, self-shading, and other forms of shading are all examples of the many different types of shading. The collection of dust, snow, bird droppings, leaves, and other debris may eventually lead to the formation of hard shading. On top of that, poles, trees, and buildings all obscure the sunlight in a distinct and characterized manner [22].

### 2.4.4 Wind

The amount of energy that is generated by a solar module is determined by the wind conditions, which include the wind speed and direction. A variety of parameters, including module temperature, surface structure, and dust deposition, are used to measure the effect that wind has on the performance of photovoltaic systems [18]. Utilizing convective heat transfer via natural wind flow to the greatest degree feasible is the most cost-effective method of doing so for cooling [23]. PV cells are particularly sensitive to the speed of the wind rather than the direction of the wind, which causes the temperature to increase [24].

### 2.4.5 Humidity

Refracting, reflecting, or diffracting water reflects sunlight away from solar cells, reducing the amount of direct sunlight that reaches them to generate electricity [25]. The humidity level affects the radiation intensity in a non-linear manner due to the increased scattering angles caused by smaller water vapor particles [26]. Prolonged exposure of PV modules in humid environment can cause corrosion due to the existence of moisture on solar cells. Moisture accumulate within the housing of the PV modules will produce much more conductivity and will lead to current leakage [27]. High relative humidity (RH) causes sticky dust layers to accumulate on PV surfaces, leading to soiling and reduced power production [28]. Increasing relative humidity by 20% leads to a 3.16 W decrease in electricity output. Research indicates that PV power output reduces by 40% at 76.3% relative humidity during rainy seasons and 45% at 60.5% relative humidity during overcast seasons [29].

## 2.5 PV panels cooling system

The world is shifting to current renewable energy since fossil fuels are the most polluting and harmful sources of energy. These sources of energy are also considerably safer and cleaner than fossil fuels. Solar energy is now the source of alternative power that is adopted by the greatest number of people, same goes with wind energy[30]. For the purpose of the global need for decreased energy use, renewable energy sources are absolutely necessary. Photovoltaic solar energy is one kind of energy that may be considered renewable. PV cells, which are a kind of semiconductor, have the potential to convert sunlight into electricity. The percentage of irradiances that a PV cell can convert are rather low, in which to be precise around 20%. The equilibrium system causes a rise in the temperature of the cell. As a result, the cell needs to operate at a higher temperature, which there is a drawback for this problem, where when the temperature increases, there is a noticeable decrease in voltage of the PV cell. Cooling PV panels reduces the power output reduction when operational temperature rises. Creating and appropriate cooling systems offsets power output loss and improves stability of the system [30]. Several environmental factors influence the performance of a solar panel such as humidity, wind velocity, temperature, sunlight, etc. Among various variables, solar irradiances and temperature are the main factors [31]. Hence, cooling systems are used to regulate and disperse surplus heat, hence enhancing the overall efficiency and durability of the PV system. Various PV panel cooling solutions exist, each with distinct benefits and factors to consider.



### 2.5.1 Passive cooling system

Passive cooling is a method that utilizes natural convection and heat conduction, without the need for mechanical components, to dissipate or eliminate heat from photovoltaic modules. The operational principle relies on the transfer of heat from the source to the surrounding environment. To enhance the heat transfer surface of photovoltaic (PV) panels, high thermal conductivity materials such as pipes or fins are employed. Passive cooling systems can be broadly categorized into natural circulation cooling methods utilizing air, water, or phase change materials. This method of cooling PV modules is widely adopted due to its simplicity and popularity. This method enhances the system's energy efficiency and cost-effectiveness with a modest investment [30].

A study showed the effectiveness of a passive cooling device in improving the performance of solar panels was investigated. By incorporating a flat aluminium plate behind the solar panel, the working temperature was observed to decrease by 6.1°C, while the electrical efficiency increased by 1.77%. These findings highlight the potential of such cooling mechanisms in enhancing the overall performance of solar energy systems [32]. Another study showed the potential for enhancing the efficiency of solar cells through a reduction in operating temperature was explored [33]. The research proposed the incorporation of cooling fins beneath the surface of solar panels to achieve this objective. By implementing this cooling mechanism, it was hypothesised that the overall performance of solar cells could be significantly improved. In a study conducted by an undisclosed source, the comparative analysis of solar panels utilising fins and those without fins revealed a notable disparity in their average efficiencies. Specifically, the solar panels equipped with fins exhibited an average efficiency that surpassed their finless counterparts by a margin of 1.8%. This finding underscores the potential benefits of incorporating fins into the design of solar panels, suggesting that such enhancements may contribute to improved overall performance and energy conversion. The researchers explored the impact of incorporating fins onto solar panels on the output power. The results revealed that the inclusion of fins led to a notable increase in the output power, with an approximate gain of 5W when compared to solar panels without fins. This finding highlights the potential of fins as a means to enhance the performance of solar panels, thereby contributing to the advancement of solar energy technology [33].



### 2.5.2 Active cooling system

Active cooling system involves the use if mechanical devices such as fans and pumps to facilitate the flow of coolant and reduce the temperature of PV cells. Active cooling methods involve the use of forced circulation of water, air, or nanofluids. Auxiliary equipment typically requires extra energy, but it offers a much higher efficiency compared to passive cooling, Moreover, the utilization of active cooling techniques can enhance the usefulness of waste energy heat generated by PV modules [30].

In the realm of solar cell technology, active cooling has emerged as a promising approach to mitigate the challenges posed by excessive working temperatures. By harnessing the assistance of specific input power, active cooling techniques have demonstrated the ability to significantly reduce the operating temperature of solar cells by an impressive 7.5°C [33]. This reduction in temperature holds great potential for enhancing the overall performance and efficiency of solar cells, thereby paving the way The utilisation of this particular approach, however, presents a notable drawback in the form of necessitating supplementary cooling components that are reliant on an external power source. In the realm of environmental cooling techniques, employing a fan has emerged as a prominent method. The utilisation of a fan entails the manipulation of air currents to achieve a desired cooling effect. This approach has garnered considerable attention due to its simplicity and cost-effectiveness. By circulating air and facilitating evaporation, fans have proven to be an efficient means of dissipate. The utilisation of fans as a means of facilitating forced cooling of various components has become a prevalent practice. This technique, which involves the active circulation of air to dissipate heat generated by solar cells, has garnered significant attention and adoption within the field. By harnessing the power of fans, researchers and engineers have been able to effectively mitigate the detrimental effects of excessive heat on solar cell performance. The cooling mechanism in solar cells is primarily attributed to the air flow generated within the system. However, it is important to note that this air flow necessitates the use of a power source to operate the fan responsible for facilitating the cooling process. In this statement, the author highlights the relationship between the electricity consumption of a fan and the electricity generated by solar cells [33]. The implication is that the fan's electricity usage will deplete the solar cells' power supply. Passive cooling, while exhibiting commendable cooling capabilities, is characterised by a relatively lower level of efficiency.

## 2.6 Natural Convection

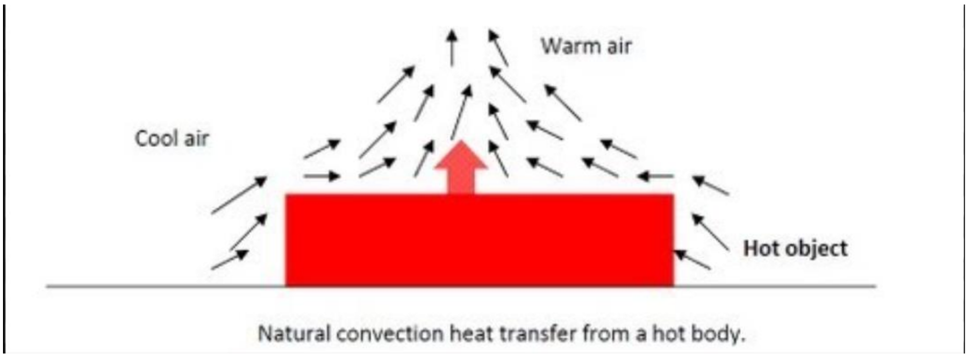



Figure 2.6.1 Overview of natural convection

The term "forced convection" refers to the process of heat transfer for convection that takes place as a result of an external forcing circumstance, such as the use of a fan. Given that density differences within the fluid are responsible for the formation of convection currents, convection heat transfer may take place even in the absence of external forcing circumstances. Free natural convection is the term that is often used to describe this occurrence. When density gradients in a fluid are present, they provide a buoyancy force, which in turn causes natural convection to occur. It is possible for temperature variations to give rise to density gradients. Because the flow velocities in natural convection are often lower than those in forced convection, the convection heat transfer rates produced by natural convection are typically lower. In most cases, applications that rely on natural convection are far bigger than those that rely on forced convection [34].



Experimental discussions have also focused on the performance of solar panels in relation to fins and natural convection cooling [35]. The implementation of a fin-based cooling system significantly decreased the temperature of solar panels, leading to a 5.5% enhancement in its power consumption during natural convection. The performance of solar panels with cooling fins has been studied in relation to various factors, including panel tilt, irradiation, temperature and wind speed [36]. The increase in temperature (ambient) resulted in decreasing of average voltage in installed fin’ s panel, although there was a slight increase of 1.3% across all panel orientations. The wind speed had a significant impact on the cooling system, resulting in enhanced power output of the system. irrespective of wind speed, panels equipped with fins exhibited a 1.8% increase in efficiency compared to panels lacking fins [37].

According to research conducted by Rajput, a heat sink's shape, the fins' combined surface area, and surrounding environmental factors like temperature and wind speed all influence the natural convection heat transfer coefficient [38]. The typical test environment is somewhat different from real world weather conditions, and the power output often drops as a result of cells being too hot. This takes place in the presence of wind conditions of 0 m/s and an irradiation of more than 1000 $W/m^2$ [39].

## 2.7 Thermal conductivity for various materials

The thermal conductivity of materials is a crucial factor in the efficient cooling of electronic equipment. The process of thermal management in electronic systems relies heavily on conduction heat transfer and thermal conductivity, which play crucial roles in transferring heat from the die, where it is generated. These components are essential for ensuring efficient heat dissipation and maintaining optimal operating temperatures within the system [40].

In the context of thermal management applications, such as heat sinks, understanding the significance of material thermal conductivity is crucial. To gain insight into this matter, it becomes necessary to dissect the overall thermal resistance attributed to conduction heat transfer into three distinct components, which are interfacial resistance, spreading resistance, and conduction resistance [40].



### 2.7.1 Interfacial resistance

The utilisation of an interface material has been found to significantly improve the thermal contact between surfaces that do not perfectly mate with each other. This enhancement in thermal contact is crucial in various applications where efficient heat transfer is essential. By introducing an interface material between the imperfect mating surfaces, the thermal resistance is reduced, resulting in improved heat conduction and overall thermal performance. This phenomenon has been extensively studied and documented in the literature, with researchers exploring different types of interface materials and their effects on thermal contact enhancement. The findings the reduction of interfacial resistance can be achieved by employing a material that possesses high thermal conductivity and exhibits excellent surface wetting ability. By incorporating such a material, the efficient transfer of heat across interfaces can be facilitated, leading to improved thermal performance. The combination of high thermal conductivity and good surface wetting ability enables enhanced contact between the material and the surrounding surfaces, thereby minimising the resistance encountered at the interface. Consequently, the utilisation of a highly thermally conductive material with favourable surface wetting characteristics holds significant potential for optimising heat transfer processes and enhancing overall thermal efficiency [40].

### 2.7.2 Spreading resistance

The concept of spreading resistance is commonly employed to characterise the thermal resistance that arises when a relatively small heat source is connected to a larger heat sink. This phenomenon has been extensively studied and documented in the field of thermal management. By investigating the behaviour of heat transfer in such configurations, researchers have gained valuable insights into the intricacies of spreading resistance and its impact on overall thermal performance. The term "spreading The spreading resistance of a heat sink is influenced by various factors, one of which is the thermal conductivity of its base [40].



### 2.7.3 Conduction resistance

The term of conduction resistance is commonly employed in the analysis of heat sinks, serving as an indicator of the internal thermal resistance within the system. This resistance arises as heat traverses from the heat sink's base to its fins, ultimately dissipating into the surrounding environment. The significance of conduction resistance in heat sink design varies depending on the prevailing conditions of natural convection and air flow. In scenarios characterised by low air flow and natural convection, the role of conduction resistance is relatively less significant. However, as flow rates escalate, the importance of conduction resistance becomes more pronounced [40].

Table 2.7.3.1 Thermal Conductivity of various material [41].

| Material | Thermal Conductivity (W/mk) |
|---|---|
| Silver (Pure) | 418 |
| Copper 11000 | 388 |
| Aluminium 6061 T6 | 167 |
| Zinc (Pure) | 112.2 |
| Cast Iron | 55 |
| Titanium | 15.6 |

## 2.8 Combined Approach of Aluminium Cooling Fins and Natural Convection

The phenomenon of natural convection heat transfer from a heat sink has garnered significant attention in both experimental and theoretical research. Numerous studies have been conducted to explore and understand this phenomenon in depth. The utilisation of heat sinks with extended surfaces has gained significant popularity across a range of engineering domains. These surfaces have found extensive application in areas such as air conditioning, electronic devices, electrical and internal combustion systems, solar energy applications, cooling of nuclear reactor fuel elements, and enhancing heat transfer in air conditioning radiators and air-cooled heat exchangers. The utilisation of air as the ultimate heat transfer medium is prevalent in the majority of electronics cooling applications [42].

Huang et al. [43] conducted an experimental study to investigate the natural convection heat transfer characteristics of square pin fin and plate fin heat sinks, with a particular focus on the influence of orientation. The study aimed to enhance the understanding of heat transfer mechanisms in these types of heat sinks and provide valuable insights for optimising their performance. By conducting experiments, the researchers sought to gather empirical data and analyse the effects of different orientations on heat transfer rates. The findings of this study contribute to the existing body of knowledge on heat transfer in heat sinks and offer valuable information for future research and design considerations in thermal management applications. In a study examining the heat transfer coefficient of pin fin and plate fin geometries, researchers investigated a range of $1.8\times10^6 < Ra < 4.8\times10^6$. The findings indicated that the downward facing orientation consistently exhibited the lowest heat transfer coefficient across this tested range. This observation held true for both pin fin and plate fin configurations. In the investigation of pin fin heat transfer, the concept of the finning factor, Φ has emerged as a crucial parameter. This factor, denoted as Φ, is defined as the ratio of the total surface area ($A_t$) to the base plate area ($A_{bp}$) for a given pin fin configuration. By comparing the finning factors of different pin fin designs, valuable insights can be gained regarding their respective heat transfer capabilities. In the specific case of the perforated pin fin and the solid pin fin, a notable disparity in the finning factors was observed. The finning factor for the perforated pin fin was found to be greater than that of the solid pin fin. This discrepancy suggests that the perforated pin fin possesses a larger total surface area in relation to its base plate area compared to the solid pin fin. The implications of this discrepancy in finning factors are significant. A higher finning factor indicates a larger surface area available for heat transfer, which can potentially enhance the overall heat transfer performance of the pin fin. Therefore, the perforated pin fin, with its greater finning factor, may exhibit improved heat transfer characteristics compared to the solid pin fin. It is worth noting that the exact reasons behind the disparity in finning factors between the two pin fin configurations require further investigation. Factors such as the geometry, arrangement, and distribution ofIn the realm of heat transfer, it has been observed that there exists a direct relationship between the heat transfer coefficient and the finning factor. Specifically, as the finning factor decreases, the heat transfer coefficient experiences an increase. This finding has been documented in various studies and has significant implications for the design and optimisation of heat transfer systems. By understanding this relationship, engineers and researchers can make informed decisions regarding the selection of finning factors to enhance heat transfer efficiency. Furthermore, it is worth noting that the utilisation of pin fins offers a distinct advantage, particularly as the Rayleigh number increases. This advantage stems from the fact that pin fins possess more open ends, thereby facilitating enhanced air ventilation.

In a study conducted by Elshafei [44], the focus was on investigating the natural convection heat transfer characteristics of circular pin fin heat sinks. The research aimed to examine the impact of various factors such as the heat sink's geometry, heat flux, and orientation on the heat transfer process. By analysing these parameters, Elshafei sought to gain a deeper understanding of the intricate mechanisms underlying natural convection heat transfer in pin fin heat sinks. In their study, the researchers examined the performance of solid pin fin heat sinks in both upward and sideward orientations. They found that the competitiveness of these heat sinks depended on the Rayleigh number, which ranged from $3.8 \times 10^6$ to $1.65 \times 10^7$. Overall, the solid pin fin heat sinks demonstrated higher heat transfer coefficients compared to the perforated/hollow pin fin heat sinks. These findings highlight the potential of solid pin fin heat sinks for efficient heat dissipation in various orientations. In the realm of heat transfer, the investigation of heat sinks with hollow or perforated pin fins has yielded noteworthy findings. It has been observed that the heat transfer performance of such heat sinks surpasses that of their solid pin counterparts. This assertion is supported by empirical evidence and experimental data, which have consistently demonstrated the superior thermal efficiency of heat sinks featuring hollow or perforated pin fins. By leveraging these innovative designs, it was observed that the temperature disparity between the base plate and the ambient air was found to be lower in the case of these heat sinks compared to solid pin configurations.

In their study, Zografos and Sunderland [45] conducted an investigation on the heat transfer performance of inline and staggered pin fin arrays in natural convection. The researchers explored the impact of different inclination angles on the heat transfer rates. Based on their findings, it was determined that the inline arrays consistently exhibited higher heat transfer rates compared to the staggered arrays. This conclusion sheds light on the relative effectiveness of these two types of pin fin arrays in facilitating heat transfer in natural convection scenarios. Furthermore, the findings of their study revealed minimal impact of inclination on the observed outcomes, particularly when the inclination angle deviated by less than 30 degrees from the vertical orientation.

Sparrow and Vemuri [46] conducted a comprehensive investigation on the impact of fin orientation on the heat transfer process involving natural convection and radiation in pin fin arrays. In their investigation, the researchers observed that the orientation of the heat transfer surface had a significant impact on the heat transfer rates. Through their analysis, it was determined that the upward facing orientation exhibited the highest heat transfer rates, followed by the sideward facing and the downward facing orientations. These findings shed light on the importance of considering the orientation of heat transfer surfaces in order to optimise heat transfer efficiency.

A study by Dialameh et al. [47] conducted a numerical investigation aimed at predicting the phenomenon of natural convection. Specifically, they focused on an array of aluminium horizontal rectangular thick fins with varying thicknesses ranging from 3 mm to 7 mm. These fins were relatively short, with lengths not exceeding 50 mm, and were attached to a horizontal base plate. The authors employed numerical methods to analyse and simulate the convective heat transfer occurring in this configuration. In this study, the findings indicate that the natural convection heat transfer coefficient exhibits a positive correlation with temperature differences and fin spacing. Conversely, a negative relationship is observed between the heat transfer coefficient and fin length. Interestingly, the dimensions of fin thickness and fin height do not appear to significantly impact the average heat transfer coefficient. These results provide valuable insights into the factors influencing natural convection heat transfer in this particular system.

Kobus and Oshio [48] conducted a comprehensive investigation encompassing both theoretical and experimental aspects to evaluate the efficiency of pin fin heat sinks. By investigating into this subject matter, the researchers aimed to shed light on the performance characteristics of these heat sinks and provide valuable insights for further advancements in thermal management technology. Through a meticulous examination of the underlying principles and employing rigorous experimental. In this study, the authors put forth a theoretical model aimed at forecasting the impact of diverse geometrical, thermal, and flow characteristics on the effective thermal conductivity of heat sinks. The proposed model seeks to provide valuable insights into the intricate relationship between these factors and the overall thermal performance of heat sinks. By considering a range of influential variables, this model offers a comprehensive framework for understanding and predicting the thermal resistance. In a subsequent study, Kobus and Oshio investigated the impact of thermal radiation on the heat transfer characteristics of pin fin heat sinks [49]. Their research findings revealed an overall heat transfer coefficient that was determined by the combined influence of an effective radiation coefficient and a convective heat transfer coefficient. The authors' work shed insight into the intricate interplay between thermal radiation and convective heat transfer in the context of pin fin heat sinks.

In their seminal work, Fisher and Torrance [50] provided a comprehensive analysis of the analytical solutions pertaining to the boundaries of free convection in the context of pin fin cooling. Their study focused on explaining the fundamental principles and constraints governing the heat transfer process in this particular configuration. By examining the analytical solutions, Fisher and Torrance shed light on the intricate dynamics and limitations associated with free convection in pin fin cooling. Their findings have since served as a valuable reference for researchers and engineers seeking to optimise heat dissipation in various applications. In their suggestion, the authors propose that the optimisation of the pin fin heat sink design can be achieved through the careful selection of two key parameters: the pin fin diameter and the heat sink porosity. In the realm of conventional heat sinks, an examination of their thermal resistance reveals that it tends to be approximately twice as high as the theoretical limit. This observation is based on a model that assumes the absence of viscosity in the flow and idealised local heat transfer conditions.

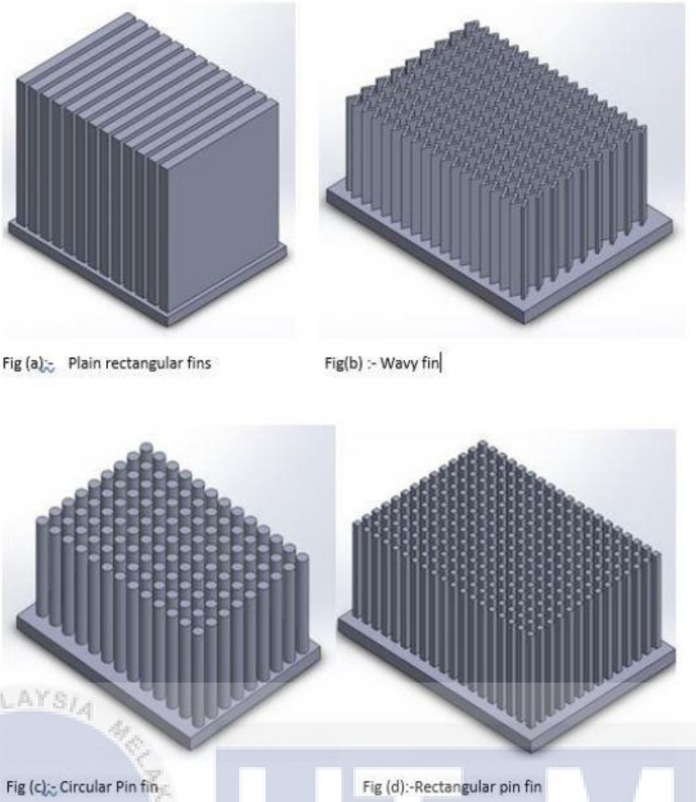



Figure 2.7.1 Different pattern of fins

A research project was carried out to demonstrate that the various kinds of fins also have an impact on the heat transmission of photovoltaic panels [32]. The lengths, angles, and areas covered by the fins, in addition to the particular form and kind of the fins, all have a role in determining the amount of heat that is transferred by the different types of fins.

| **Fin pattern** | **Maximum temperature (K)** | **Minimum temperature (K)** | **Temperature difference (K)** |
|---|---|---|---|
| No fin | 3.273e+03 | 3.267e+03 | 0.006e+03 |
| plain rectangular fin | 3.273e+03 | 2.694e+03 | 0.579e+03 |
| Wavy fin | 3.273e+03 | 2.892e+03 | 0.381e+03 |
| circular pin fin | 3.273e+03 | 2.968e+03 | 0.305e+03 |
| rectangular pin fin | 3.273e+03 | 2.739e+03 | 0.534e+03 |
| Circular pin fin (with less diameter and more number) | 3.273e+03 | 2.740e+03 | 0.533e+03 |

Figure 2.7.2 Results from different pattern of fins

A simulation performed in SOLIDWORKS yielded the findings that are shown in the table above [32]. To put it another way, the plain rectangular fin that has the biggest difference in temperature is the one that has the most heat transfer potential among all of them.

Table 2.8 Summary of findings

| Author | Focus | Findings |
|---|---|---|
| Huang et al. [43] | Orientation focused natural convection heat transfer of square fin and plate fin heat sinks | The direction that faces downward always has the lowest heat transfer coefficient. Finning factor (T) is very important; a perforated pin fin shows a bigger T than a solid pin fin, which could make heat transfer better. There is a direct link between the finning factor and the heat transfer coefficient. As the Rayleigh number goes up, pin fins become more useful. |
| Elshafei [44] | Geometry, heat flow, and orientation of circular pin fin heat sinks for natural convection heat transfer. | When it comes to heat absorption, solid pin fin heat sinks are better than perforated or hollow pin fin heat sinks. With less temperature difference between the base plate and the air around it, hollow or open pin fin heat sinks are more thermally efficient. |
| Zografos and Sunderland [45] | Heat transfer of inline and staggered pin fin arrays under natural convection. | Inline arrays transfer heat faster than staggered ones. Inclination has little effect on results, especially when less than 30 degrees from vertical. |
| Sparrow and Vemuri [46] | Pin fin array heat transfer by natural convection and radiation: fin orientation factor. | The maximum heat transfer rate is upward, followed by sideward and downward. The importance of heat transfer surface orientation for efficiency |
| Dialameh et al. [47] | Calculations of natural convection in aluminium horizontal rectangular thick fins of various thicknesses. | Natural convection heat transfer coefficient, fin spacing, and temperature differential are positively correlated. Fin length inversely related. Fin height and thickness barely affect average heat transfer coefficient. |

| | | |
|---|---|---|
| Kobus and Oshio [48] | Experimental and theoretical evaluation of pin fin heat sinks; thermal radiation's effect on heat transfer. | A theoretical model predicts how geometrical, thermal, and flow variables affect effective thermal conductivity. Radiation and convective heat transfer coefficients affect thermal resistance. Optimize pin fin design by choosing diameter and heat sink porosity. |
| Fisher and Torrance [50] | Analytical pin fin cooling free convection boundary solutions. | Pin fin cooling heat transfer principles and restrictions explained. Pin fin diameter and heat sink porosity optimize pin fin design. Thermal resistance of traditional heat sinks is almost twice theoretical limit. |

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

The methodology employed in this study involves a systematic and theoretical analysis of the methods utilized within the chosen field of study. The methodology encompasses the systematic examination of the collection of techniques and principles linked to a specific field of understanding. The methodology typically encompasses the following concepts: paradigm, theoretical model, phases, and quantitative techniques. For this project, MATLAB and SOLIDWORKS were chosen to do the design of the aluminium cooling fins, simulate heat dissipation when heat is applied on the cooling fins, and to study I-V and P-V curve of PV cell.

## 3.2 Gannt chart

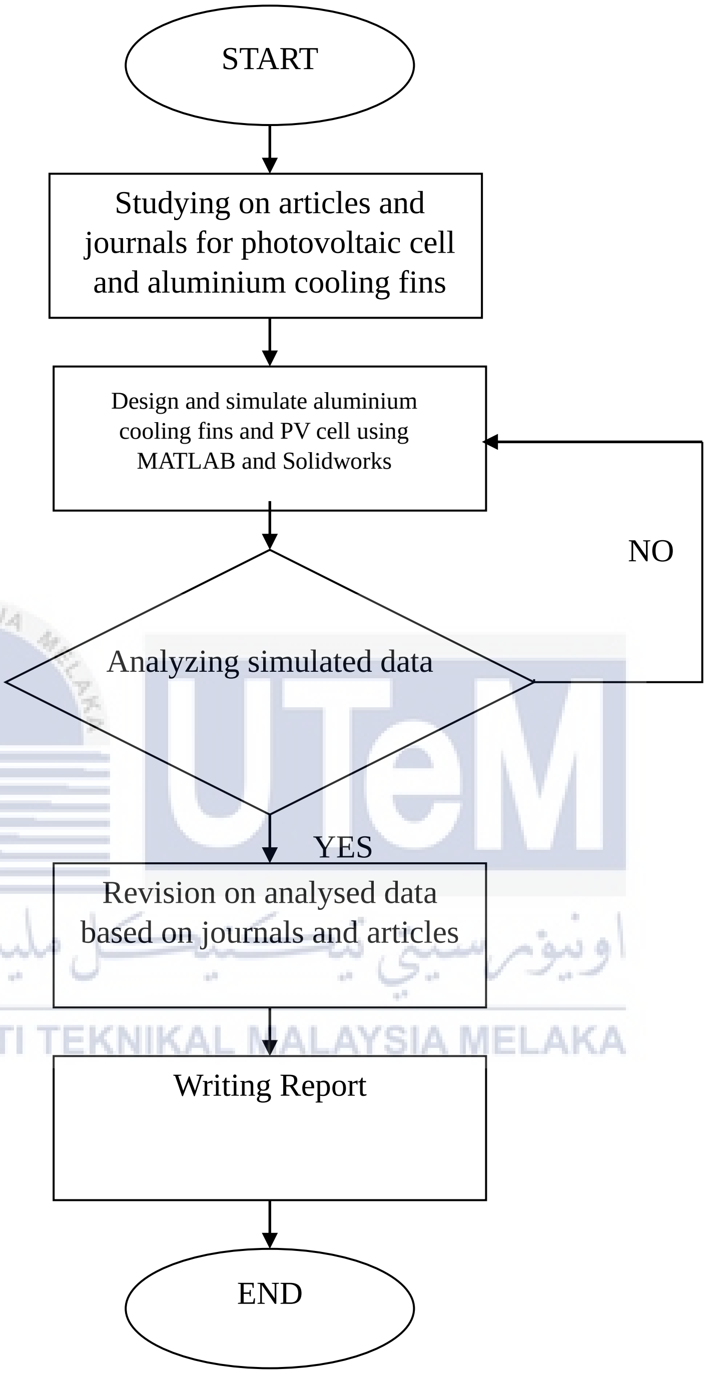
Table 3.2.1 Gannt Chart for Semester 1

| Task | Weeks (Sem1) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Discussion | ■ | ■ | ■ | | | | | | | | | | | |
| Learning fundamental of photovoltaic panel | | ■ | ■ | ■ | ■ | | | | | | | | | |
| Design aluminium cooling fins in Solidworks | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Design photovoltaic cells in MATLAB | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| Make analysis | | | | | | | | ■ | ■ | ■ | | | | |
| Report writing | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ |

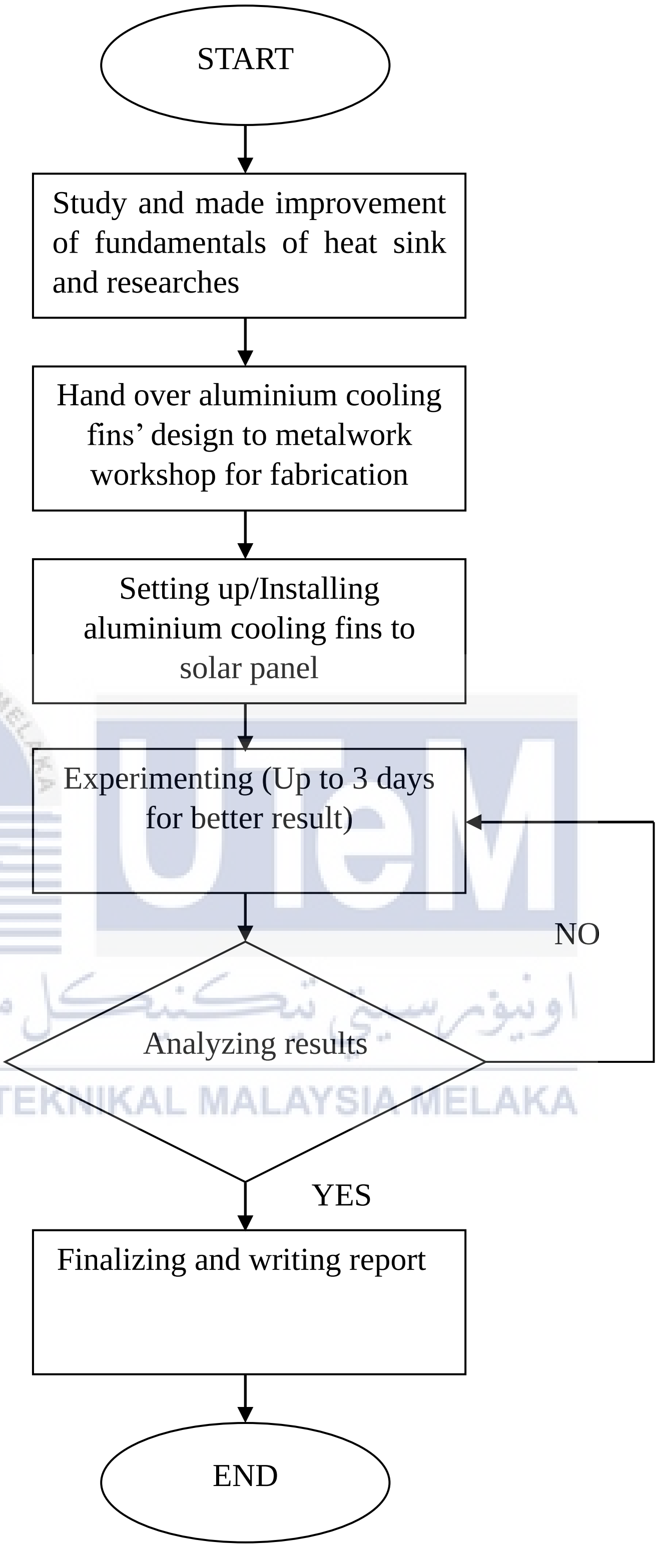
| Task | Weeks (Sem1) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Discussion with supervisor | | | | | | | | | | | | | | |
| Revising and improvement for fundamentals of aluminium cooling fins | | | | | | | | | | | | | | |
| Searching for metalwork workshop to fabricate aluminium cooling fins | | | | | | | | | | | | | | |
| Setting up stand and photovoltaic panel along with aluminium cooling fins | | | | | | | | | | | | | | |
| Experimenting aluminium cooling fins under natural convection | | | | | | | | | | | | | | |
| Analyzing result | | | | | | | | | | | | | | |
| Report writing | | | | | | | | | | | | | | |

### 3.3 Flowchart

#### 3.3.1 Flowchart for Semester 1



### 3.3.2 Flowchart for Semester 2



## 3.4 MATLAB Simulation

On this part, a simple PV cell circuit to determine the I-V and P-V curve is conducted through a simple circuit using MATLAB software by varying the irradiances. The constant block is used to set different value of irradiances starting from 800 $\frac{w}{m^2}$ up until 1200 $\frac{w}{m^2}$.

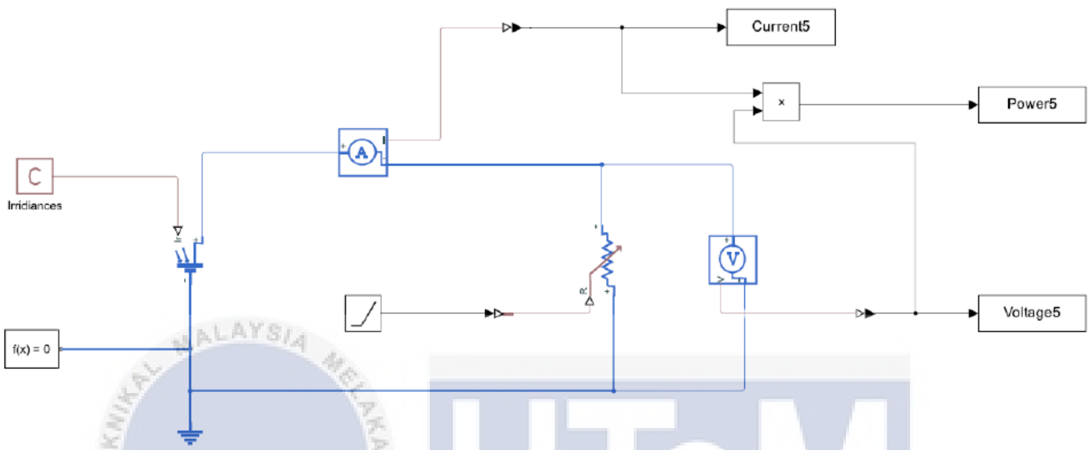



Figure 3.4.1 Circuit simulation of solar cell using MATLAB

The design shown above utilises the Constant block, represented by C, to modify irradiances. The initial value is thereafter sent via the PS Simulink block prior to being directed towards the solar cell, where it is transformed into a signal that is then visualised on the workspace. The PS Simulink block is used to transform current and voltage into a signal, which may be visualised as a graph.



### 3.4.1 Short Circuit Current ($I_{SC}$) and Open Circuit Voltage ($V_{OC}$)

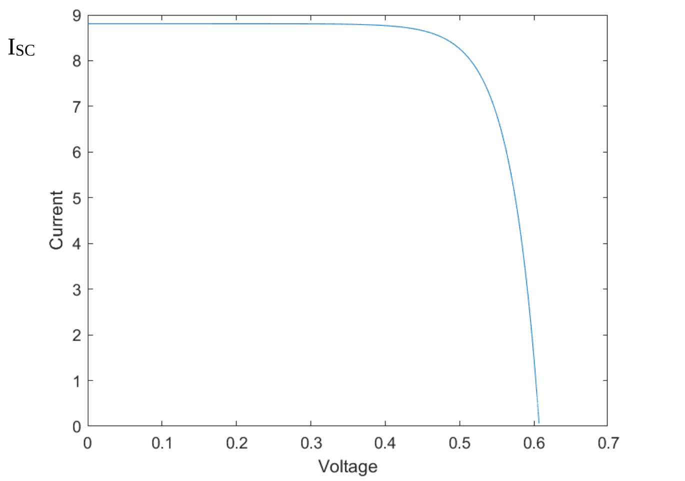



Figure 3.4.1.1 I-V characteristic

$V_{OC}$

Based on figure above, short circuit current refers to the current flows through a solar cell when the voltage across it reduces to zero, meaning that both positive and negative output of the PV module is connected to produce short circuit current. The occurrence of $I_{SC}$ can be explained due to the process of generating and collecting carriers produced by the light. Consequently, the maximum current that may be extracted from a solar cell with zero voltages is short circuit current.

When there is no current flowing through a solar cell, the Open Circuit Voltage ($V_{OC}$), is the greatest voltage that can be obtained from the cell. Due the bias of the solar cell junction with the light generated current, the open circuit voltage is equivalent to the amount of forward bias that is present on the solar cell by virtue of the solar cell junction. For the best result of $V_{OC}$, it should be measured early in the morning where the sunlight hit the cell when temperatures are still cold.

### 3.4.2 Efficiency of Solar panel

To determine how efficient solar cells are, the fill factor (FF) is a crucial metric to consider. Dividing a cell's maximal potential power output by its actual power output yields the fill factor. Solar cells that have a greater fill factor are more attractive due to their higher efficiency. FF can be represented as



$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}$$

Where,

$$V_{MP} = Voltage\ maximum$$

$$I_{MP} = Current\ maximum$$

$$V_{OC} = Open\ circuit\ voltage$$

$$I_{SC} = Short\ circuit\ current$$

To ensure consistent comparison of various solar cells in the field of solar cell research, a standardized formula is employed to determine their efficiency.

The power conversion efficiency (PCE), which quantifies the standardized efficiency, can be determined using equation:

$$PCE = \frac{V_{OC} I_{SC} FF}{P_{IN}}$$

Where,

$$FF = Fill\ factor$$

$$P_{IN} = Irradiance\ power$$

$$V_{OC} = Open\ circuit\ voltage$$

$$I_{SC} = Short\ circuit\ current$$

## 3.5 SOLIDWORKS Simulation

For this part, the dimensions of the cooling fins are based on dimensions of PV module, in this case is PV module Polycrystalline model ths-20W. The design of the cooling fins contains 20 rectangular plain fins with 90° angle as the rectangular plain fins provide more heat transfer. I chose 90° angle as a starter because angle of fins does not give much difference in temperature.



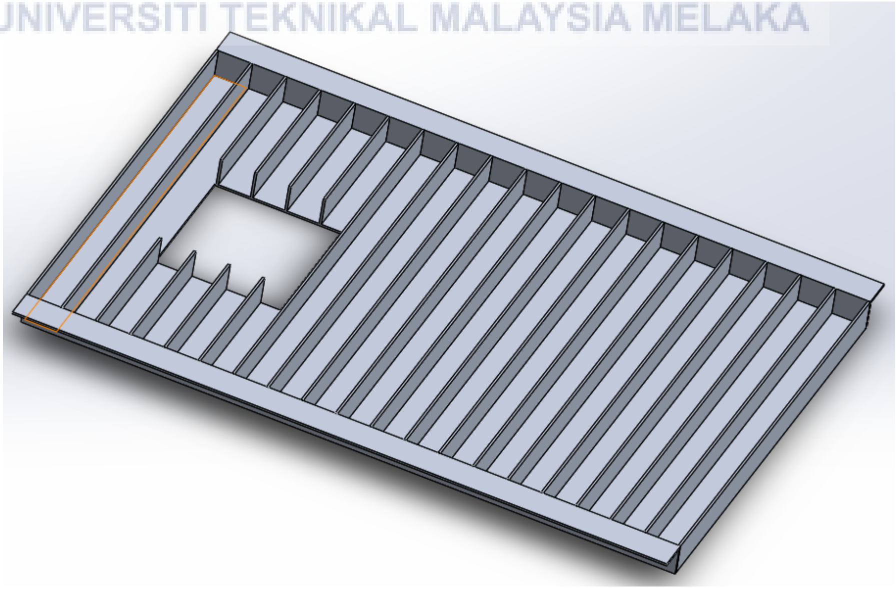


Figure 3.5.1 Overview of complete assembly of cooling fins

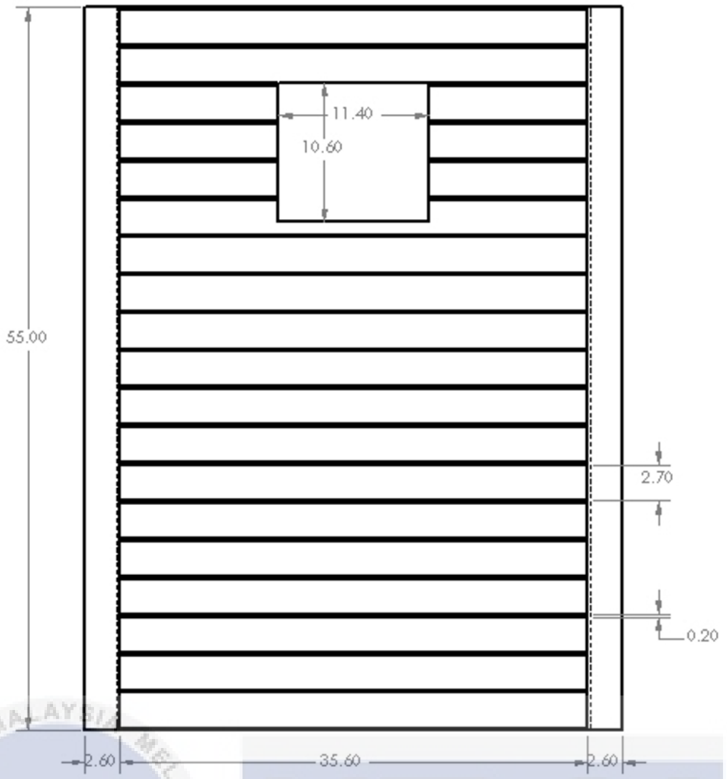



Figure 3.5.2 Dimension from top view


Figure 3.5.3 Dimension from front view



Figures 3.5.2 and 3.5.3 are the dimensions of cooling fins based on dimensions of PV module. All of the dimensions are calculated in centimeter (cm). The gap of each fins is 2.7 cm with a total of 20 fins, and 2.6 cm in height.

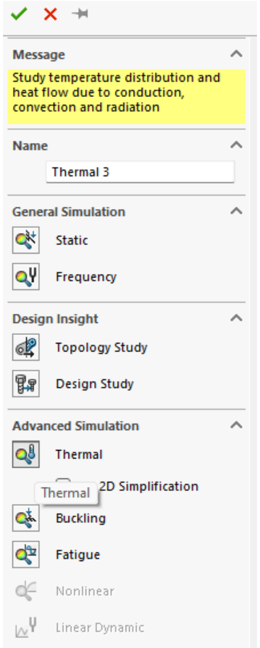



Figure 3.5.4 Thermal simulation

For this part, I chose thermal simulation to run the heat transfer simulation.

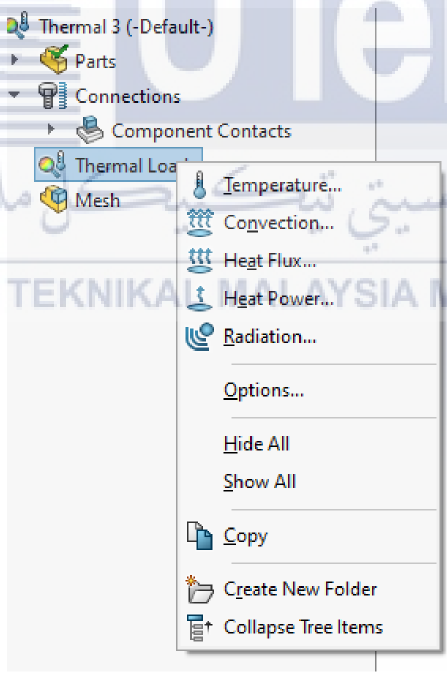



Figure 3.5.5 Thermal load characteristics

There are 5 characteristics of thermal load. I only chose Heat Power and Convection as it meets my simulation requirements.

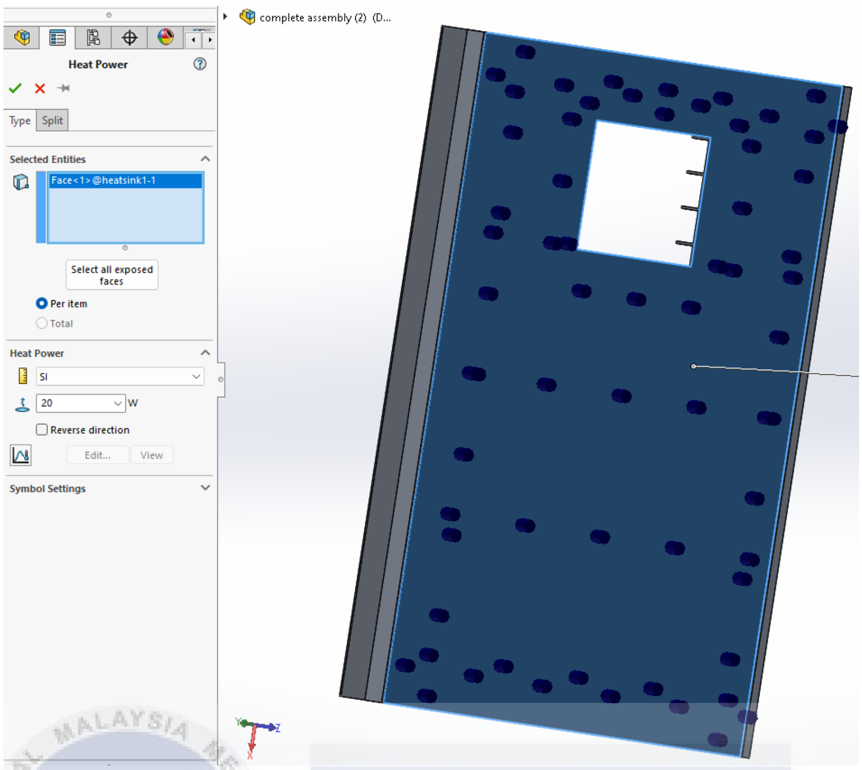



Figure 3.5.6 Heat power characteristics

On this part, I chose only back of the panel to be exposed to heat as it directly face the back of PV module to transfer the heat. The heat power is set to 20W for a starter. This value will vary depending on real world simulation.

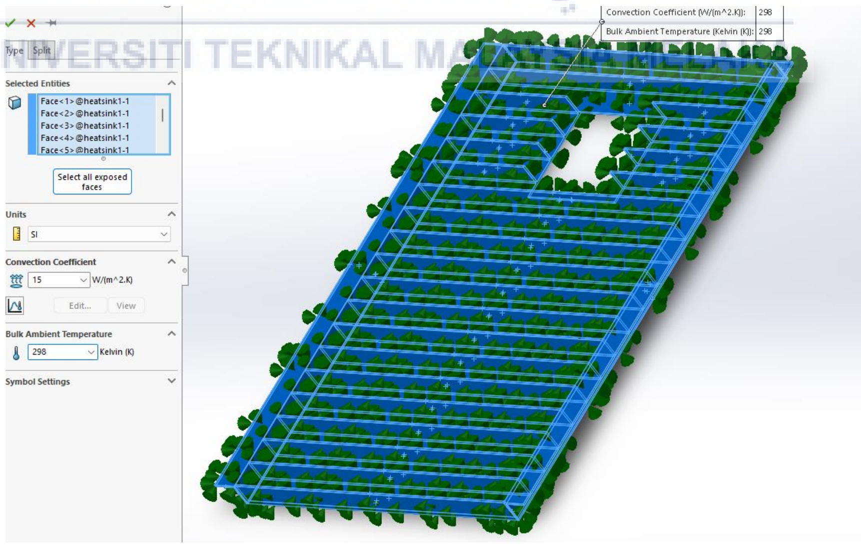



Figure 3.5.7 Convection characteristics (Front)

Next, I chose convection characteristic to simulate the natural convection. The surfaces that were selected are all except for the back of cooling fins as it will have a different value from the rest of the surfaces. The convection coefficient of this part is set to 15 $\frac{W}{m^2K}$ based on average wind speed in Melaka. (This will be change during the experimental setup according to the wind speed on experimental day). Bulk ambient temperature is set to 298 K indicating that this panel conducted under Standard Testing Conditions (STC).

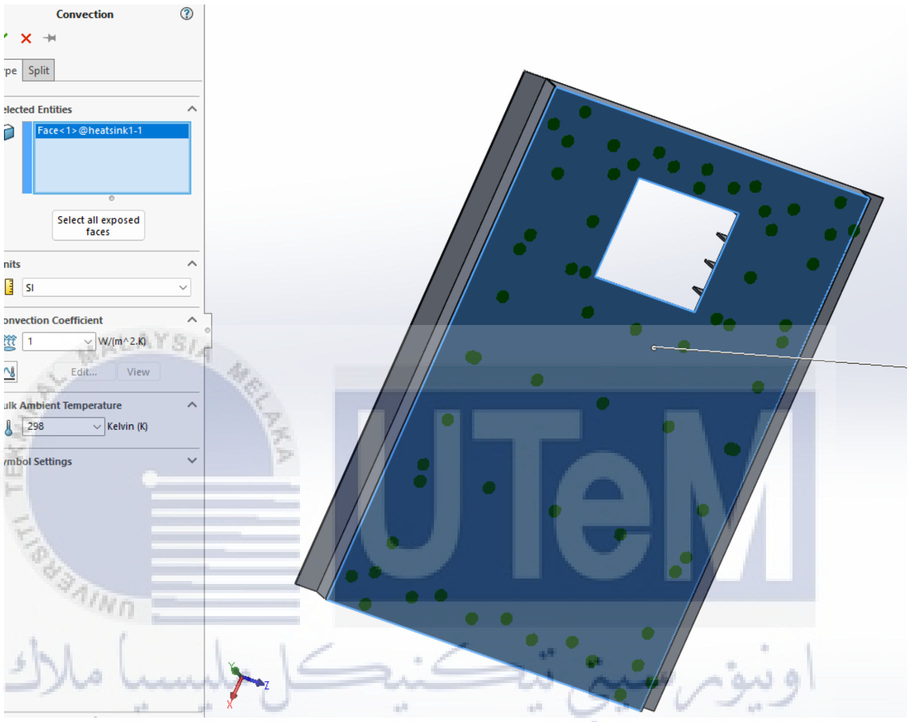


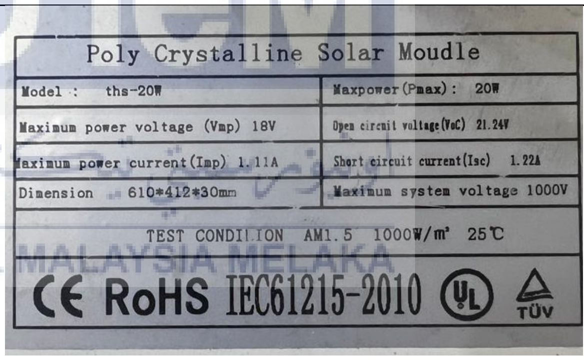

Figure 3.5.8 Convection characteristics (Back)

Next, I set a different value for the back of the cooling fins because the back of PV module is not fully covered that will allow wind to go through under the cooling fins but not as much as on the fins side. The convection coefficient is set to 1 $\frac{W}{m^2K}$ (Assuming there is slightly wind go through under the cooling fins) and bulk ambient temperature remain the same. After all is done, simulation is conducted to view the simulation results.

## 3.6 Hardware setup

The experiment is carried out in an exposed car pouch situated at Taman Belimbing Harmoni, Durian Tunggal, Melaka. The data was gathered over a period of 3 days, from 9 AM to 5 PM, with measurements taken once per hour, in order to get a more accurate average result. This experiment is carried out using two 20W solar panels, one equipped with aluminium cooling fins and the other without. The objective of this experiment is to analyse the collected data for both solar panels, specifically examining the temperature and output of each panel. The panels are positioned on a platform at a tilt angle of 20° to optimise sunlight absorption. The instruments used for this experiment include an infrared temperature gun for measuring the temperature of the panels, and a multimeter for measuring the output voltage during the completed experiment. Table below shows all the details for the equipment involves.

Table 3.6.1 Detail of equipment

| **Equipment** | **Detail** |
|---|---|
| Solar panel | <br>i) This experiment is conducted using 2 sets of Polycrystalline solar panels; one with aluminium cooling fins one without. This 2 sets are similar solar panels. |

| | |
|---|---|
| Multimeter | <br>i) Model number XL830L (EXCEL)<br>ii) Use to measure output voltage for both panels |
| Temperature gun | <br>i) Infrared temperature gun<br>ii) Use to measure temperature for both panels during experiment. |

Figure 3.6.1 Process installing aluminium cooling fins behind solar panel.

Figure 3.6.2 Solar panels with and without aluminium cooling fins placed in exposed car pouch at Taman Belimbing Harmoni, Durian Tunggal.


Figure 3.6.3 Temperature taken for solar panel with aluminium cooling fins at 9:00 A.M.




Figure 3.6.4 Output voltage taken for solar panel with aluminium cooling fins at 9:00 A.M.

With the formula stated for Fill Factor (FF) and given data of PV panel above,

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}$$

$$FF = \frac{18 \times 1.11}{21.24 \times 1.22} = 0.771$$

To calculate output current (A) of PV panel, temperature coefficient is involved. For this solar module, the temperature coefficient is,

$$\alpha = \frac{0.0005}{°C}$$

$$\beta = \frac{-0.003}{°C}$$

In which α stands for temperature coefficient for current, short circuit current ($I_{SC}$) that changes with temperature, and β stands for temperature coefficient for voltage, open circuit voltage ($V_{OC}$) that changes with temperature. This temperature coefficient is used for calculating $I_{SC}$ and $V_{OC}$ at specific temperatures. The formulas are,

$$I_{SC} = I_{SC(STC)}[1 + \alpha(T - T_{STC})]$$

$$V_{OC} = V_{OC(STC)}[1 + \beta(T - T_{STC})]$$



For Maximum Power Point Current ($I_{MPP}$), it is crucial to find current at maximum power output. To calculate $I_{MPP}$, the formula is



$$I_{MPP} = I_{SC} \times FF$$

To find output current of PV panel, the formula is

$$I = I_{Mpp} \times \frac{V}{V_{OC}}$$

With these formulas, the approximate current value of PV panel at certain temperature can be obtain.

# CHAPTER 4

# RESULTS AND ANALYSIS

## 4.1 MATLAB Simulation

On this part, it will explain the effect of irradiance on solar panel and effect of temperature on solar panel using results obtained from MATLAB Simulation. It will describe on how difference of irradiance and temperature affect the efficiency of power output on PV panel.

### 4.1.1 Irradiance

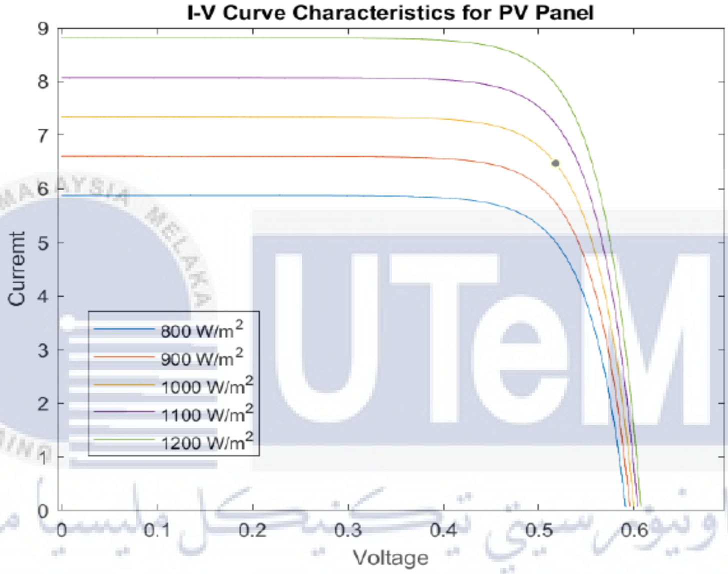





Figure 4.1.1.1 I-V curve for Irradiance

The results indicate that as the light intensity increased from 800 $\frac{W}{m^2}$ to 1200 $\frac{W}{m^2}$, the short circuit current ($I_{SC}$) also increased. At 800 $\frac{W}{m^2}$, the $I_{SC}$ was approximately 5.9 A. This value then increased to 6.6 A, 7.3 A, 8.1 A, and 8.9 A for light intensities of 900 $\frac{W}{m^2}$, 1000 $\frac{W}{m^2}$, 1100 $\frac{W}{m^2}$, and 1200 $\frac{W}{m^2}$, respectively. The results indicate a positive correlation between light intensity and short circuit current. As the light intensity increases, there is a corresponding increase in the short circuit current. This suggests that the light intensity has a direct impact on the magnitude of the short circuit current. The relationship between irradiance and short circuit current can be described as directly proportional.

### 4.1.2 Temperature

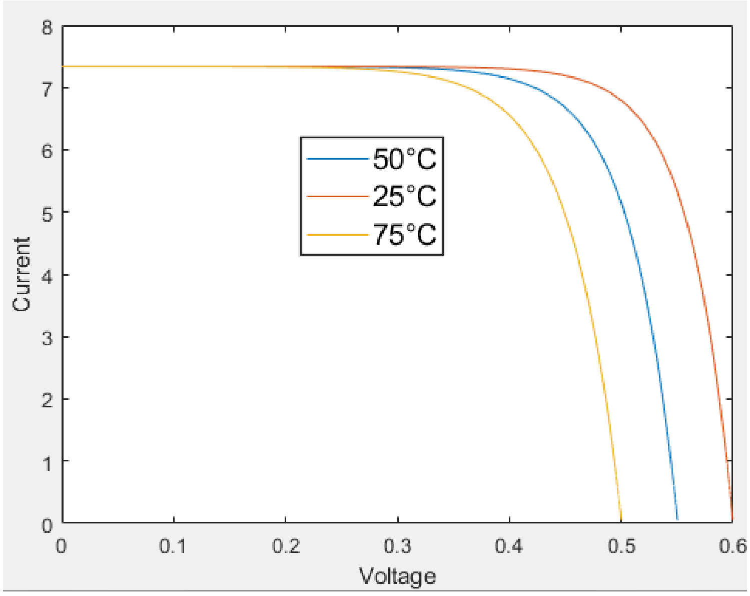



Figure 4.1.1.2 I-V curve for Temperature

Temperature plays a major role in efficiency of the PV panel. The results obtained above are simulated under STC (Standard Testing Conditions). When the temperature is set to 75°C, the voltage falls at 0.5V. For temperature 25°C and 50°C, the voltage falls at 0.55V and 0.6V respectively. Meaning that temperature is inversely proportional to voltage.

### 4.1.3 Power



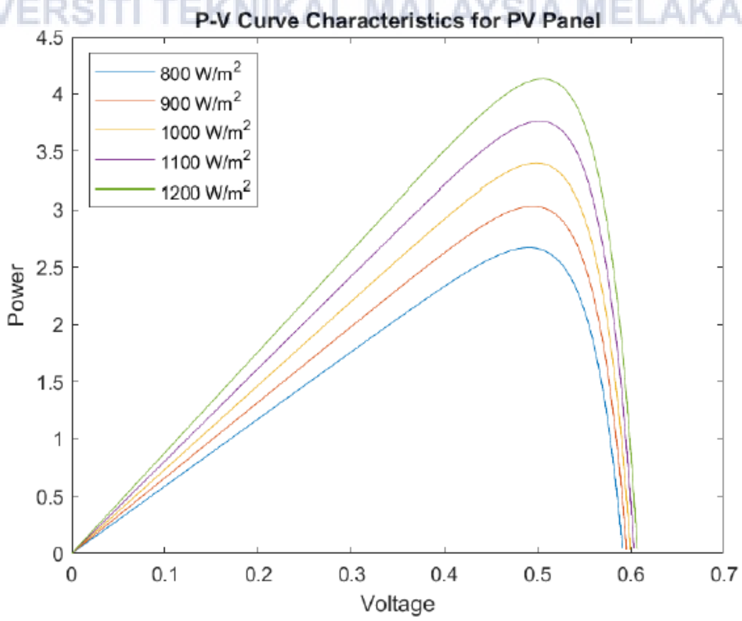



Figure 4.1.1.3 P-V curve for Power

During the STC simulation, the light intensity of 800 w/m^2 results in a power output of around 2.6W. This is followed by power outputs of 3.0W, 3.4W, 3.7W, and 4.1W for light intensities of 900 $\frac{w}{m^2}$, 1000 $\frac{w}{m^2}$, 1100 $\frac{w}{m^2}$, and 1200 $\frac{w}{m^2}$, correspondingly. According to the findings, the power exhibits a positive correlation with the rise in irradiation. Power and irradiance have a direct proportional relationship.

### 4.1.4 Summary of Irradiance, Temperature, and Power

The simulation results revealed that the performance of the PV panel greatly influenced by the variations of irradiance and temperature. As the irradiance increases, the output power of the PV panel is also increased. The temperature, otherwise, when it increases, the performance will be drop. To get the best performance of PV panel, the temperature must be lower with a great irradiance.

## 4.2 SOLIDWORKS Simulation

This section will explain how heat dissipates through cooling fins with different heat power applied from 20W up to 50W. The difference between minimum and maximum temperatures will show how great the heat transfer is.



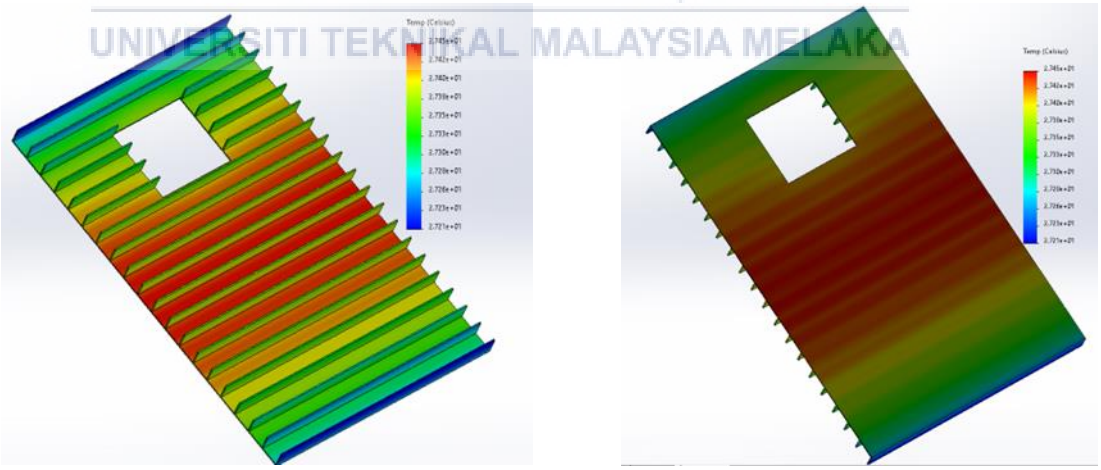


Figure 4.2.1 Heat power of 20W

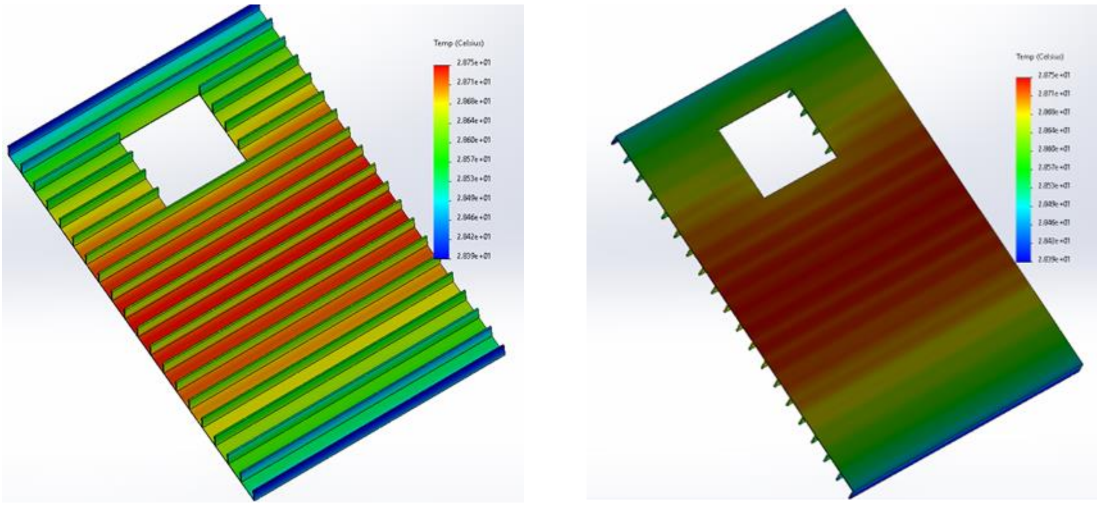



Figure 4.2.2 Heat power of 30W

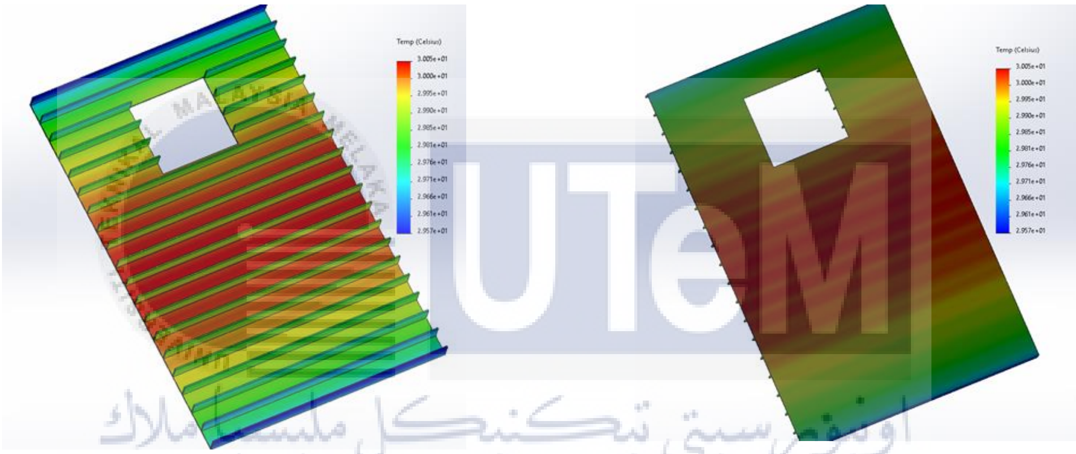



Figure 4.2.3 Heat power of 40W



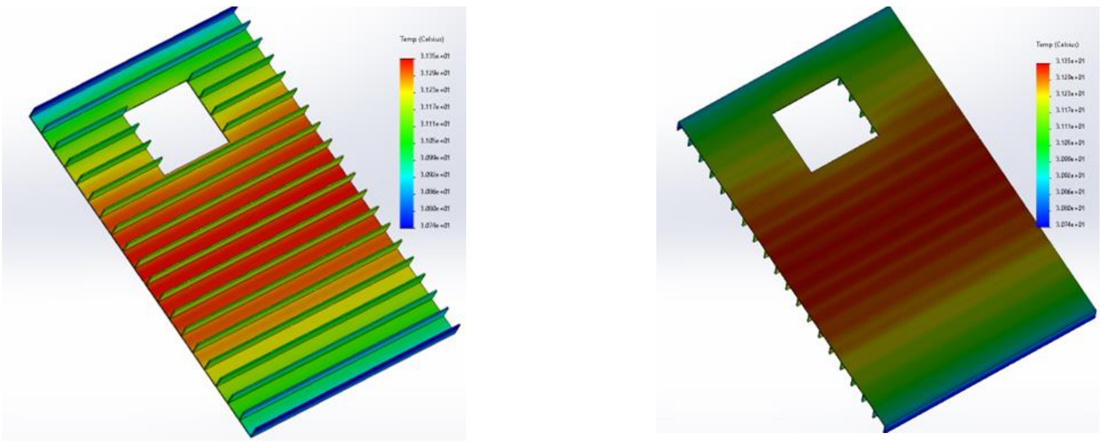



Figure 4.2.4 Heat power of 50W

Table 4.2.1 Obtained results from SOLIDWORKS Simulation

| **Heat power (W)** | **Min temp (°C)** | **Max temp (°C)** | **Temp difference (°C)** |
|---|---|---|---|
| 20 | 27.21 | 27.45 | 0.24 |
| 30 | 28.39 | 28.75 | 0.36 |
| 40 | 29.57 | 30.05 | 0.48 |
| 50 | 30.74 | 31.35 | 0.61 |

According to the data in the table, the heat power of 50W shows the largest temperature difference of 0.61°C compared to the other heat powers. The heat power of 20W, 30W, and 40W demonstrates a substantial rise in temperature difference, indicating effective heat transfer. The design was informed by the literature review, which indicated that a plain rectangular fin provides a larger surface area for improved heat dissipation compared to alternative designs.

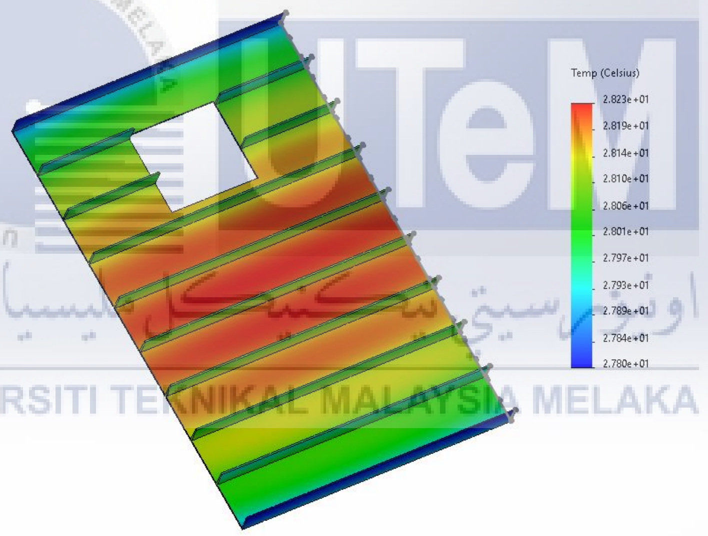





Figure 4.2.5 Aluminiun cooling fins with 10 fins

Table 4.2.2 Temperature difference between 10 fins and 20 fins

| **Heat power (W)** | **Min temp (°C)** | **Max temp (°C)** | **Temp difference for 10 fins (°C)** | **Temp difference for 20 fins (°C)** |
|---|---|---|---|---|
| 20 | 26.32 | 26.54 | 0.22 | 0.24 |
| 30 | 26.82 | 27.1 | 0.28 | 0.36 |
| 40 | 27.14 | 27.48 | 0.34 | 0.48 |
| 50 | 27.8 | 28.23 | 0.43 | 0.61 |

The table above illustrates the difference in temperature between aluminium cooling fins with 10 and 20 fins. The difference in temperature between the aluminium cooling fins, consisting of 10 fins, is measured to be 0.22°C, 0.28°C, 0.33°C, and 0.43°C for heat power inputs of 20W, 30W, 40W, and 50W correspondingly. The temperature disparity between the two designs is significant because the increased number of fins allows more efficient heat dissipation.

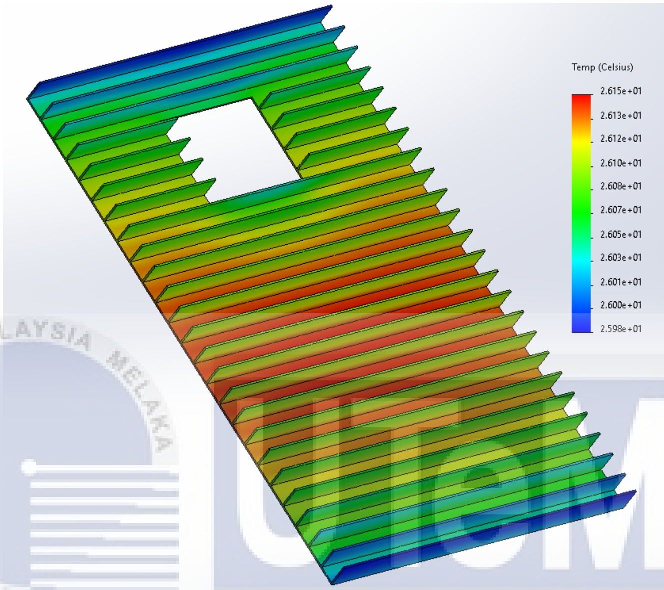



Figure 4.2. 6 Aluminium cooling fins with 25 fins

Table 4.2.3 Temperature difference between 20 fins and 25 fins

| Heat power (W) | Min temp (°C) | Max temp (°C) | Temp difference for 10 fins (°C) | Temp difference for 20 fins (°C) |
|---|---|---|---|---|
| 20 | 25.98 | 26.15 | 0.17 | 0.24 |
| 30 | 26.36 | 26.58 | 0.22 | 0.36 |
| 40 | 26.73 | 27.02 | 0.29 | 0.48 |
| 50 | 27.11 | 27.45 | 0.34 | 0.61 |

Aluminium cooling fins with 25 fins exhibit a significantly smaller temperature difference compared to those with 10 and 20 fins. The temperature differences for heat powers of 20W, 30W, 40W, and 50W are 0.17°C, 0.22°C, 0.29°C, and 0.34°C correspondingly. The difference occurs from the narrow spacing between the fins, which restricts the airflow during natural convection.

## 4.3 Experimental results

This experiment was done for 3 days to achieve an average result of solar panels (20 W) with and without aluminium cooling fins. It was put in an exposed car pouch in Taman Belimbing Harmoni, Durian Tunggal for a greater solar exposure and under natural convection. The data was obtained during 9:00 A.M. till 5:00 P.M. while the sun is still generating sunlight.

### 4.3.1 Average data

This average data was taken for 3 days for a better result of the experiment. It is proved that the installation of the aluminium heat sink with photovoltaic panel helps to improve the efficiency of the PV panel itself. Tables below show the overall result for this experiment.

Table 4.3.1.1 Data taken on 10th May 2024

| Day 1 (10/05/24) | | | | |
|---|---|---|---|---|
| Hour (24 format) | With cooling fins | | Without cooling fins | |
| | Temperature (°C) | Voltage (V) | Temperature (°C) | Voltage (V) |
| 0900 | 37 | 19.5 | 39.2 | 19.42 |
| 1000 | 39.5 | 19.2 | 51.5 | 18.8 |
| 1100 | 39.5 | 19.3 | 47.2 | 18.7 |
| 1200 | 43.6 | 17.78 | 54.4 | 17.24 |
| 1300 | 44.8 | 18.45 | 58.1 | 18.14 |
| 1400 | 42.6 | 18.8 | 53.6 | 18.3 |
| 1500 | 44.1 | 18.6 | 57.2 | 18.2 |
| 1600 | 29.1 | 12.84 | 29 | 12.65 |
| 1700 | 30.8 | 17.34 | 31.5 | 17.2 |

Table 4.3.1.2 Data taken on 18th May 2024

| Day 2 (18/05/24) | | | | |
|---|---|---|---|---|
| Hour (24 format) | With cooling fins | | Without cooling fins | |
| | Temperature (°C) | Voltage (V) | Temperature (°C) | Voltage (V) |
| 0900 | 36.9 | 19.4 | 38.8 | 19.3 |
| 1000 | 42.9 | 20 | 50.3 | 19.8 |
| 1100 | 45.3 | 19.9 | 58.1 | 19.5 |
| 1200 | 44.9 | 18.7 | 60.2 | 18.5 |
| 1300 | 42.3 | 19.3 | 52.9 | 18.92 |
| 1400 | 48.8 | 18.7 | 63 | 18.2 |
| 1500 | 45.2 | 18.6 | 55.7 | 18.1 |
| 1600 | 42.6 | 18.9 | 51.2 | 18.7 |
| 1700 | 38.6 | 19.54 | 42.5 | 18.51 |

Table 4.3.1.3 Data taken on 19th May 2024

| Day 3 (19/05/24) | | | | |
|---|---|---|---|---|
| Hour (24 format) | With cooling fins | | Without cooling fins | |
| | Temperature (°C) | Voltage (V) | Temperature (°C) | Voltage (V) |
| 0900 | 38.8 | 19.8 | 39.1 | 19.7 |
| 1000 | 38.2 | 19.5 | 38.6 | 19.1 |
| 1100 | 44.2 | 18.9 | 59.8 | 18.3 |
| 1200 | 37.8 | 17.4 | 40.2 | 16.54 |
| 1300 | 40.7 | 19.1 | 61.6 | 17.5 |
| 1400 | 40.7 | 19.1 | 56.6 | 18.4 |
| 1500 | 43.3 | 18.5 | 56.6 | 18.1 |
| 1600 | 40.9 | 19 | 49.2 | 18.6 |
| 1700 | 38.4 | 19.1 | 45 | 18.54 |



The variability of the outcomes may be related to the unfavourable weather conditions, which included cloudiness and drizzle, that occurred throughout the experiment. In order to fix the discrepancy, the average of all the findings collected over a period of 3 days will be calculated and used.

Table 4.3.1.4 Average data taken for overall result

| Hour (24 format) | With cooling fins | | Without cooling fins | |
|---|---|---|---|---|
| | Temperature (°C) | Voltage (V) | Temperature (°C) | Voltage (V) |
| 0900 | 37.57 | 19.57 | 39.03 | 19.47 |
| 1000 | 40.20 | 19.57 | 46.80 | 19.23 |
| 1100 | 43.00 | 19.37 | 55.03 | 18.83 |
| 1200 | 42.10 | 17.96 | 51.60 | 17.43 |
| 1300 | 42.60 | 18.95 | 57.53 | 18.19 |
| 1400 | 44.03 | 18.87 | 57.73 | 18.30 |
| 1500 | 44.20 | 18.57 | 56.50 | 18.13 |
| 1600 | 37.53 | 16.91 | 43.13 | 16.65 |
| 1700 | 35.93 | 18.66 | 39.67 | 18.08 |

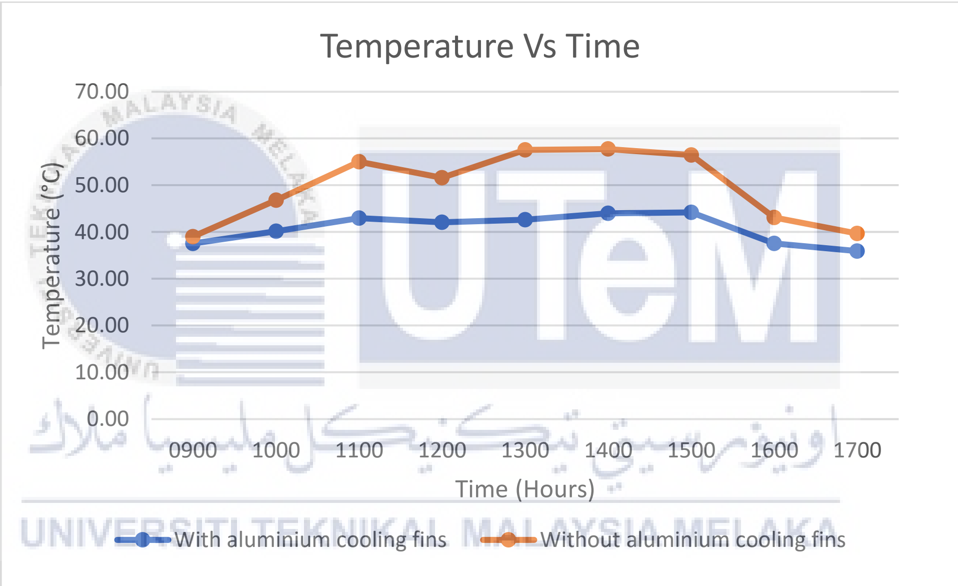



Figure 4.3.1.1 Graph Temperature Vs Time for Photovoltaic panel with aluminium cooling fins and without aluminium cooling fins

From the graph shown, it is clear that the temperature of the PV panel equipped with aluminium cooling fins is much lower in comparison to the temperature of the PV panel without aluminium cooling fins. The temperature range for PV panels equipped with aluminium cooling fins is around 37°C to 44°C. However, for PV panels without cooling fins, the temperature range is roughly 37°C to 57°C. The maximum temperature recorded is 57.79°C at 1400 hours for a PV panel without aluminium cooling fins, and 44.2°C at 1500 hours. (Please note that the following data represents the average values collected over a period of three consecutive days.)

By using formulas stated in Chapter 3,

$$FF = 0.771$$

$$I_{SC} = I_{SC(STC)}[1 + \alpha(T - T_{STC})]$$

$$I_{SC} = 1.22 \times [1 + 0.0005(37.57 - 25)] = 1.23\ A$$

$$V_{OC} = V_{OC(STC)}[1 + \beta(T - T_{STC})]$$

$$V_{OC} = 21.24[1 - 0.003(37.57 - 25)] = 20.44\ V$$

$$I_{MPP} = I_{SC} \times FF$$

$$I_{MPP} = 1.23 \times 0.771 = 0.95\ A$$

$$I = I_{Mpp} \times \frac{V}{V_{OC}}$$

$$I = 0.95 \times \frac{19.47}{20.44} = 0.91\ A$$

For the rest of the output current, it is shown in the table below.

Table 4.3.1.5 Output current of PV panels

| Hour (24 format) | With cooling fins | | Without cooling fins | |
|---|---|---|---|---|
| | Temperature (°C) | Current (A) | Temperature (°C) | Current (A) |
| 0900 | 37.57 | 0.91 | 39.03 | 0.91 |
| 1000 | 40.20 | 0.91 | 46.80 | 0.92 |
| 1100 | 43.00 | 0.91 | 55.03 | 0.93 |
| 1200 | 42.10 | 0.85 | 51.60 | 0.85 |
| 1300 | 42.60 | 0.89 | 57.53 | 0.91 |
| 1400 | 44.03 | 0.89 | 57.73 | 0.91 |
| 1500 | 44.20 | 0.88 | 56.50 | 0.90 |
| 1600 | 37.53 | 0.78 | 43.13 | 0.79 |
| 1700 | 35.93 | 0.86 | 39.67 | 0.84 |

According to the data provided, it is obvious that the output current of the PV panel ($I_{SC}$) varies for both panels. The PV panel without aluminium cooling fins has a somewhat higher output current compared to the other panel. The temperature of PV panels with aluminium cooling fins is somewhat greater because of the properties of charge carriers in the semiconductor material. However, higher temperatures will enhance the mobility of the chargers. Conversely, the open circuit voltage ($V_{OC}$) is negatively correlated with temperature, indicating that VOC drops as temperature increases. The table below shows this.

Table 4.3.1. 6 Output voltage for PV panels

| Hour (24 format) | With cooling fins | | Without cooling fins | |
|---|---|---|---|---|
| | Current (A) | $V_{OC}$ (V) | Current (A) | $V_{OC}$ (V) |
| 0900 | 0.91 | 20.44 | 0.91 | 20.35 |
| 1000 | 0.91 | 20.27 | 0.92 | 19.85 |
| 1100 | 0.91 | 20.09 | 0.93 | 19.33 |
| 1200 | 0.85 | 20.15 | 0.85 | 19.55 |
| 1300 | 0.89 | 20.12 | 0.91 | 19.17 |
| 1400 | 0.89 | 20.03 | 0.91 | 19.15 |
| 1500 | 0.88 | 20.02 | 0.90 | 19.23 |
| 1600 | 0.78 | 20.44 | 0.79 | 20.08 |
| 1700 | 0.86 | 20.54 | 0.84 | 20.31 |

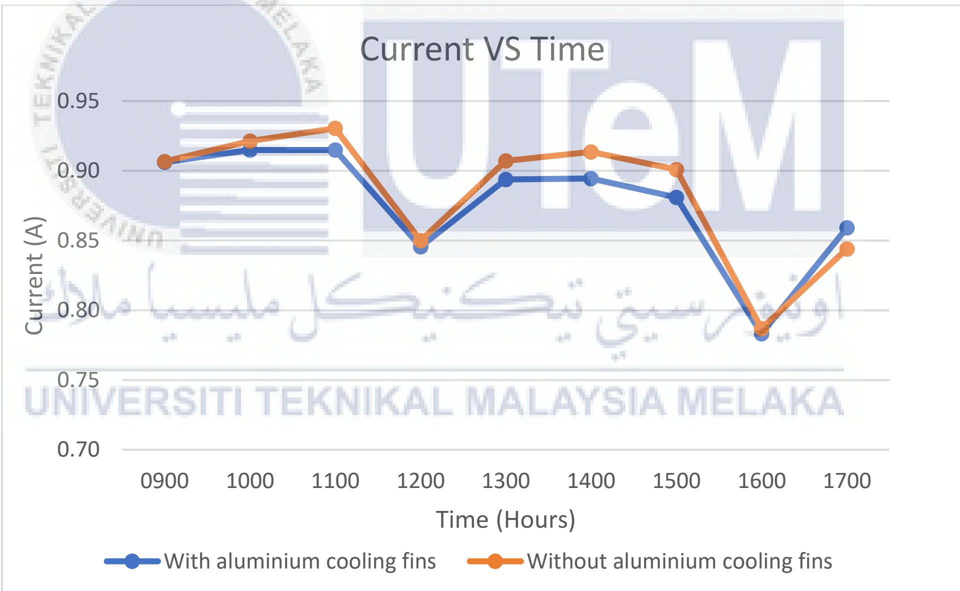




Figure 4.3.1.2 Graph Current VS Time

Based on the graph above, PV panel without aluminium cooling fins has current similar/leading from 0900 hours till 1600 hours. Last hour, PV panel with aluminium cooling fins is leading rather significantly. Better thermal management over the final hour explains why the current for the PV panel with aluminium cooling fins is somewhat greater than without aluminium cooling fins.

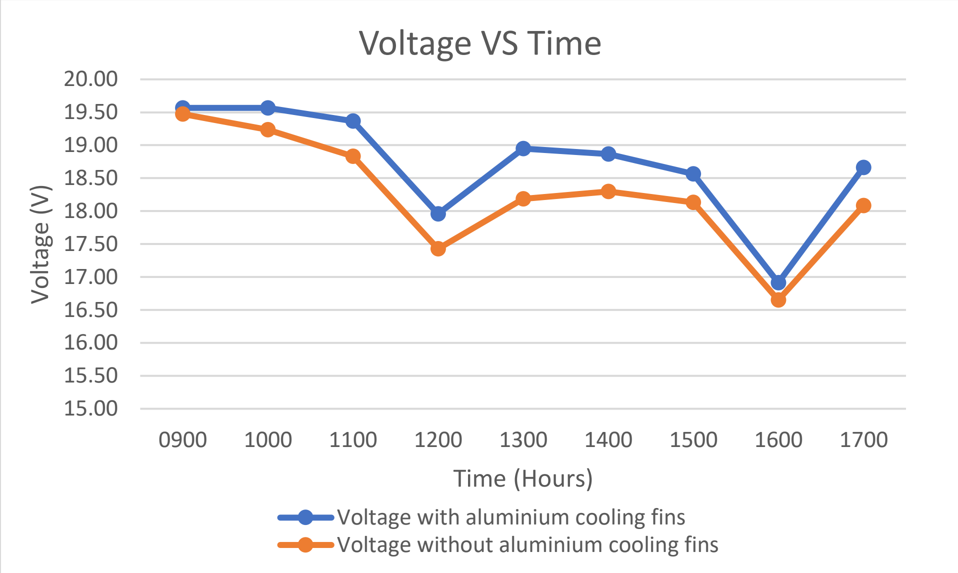



Figure 4.3.1.3 Graph Voltage VS Time

While the PV panel without aluminium cooling fins leads to a slightly greater current for PV panels, the higher temperature causes a decrease in voltage. The graph above displays the voltage output for both panels over time. As the temperature decreases and the radiance of sunlight decreases, a photovoltaic panel equipped with aluminium cooling fins will continue to generate its current output. The use of aluminium cooling fins aids in heat dissipation and stabilisation, hence retaining greater voltage levels in comparison to PV panels without aluminium cooling fins.

By using the formula P = IV to determine the output power of both PV panels, we identify the difference in power between the PV panels equipped with aluminium cooling fins and those without. Based on what we have seen, PV panels equipped with aluminium cooling fins are now showing a minor advantage in terms of output power. The maximum power output for both photovoltaic (PV) panels was measured at 1000 hours, with an average of 17.9W for the PV panel with aluminium cooling fins and 17.72W for the PV panel without aluminium cooling fins. This benefit is due to improved thermal management, which aids in maintaining greater voltage levels even with roughly the same or lower current. The specifics are shown in the table provided below.

Table 4.3.1.7 Output power for both PV panels

| Hour (24 format) | With cooling fins | | | Without cooling fins | | |
|---|---|---|---|---|---|---|
| | Current (A) | Voltage (V) | Power (W) | Current (A) | Voltage (V) | Power (W) |
| 0900 | 0.91 | 19.57 | 17.73 | 0.91 | 19.47 | 17.66 |
| 1000 | 0.91 | 19.57 | 17.90 | 0.92 | 19.23 | 17.72 |
| 1100 | 0.91 | 19.37 | 17.72 | 0.93 | 18.83 | 17.52 |
| 1200 | 0.85 | 17.96 | 15.19 | 0.85 | 17.43 | 14.81 |
| 1300 | 0.89 | 18.95 | 16.94 | 0.91 | 18.19 | 16.50 |
| 1400 | 0.89 | 18.87 | 16.88 | 0.91 | 18.30 | 16.72 |
| 1500 | 0.88 | 18.57 | 16.36 | 0.90 | 18.13 | 16.34 |
| 1600 | 0.78 | 16.91 | 13.25 | 0.79 | 16.65 | 13.10 |
| 1700 | 0.86 | 18.66 | 16.03 | 0.84 | 18.08 | 15.26 |

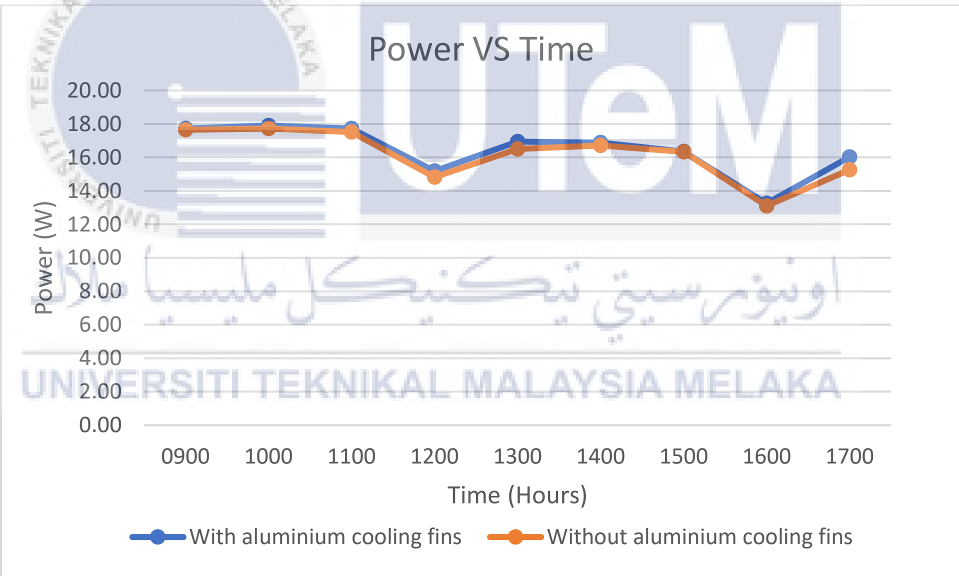





Figure 4.3.1.4 Graph Power VS Time

According to the graph, the variation in power is not significant as a result of weather-related factors. In general, the findings are as expected, with the PV panel equipped with aluminium cooling fins consistently demonstrating a greater power output.

For efficiency of PV panels, using formula

$$Efficiency\ (\%) = \frac{P_{max}}{Area\ \times 1000\ W/m^2} \times 100$$

Where,

$$P_{max} = V_{oc}I_{sc} = Maximum\ panel\ power\ (W)$$

$$Area = Area\ of\ PV\ panel\ in\ m^2$$

Given data of PV panel on Chapter 3,

$$Efficiency\ (\%) = \frac{P_{out}}{P_{in}} = \frac{1.22 \times 21.24}{(0.61 \times 0.412) \times 1000W/m^2} \times 100 = 10.3\%$$

For the rest of the hours, the details are shown in the table below.

Table 4.3.1.8 Efficiency for both PV panels

| | Efficiency (%) | |
|---|---|---|
| Hour (24 format) | With cooling fins | Without cooling fins |
| 0900 | 7.055 | 7.025 |
| 1000 | 7.123 | 7.051 |
| 1100 | 7.050 | 6.973 |
| 1200 | 6.043 | 5.893 |
| 1300 | 6.740 | 6.564 |
| 1400 | 6.716 | 6.651 |
| 1500 | 6.508 | 6.500 |
| 1600 | 5.271 | 5.213 |
| 1700 | 6.379 | 6.072 |

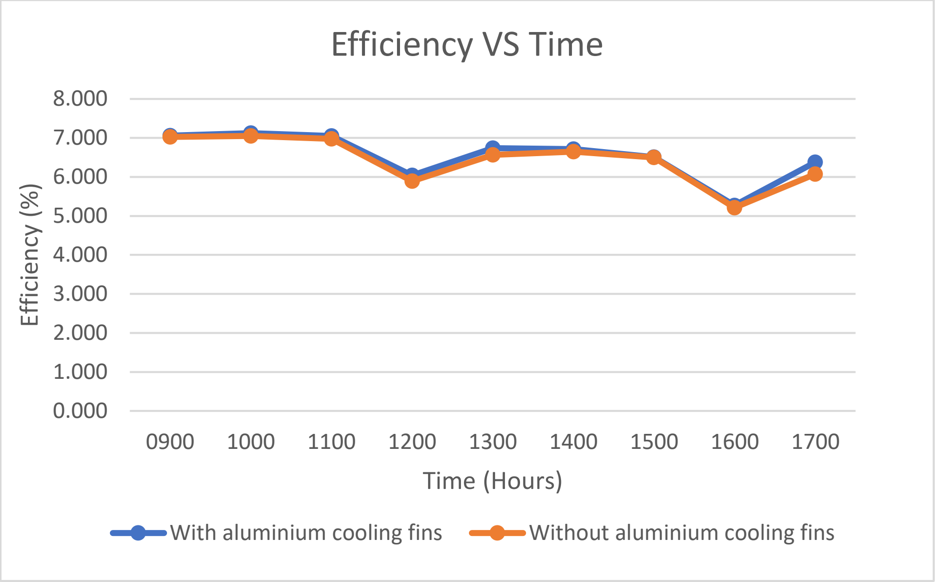



Figure 4.3.1.5 Graph Efficiency VS Time

According to the provided table and graph, PV panels with aluminium cooling fins exhibit a slightly greater level of efficiency compared to those without aluminium cooling fins. Although the difference is not very substantial, it demonstrates stability over the whole day. The highest reported average efficiency is achieved at 1000 hours, with values of 7.123% and 7.051% for PV panels with and without aluminium cooling fins, respectively. This investigation has shown that photovoltaic (PV) panels equipped with aluminium cooling fins enhance both power output and efficiency, particularly in high-temperature environments, by using natural convection.

## 4.4 Overall discussion and conclusion

When it comes to the power and efficiency of photovoltaic panels, aluminium cooling fins provide a possible solution that is both practical and efficient. There is no doubt that it demonstrates a continuous advantage in terms of efficiency throughout the peak hours of operation. By minimising the negative effects of high temperature while maintaining constant output power, aluminium cooling fins contribute to a reduction in the operating temperature of the device during operation.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

In conclusion, it can be concluded that the objectives for this experiment is a success. Using aluminium cooling fins as a medium to mitigate the effects of temperature on PV panel, the present of it can improve both power and efficiency of PV panels under natural convection. This can be proved by the result obtained during this experiment. Although not significant, but it shows consistent improvement in terms of efficiency. This shows early hypothesis is proven that aluminium cooling fins brings positive impacts the overall performance of PV panels, especially in environments where temperature is the main subject.

## 5.2 Recommendation

The performance of photovoltaic (PV) panels is significantly influenced by their operational temperature, where high temperatures often result in reduced efficiency. An efficient approach for maintaining this temperature is to attach cooling fins to the back of the panels in order to disperse heat. The design of these cooling fins is critical, as it promotes natural convection, hence allowing faster cooling of the fins. Nevertheless, data collected suggest that the present experimental location may not be ideal because of inadequate air circulation. This limitation lowers the efficiency of the cooling procedure. In order to enhance cooling and optimise outcomes, it is preferable to carry out the experiment in a wide and elevated area with excellent air circulation. By optimising airflow, the cooling fins may enhance their performance, resulting in enhanced heat dissipation and increased efficiency of PV panels.

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