PERFORMANCE EVALUATION OF ANGLE ADJUSTABLE SOLAR BLIND

ONG KAI SHENG

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

Lee Kong Chian
Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ______________________________

Name : Ong Kai Sheng

ID No. : 1206664

Date : ______________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"PERFORMANCE EVALUATION ON ANGLE ADJUSTABLE SOLAR BLIND"** was prepared by **ONG KAI SHENG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ______________________________

Supervisor : Dr. Lim Boon Han

Date : ______________________________

Specially dedicated to

my beloved grandmother, mother and father

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I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr. Lim Boon Han for his invaluable advice, guidance and his enormous patience throughout the development of the research.

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ABSTRACT

Building Integrated Photovoltaic (BIPV) window is well developed in Western countries like Germany. However, the sun altitude in tropics is relatively high compared to the non-tropics. This creates great cosine loss to the vertically placed BIPV window thus reducing the power output. Typical BIPV windows use non-transparent high-efficiency C-Si solar cells. This non-transparent solar cells restricted the daylighting effect and aesthetically not attractive. The use of semi-transparent thin film solar cells can counter these two problems but they bring low the efficiency. This project introduced a novel solar blind. This design can produce higher output without fading the daylighting and it possesses the flexibility for the user to control what he prefers. This innovative green product is particularly suitable in tropical countries such as Malaysia. It exceptionally apt for retrofit cases, hence it is targeted to be installed in high-rise building such as UTAR Sungai Long campus and other office towers that already have windows been installed. This solar blind is angle adjustable and having the ability to maintain a gap between solar panels by pulling up and keep those blinds without solar panels beneath blinds with solar panels for maximum electricity yield. This design was proven that for capable of generate 40% more energy than typical vertically placed solar windows. The study of this project was carried out in UTAR Sungai Long campus. It was tested at different tilting angle at two different directions. This solar blind promises the benefits of being able to shave the current peak demand via energy storage to reduce the electricity bill, reduction of building external energy consumption, as an investment and reducing heat transmission through windows.

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LIST OF SYMBOLS / ABBREVIATIONS

cm	centimetre
V	volt
A	Ampere
W	Watt

UTAR	Universiti Tunku Abdul Rahman
FiT	Feed in Tariff
PV	Photovoltaic
BIPV	Building Integrated Photovoltaic
BAPV	Building Attached Photovoltaic
TNB	Tenaga National Berhad

CHAPTER 1

INTRODUCTION

1.1 Background

As far as we know, the universe that we live in is made up of matter and energy. Matter is something that can occupy space and possesses rest mass. Energy, however, is something a bit more abstract than matter. According to physicians, energy is the ability to do work. In the other words, energy causes things to happen. Look at what is happening around us, the presence of energy is everywhere. During the daytime, the sun will emit light and heat energy. All the living organism on the earth depend on the sun to survive. At night, there is insufficient of sunlight irradiation, so we use the electrical energy to illuminate our world with lamps. In order to carry out our daily duties, our body need energy. This energy comes from the food that we ate. Energy possesses different forms, they are electrical, thermal, light, chemical, mechanical, nuclear energy and etc.

One of the energies that we depend on most is electrical energy. Electrical energy can be generated by using other sources of primary energy such as oil, coal, natural gas, uranium, solar, wind, biomass, hydro and geothermal energy. These primary energies can be categorized into two categories: non-renewable and renewable energy sources. Fossil fuel such as oil, coal, natural gas and natural mineral like uranium can be categorized as non-renewable energy sources while the solar, wind, hydro, biomass and geothermal fall into the category of renewable energy sources. Although there are a few major advantages of using non-renewable energy sources such as fossil fuels to generate electricity over renewable energy sources, they will eventually fall into disuse there are limited amount of resources available on the earth. The speed of they being harness is faster than the speed they being restored as they need millions of year to form. Therefore, the fossil fuels will eventually run out. Furthermore, burning fossil fuels will emit greenhouse gasses to the atmosphere which harmful to the environment.

The major resource that we used in Malaysia for generating electricity is coal as it is the cheapest and yet abundant on the earth. The total capacity of coal power plant in Malaysia is 8425 MW. The largest power station in Malaysia is Kapar Energy Venture a.k.a. Sultan Salahuddin Abdul Aziz Power Station with generating capacity of 2420 MW use coal as the primary sources besides oil and gas. However, Malaysia government actively promote the use of renewable energy to generate electricity. One of the steps taken by the government is introducing “Five-Fuel Diversification Policy” in 2001 where renewable energy was introduced as the “fifth fuel” additional to the other four fuels (oil, gas, coal and hydro) in order to minimize the emission of greenhouse gasses during the energy generation. Apart from this, Malaysia government also introduce Renewable Energy Act 2011 to enforce the feed-in tariff (FiT) scheme for catalyzing the growth of renewable energy. This scheme allowed the investors to sell the electricity produced from the renewable energy sources to the power utilities at a fixed price for a specific time.

The top 3 renewable energy sources in Malaysia are solar, hydro and wind. Among these 3 energy sources, wind energy is the least favored by the Malaysian because the average wind speed in Malaysia just in the range of 2 m/s to 13 m/s which is considered as low wind speed compared to the global mean wind speed of 80 m/s. Unlike other countries, the wind does not blow in a uniform way and the speed of the wind differ in conformity with region and month. Southwest monsoon and northeast monsoon seasons affected the wind speed in Malaysia. Moreover, only a few places in Malaysia have the potential to generate electricity using wind energy, they are Pulau Layang-layang, Pulau Perhentian Kecil and Pulau Langkawi.

Despite the fact that about 71% of the earth surface is covered by water, we cannot fully utilize them to generate electricity. Hydropower is not polluting the water, but it has an enormous impact on the environment. The large hydropower plant that has generating capacity more 100 MW does not consider as renewable energy. This is because, during construction of large hydropower station like the Bakum Dam in Malaysia (2400 MW), it altered the environment of that area. Besides that, it also affects the land use, homes of the native people and the surrounding ecology. The Bakum Dam flooded 700 km^2 of land with water which equivalent to Singapore. On the other hand, mini hydro that capable of generating 10 MW to 30 MW power or other smaller hydro plant are consider to be renewable energy because they have smaller impact on the environment compared to the large hydro plant

Solar energy is well liked by the Malaysian. The main reason is Malaysia an equatorial country that has high solar irradiance level which is excellent for Photovoltaic (PV) generation. With more than 10 hours of sunlight per day, the level of solar irradiance on Malaysia is in the range of 1470 to 1900 kWh/m^2/year, averaging about 1643 kWh/m^2/year. One of the most popular applications in Malaysia for harvesting solar energy is solar water heater. Many residences choose to install solar water heater as part of a contribution to sustain the environment. Besides that, PV also widely used in street lamps and emergency phone booths along the streets and highways. Since the government enforced FiT scheme, more people choose to invest in building attached photovoltaic (BAPV) or building integrated photovoltaic (BIPV) as there is significant of profit can be made.

1.2 Project Background

Building Integrated Photovoltaic (BIPV) system is fond of many countries especially the European. It is one of the fastest growing sectors in PV industry. In this system, the PV panels are integrated into the building as a portion of the building materials while the common solar panels are just stack on or attached to the buildings. Windows in high-rise building which cover a large amount of area have become the focus of BIPV window installation. However, BIPV windows are not widely adopted in Malaysia and other tropical countries for some reasons. The following pictures show some of the BIPV installation:

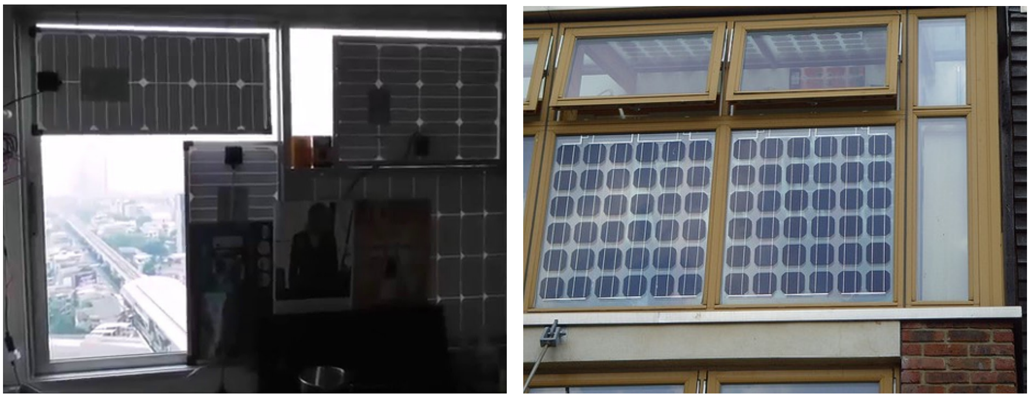

Figure 1.1 C-Si on Vertical Window

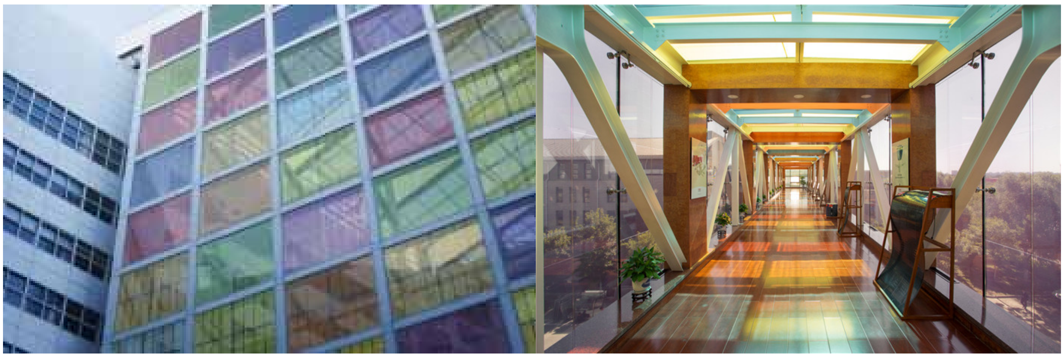

Figure 1.2 Dye-sensitized Semi-Transparent Window

Crystalline silicon (C-Si) solar cells have relatively high efficiency, commercially inexpensive and matured in technology. An example of using C-Si in BIPV window is shown in Figure 1.1. However, the disadvantages of this method, especially in Malaysia and other tropical countries are:

- Aesthetically not good.
- Poor daylighting effect – too much sunlight blocked by the non-transparent cells.
- Medium output - low light collection angle due cosine loss, which is related to the nature of the sun trajectory in tropics.

By using semi-transparent thin file such as dye-sensitized and amorphous solar cells as shown in Figure 2.2, the daylighting effect and aesthetic problems can improve, but it pays off:

- Very low energy efficiency for semi-transparent effect.
- Low output - low light collection angle due cosine loss, which is related to the nature of the sun trajectory in tropics.
- Not durable – dye-sensitized solar cells and organic solar cells are not really mature in technology.

In the existing technology, the BIPV window is placed in vertical position as normal windows. This will cause low output and low efficiency if we need to maintain excellent daylighting effect and good aesthetic. The low light collection issue can be explained by Figure 1.3 (a), (b) and Figure 1.4. Figure 1.3 shows the sun trajectories (red lines in the figures) in tropic and non-tropic for different seasons of a year. It shows that the sun altitude angle, α, in tropical countries is much higher than the non-tropical countries. Therefore, when the sunlight incident in the vertical placed BIPV window, it will receive less light as shown in Figure 1.4. This loss is known as cosine loss. However, if the window is tilted with a certain angle, it receives more sunlight compared to the vertically placed BIPV window.

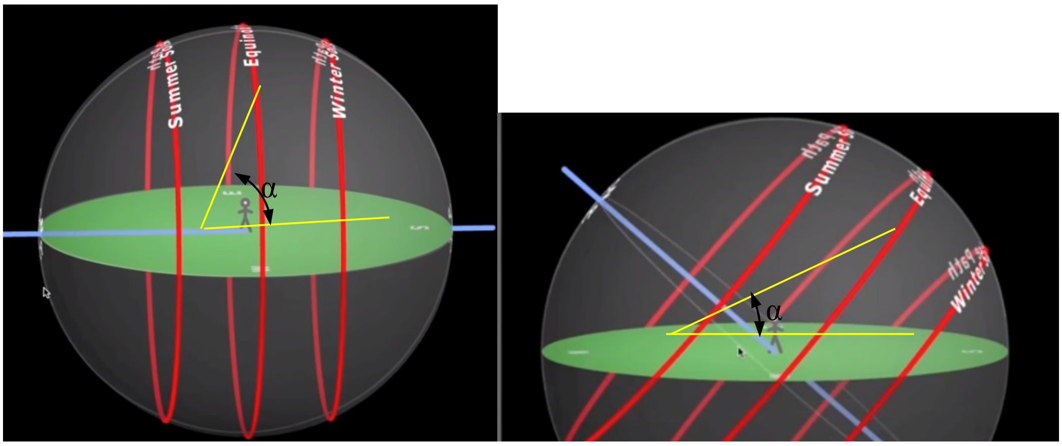

Figure 1.3 Sun Trajectories in (a) Tropics and (b) Non-tropics

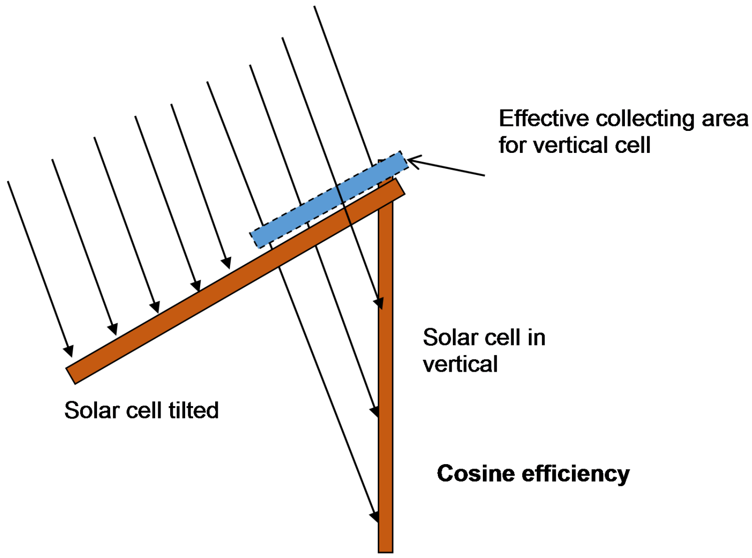

Figure 1.4 Illustration of Cosine Effect

1.3 Project Motivation

The main purpose of this project is to design and build solar blinds. The design of the solar blinds is inspired from common blinds and shades such as the pleated shades, aluminum blinds, faux wood blinds and the Roman shades. These solar blind will replace the existing window blinds by substituting the blades of the window blinds with solar panels. The angle adjustable mechanism can allow more sunlight to pass through without sacrificing the electricity generation. Hence, these solar blinds are more applicable than the typical BIPV window in tropical countries such as Malaysia. They are targeted to install at high-rise building such as UTAR Sungai Long Campus and other office towers where the windows have already been installed. Therefore, the installation of the solar blinds does not bring big impact to the structure of the building.

UTAR Sungai Long campus is recommended to implement this system. One of the benefits is able to shave the peak demand curve via the energy storage. This can help UTAR to save money on the electricity bill. Since the used of this new building, UTAR has spent around RM30000 per month as a penalty of high demand for electricity during peak hours. Apart from UTAR Sungai Long campus, this situation also happens to other office towers situated in city central. By installing these solar blinds, the electricity generated can be stored in batteries and supplied to the campus during peak demand time through the bidirectional inverter. Thus reducing the electricity bills.

Another benefit promise from solar blinds is able to lessen the building external energy consumption. This is to target UTAR Sungai Long campus for becoming a greener building through self-consumption when a new regulation, net energy metering is going to be implemented in 2017. This net energy metering allows the energy generated from solar PV system to be consumed in situ (self-consumption and this would reduce buying electricity from the grid (BERNAMA, 2016). On the other hand, the present Green Building Index will also benefit UTAR. Since Malaysia government is encouraging community building such as universities to install renewable energy system, this design can act as an investment. Under the current FiT scheme, it is estimated to pay back within 10 years while the FiT will be given for 21 years. Lastly, it can reduce heat transmission through the windows while generating power from the sun. This will help to reduce energy consumed for air conditioning after some infrared light is blocked.

1.4 Aims and Objectives

- To design and construct a solar blind.
- To study the performance of solar blind at different tilting angles.
- To compare the performance of solar blind at different directions.

1.5 Project Overview

This section showed the timeline to complete this project. The details of the planning is shown in Table 1.1:

Table 1.1 Gantt chart of Project

		FYP 1					FYP 2			
Stage	Task	Ja n	Fe b	Ma r	Apr	May	Jun	Jul	Aug	Sep
Preparation	Research on Journal and article.									
	Research for suitable solar panel.									
	Prototype Design.									
	FYP 1 progressive report.									
Engineer	Procurement.									
	Assembly and wiring.									
Data Collection	Shading Calculation									
	Effect of sun elevation angle and blades' tilting angle.									
Finalize	Data and graph analysis.									
	FYP 2 progressive report.									

	Completion of FYP 1
	Completion of FYP 2

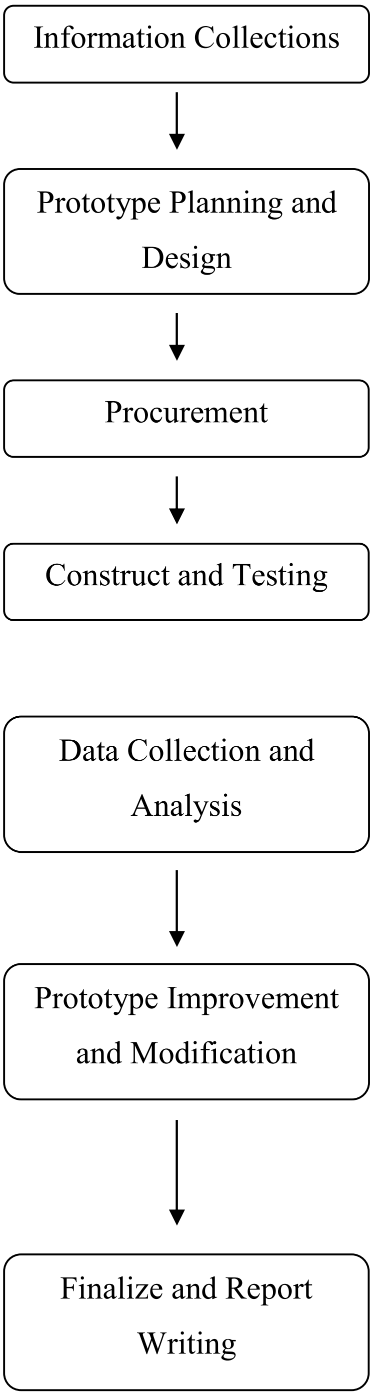

Figure 1.5 Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This review introduced different types of Photovoltaic (PV) cells available in the market, the working principle behind the PV, the electrical characteristic of PV and the factors that affect the efficiency of PV. Besides, this review covered the comparison of different window blinds and shades.

2.2 Photovoltaics Cell (PV)

The word "photovoltaics" originates from a Greek word φῶς (*phōs*), meaning "light" and combine with the unit of electromotive force, "volt" which comes from the last name of famous Italian physicist who invented battery named Alessandro Volta. Since 1849, the word "photovoltaic" has been used in English (Smee, 1849). Photoelectric effect was discovered by a French physicist, Edmund Bequerel, the sun of Antoine César Becquerel and father of Henry Becquerel, in 1839 where he observed that when two platinum electrodes are placed in a solution, it will produce electrical current when exposed to sun light (Knier, 2002). In 1954, Bell Laboratories build the first silicon PV module but it was too uneconomical for mass production. Until 1970s, PV only started to gain its recognition in public. PV systems can be categorized into stand-alone systems and grid-connected systems. Solar blinder is considered a stand-alone system. Stand-alone system usually have a storage system included because the time the electricity generated is not necessary the electricity being used. Therefore, a stand-alone system includes PV module, regulator, battery and load. There are a few type of solar cell technologies available in the market. They are monocrystalline silicon cell, polycrystalline silicon cell, thin-film cell and building integrated photovoltaics (BIPV).

Monocrystalline a.k.a. single-crystal silicon cell (Figure 2.1), is fabricate under the Czochralski process. Under this process, the polysilicon will melt into a quartz container at about 1420°C. A seed crystal will dip into the saturated silicon solution and slowly be drawn upwards out of the solution. The crystal is formed into a cylindrical monocrystal. This block of cylindrical monocrystal will be slice into different wafer shapes according to the requirement. These wafers will undergo phosphorous diffusion where thin layer of p-n junction is created. Finally an anti-reflective coating and current collector lines are added. Depends on the sizes and technologies applied, the open circuit voltage of monocrystalline silicon cell is around 0.6V while the short circuit current is about 3A to 16A.

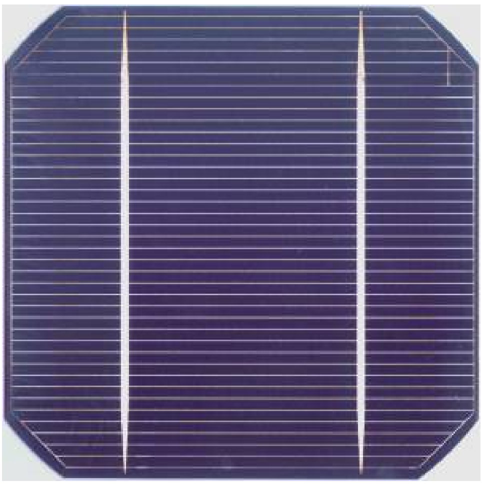

Figure 2.1 Semi-square Monocrystalline Cell

The fabrication process of polycrystalline silicon cell (Figure 2.2) is a bit differ from monocrystalline silicon cell. The polysilicon will be melted in a quartz crucible, doped with boron and shape into rectangular form using mould. The saturated silicon solution will be cooled evenly in one direction by manipulating the temperature. The purpose of cooling the solution in one direction is to form as many as possible the homogeneous silicon crystal. However this will increase the recombination risk thus the efficiency will be lower than monocrystalline silicon cell. The solidified silicon crystal or the ingots will be cut into wafers and undergo phosphorus doping, anti-reflective coating and finally the current collector lines are added which will form the polycrystalline silicon solar cells (Figure 2.3).

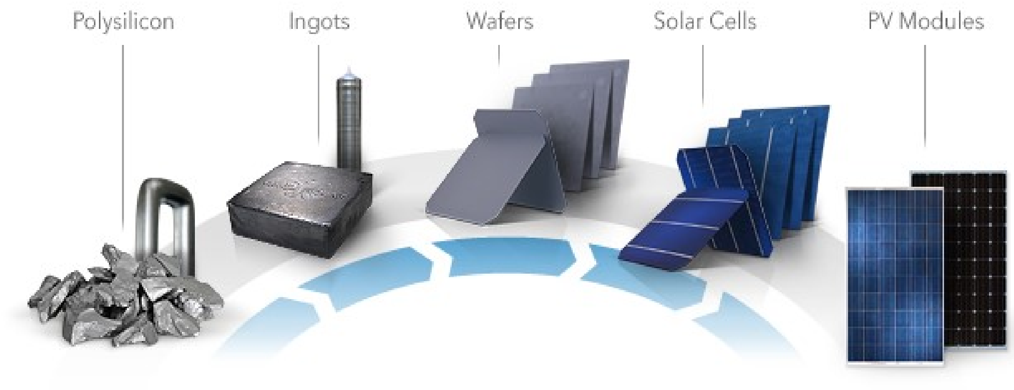

Figure 2.2 Fabrication Process of Polycrystalline Silicon Cell

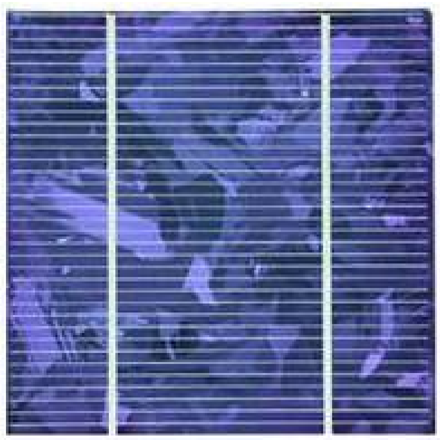

Figure 2.3 Polycrystalline Silicon Cell

Another solar cell technology is called thin-film cell technology (Figure 2.4). It is the second generation of PV solar cell. It is differ from monocrystalline and polycrystalline silicon cells as a thin layers of photoactive semiconductors are laminate to a low-substrate like glass. The common techniques used are vapor deposition, sputter processes and electrolytic bath. The photoactive semiconductor materials used are amorphous silicon, copper indium diselenide (CIS) and cadmium telluride (CdTe). Unlike monocrystalline and polycrystalline cells, thin-film cells are not bounded with standard wafer sizes. Besides that, the connection of thin-film cells are also different. Thin-film cells are electrically separated and interconnected during the fabrication while the other two are soldered together from cell-to-cell. It has more flexible structure and lighter in weight. The typical thin-film cell available is amorphous cells. The common application of amorphous cell can be observed in calculators, watches and etc.

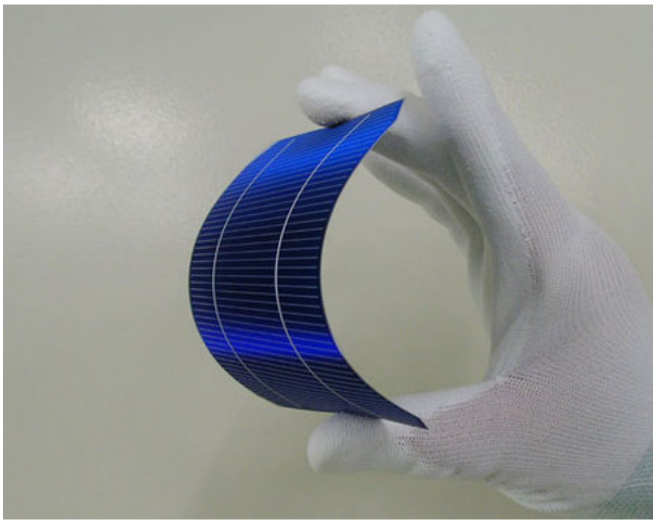

Figure 2.4 Thin-film Cell Technology

Table 2.1 Comparison of Different PV Cell Technology

	Monocrystalline	Polycrystalline	Thin-Film (amorphous cell)
Efficiency	15%-18.8 %	13%-17.1%	5%-7%
Thickness	0.14-0.3mm	0.16-0.24mm	0.3μm
Appearance	Uniform	Crystal with different orientation	Uniform
Colour	Dark blue to black (with AR);	Blue (with AR); Silver grey	Reddish brown to blue

	Grey (without AR)	(without AR)	

Table 2.1 show a few comparison between the 3 types of solar cell technologies. In term of efficiency, the monocrystalline silicon cell has the highest efficiency follow by the polycrystalline silicon cell and the thin-film cell has the lowest efficiency. Monocrystalline silicon cell is the thickest among them. As shown in Figure 2.4 above, the polycrystalline silicon cell appear to have crystal with different orientation on its surface while the other 2 have uniform crystal spreading across the surface. The colour of monocrystalline silicon cell is darker compared to the other two solar cells.

2.3 Building Integrated Photovoltaics (BIPV)

It is a fact that the initial cost of PV installation is very high. Based on the data provided by FiTSolarPlan Malaysia, one time cost of a minimum entry package for Malaysian to install a 5kWp PV system in their house is RM52500, the break-even point will take 6.2 years to achieve. The one time cost of maximum residential package for 12kWp Solar system is RM105000 and need 5.2 years to achieve break-even point (FiTSolarPlan, 2014)(Figure 2.5). The data show that the installation fees of solar system is high and it takes more than 5 years to gain profit. Therefore, many people are unaffordable to install PV system.

Figure 2.5 Estimate Cost, Earning and ROI

The high initial cost of solar PV system make the building integrated photovoltaic (BIPV) system stand out from the conventional solar PV systems. The concept of BIPV is contrasting to the conventional solar PV system. BIPV take over the role of regular building material which means that BIPV is integrated into building texture rather than just stack onto the building like the conventional solar PV system. This give the advantages to the BIPV to offset the high initial cost by reducing the building raw material and money spend on hiring labour. Hence BIPV is one of the rapid growing sections in the PV industry. Typical applications of BIPV around the world are flat roofs, pitched roofs, façade and glazing.

Figure 2.6 BIPV Window

Many application of BIPV are using crystalline silicon solar cell as the material. However, the crystalline silicon solar cells such solar window shown in Figure 2.6 are aesthetically not good, having medium power output due to not adjustable and poor daylighting effect because too much sunlight being blocked by the non-transparent solar cells. The aesthetic problems can be solved by using the semi-transparent thin film cell such as the amorphous silicon and copper indium diselenide solar cells that have different colours. In Cristina paper, she uses Comfort Fanger Approach and Adaptive Comfort Approach to study the human confort when using semi-transparent BIPV. Her study showed that semi-transparent BIPV is better than crystalline silicon cell to keep indoor in comfort condition. (Cristina S. Polo López, 2013). However, the semi-transparent solar cells have very low efficiency. Therefore, the typical problems to the existing BIPV are low output in Malaysia and low efficiency if want to maintained good lighting and aesthetic issue.

2.4 Working Principle

In exchange for electrical energy from the light, semiconductor material such as silicon, gallium arsenide, cadmium telluride or copper indium diselenide are used in the solar cells (Deutsche Gesellschaft für Sonnenenergie, 2013). Crystalline solar cell is the most commonly used solar cell and the crucial material of it is silicon.

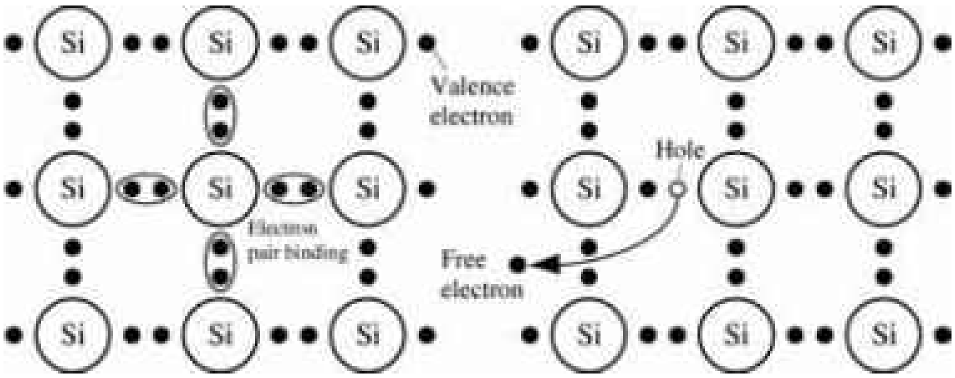

Figure 2.7 Crystal Structure of Silicon and Intrinsic Conductivity

Crystalline silicon cells are taken as an example for explanation. High purity and quality of silicon is required to make solar cells. From the Figure 2.7 above, a stable crystal lattice is form by connecting silicon atoms. In order for the silicon to achieve its stable noble gas configuration with eight outer electrons, it need to have four neighbour to form electron bond pair. Electron bond can be break down by heat and light. When the bond are broke, a free electron will move around the atoms and leave a hole in the crystal lattice as shown in figure above. This electron excitation process is known as intrinsic conductivity.

At this stage, the intrinsic conductivity of the silicon lattice cannot be used to generate electricity although there are electrons moved freely. Just like other intrinsic semiconductor, to grant the crystalline silicon ability to generate electricity, impurity atoms must be added to the crystal lattice. These doping atoms are phosphorus and boron (see Figure 2.8). Phosphorus has one electron more and boron has one electron less compared to silicon.

Doping of phosphorus is referred to n-doped. In this case, there is extra electron for each phosphorus atom in the silicon crystal lattice. These electron will move freely around in the crystal lattice and thus carry the electric charge around. P-doped is referred to boron doping. Unlike n-doped with surplus electron, n-doped will have a hole for each boron atom that bond with the silicon atoms. The electrons from neighbouring silicon atoms will eventually filled up the holes of boron while creating holes in other places. This conduction technique by doping the impurity atoms is known as extrinsic conduction and is completed under high temperature.

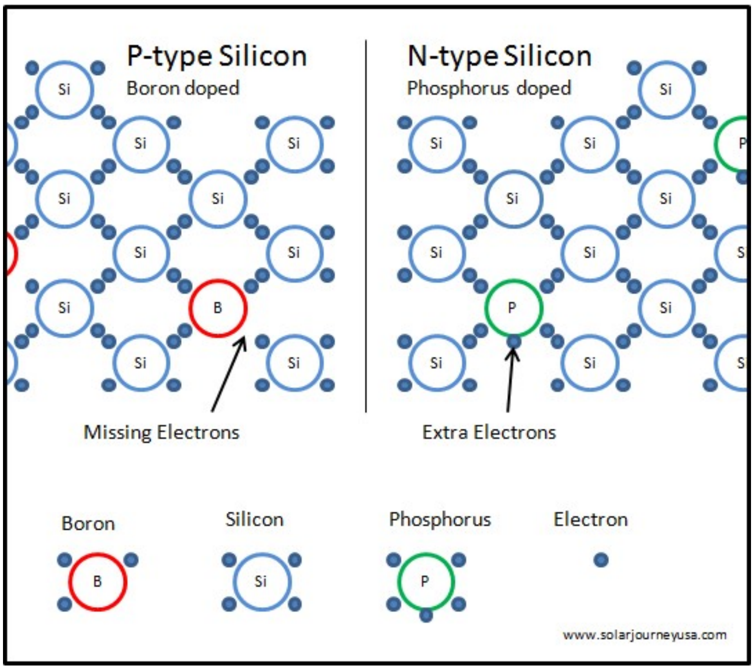

Figure 2.8 Crystalline Structure of Silicon

N-type semiconductor layer have electrons that carry negative charges while in p-type semiconductor layer, the holes carry positive charges. These charges are free and mobile so they can carry electrical current around. When n-doped and p-doped of silicon layers are brought close to each other, a thin layer of p-n junction will be formed (See Figure 2.8). At this zone, the extra electron phosphorus from the n-type semiconductor layer will diffuse into the p-type semiconductor layer and combine with the holes leaving behind static positive charges on the atoms. The holes from the p-type semiconductor layer will diffuse into the n-type semiconductor layer and combine with the electron leaving behind static negative charges on the atoms. The combination of holes and electrons will create neutral zone as shown in Figure 2.8 below. This process creates a zone with free charge carries known as the space charge region or depletion zone near the p-n junction. The movement of the free charge carries will produced an electrical field at the depletion zone.

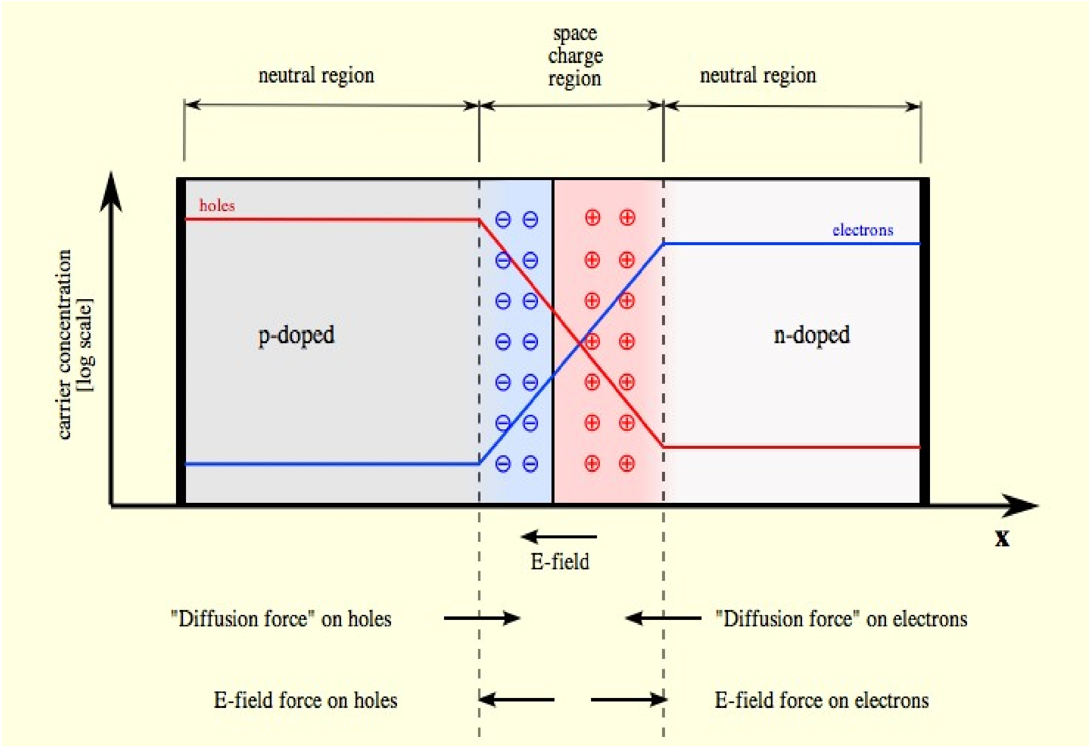

Figure 2.9 Space Charge Region

When the solar cell is put under the sun, photons are absorbed by the electrons. The electrons will gain enough energy to break the electron bonds, creating extra free moving electrons and holes. As the positive charges will attract negative charges, the extra electrons will be drawn into n-region by electric field while the extra holes will flow into p-region. This process is known as photovoltaic effect. Potential different or voltage is formed when the positive and negative charges are separated at the p-n junction. By connecting the solar cell to an external load, the electrons and holes will travel through the circuit and recombine, creating an electric current that can be utilised. The whole process will be repeated.

Figure 2.9 shows the anatomy of a solar panel. The layer that facing the sun is always the n-type semiconductor layer. In order to harvest power from the solar panel, metallic contacts need to be placed at the front at back of the solar panel. In order to let as much sun light to pass through, the metallic contact at front part of the solar panel usually aligned in the form of thin grid or tree structure. Furthermore, a thin layer of anti-reflective coating (Figure 2.10) is deposited onto the front surface to minimize the light reflection. The recombination process discuss before, unavoidable reflection and shading cause by the front metallic contact will contribute to the losses. The energy balance of solar cell is shown in Table 2.2.

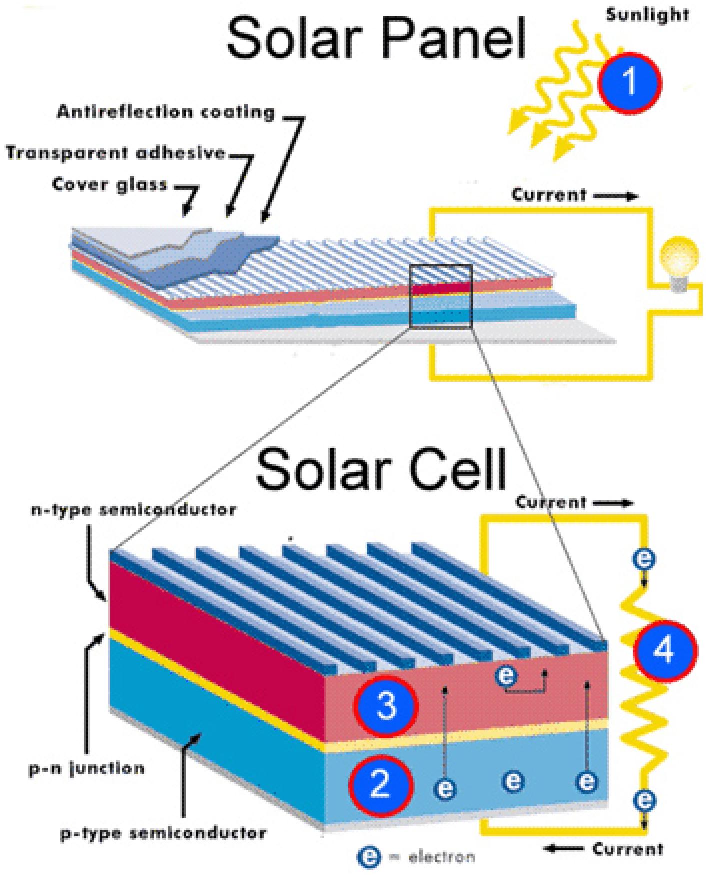

Figure 2.10 Anatomy of a Solar Panel

Table 2.2 Energy Balance of Crystalline Solar Cell (Deutsche Gesellschaft für Sonnenenergie, 2013)

Incident solar energy	100%
Reflection and shading cause by front contact	-3%
Low photon energy in long-wave radiation	-22%
Excessive photo energy in short-wave radiation	-30%
Recombination losses	-8.5%
Potential gradient within the cell	-20%
Ohmic losses	-0.5%
Usable electrical energy	16%

2.5 Electrical Characteristic

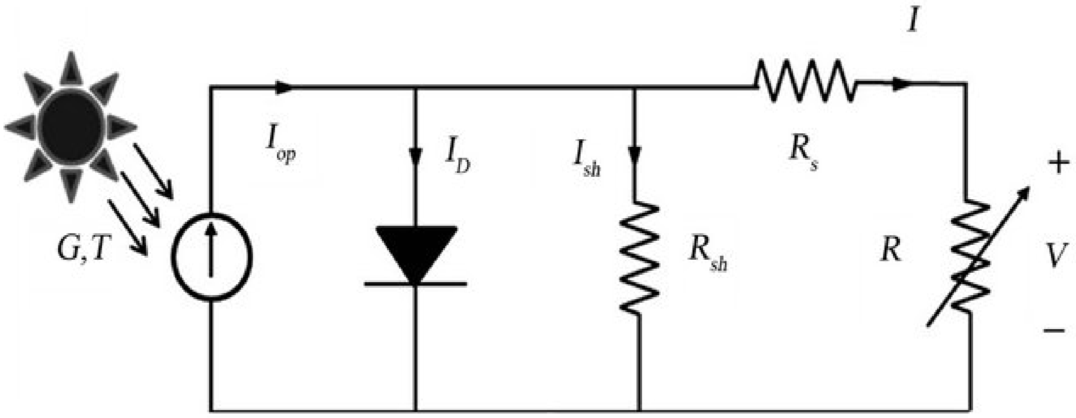

Figure 2.11 Solar Cell Equivalent Circuit (Nur Mohammad, 2013)

The working principle of a solar cell is identical to a silicon diode which means that they share the same electrical properties. The equivalent circuit of the solar cell can be portray by a diode circuit as shown in Figure 2.11 above. The strength of the photoelectric current I_{op} is depending to the irradiance level. When the charge carries are dislodge from the semiconductor to the metallic contact, a potential different will occur. This can be describe by series resistor R_s in the circuit above. The function of the series resistor is to allow calculation of current and voltage characteristic curve of a solar cells at different level of irradiance and temperature.

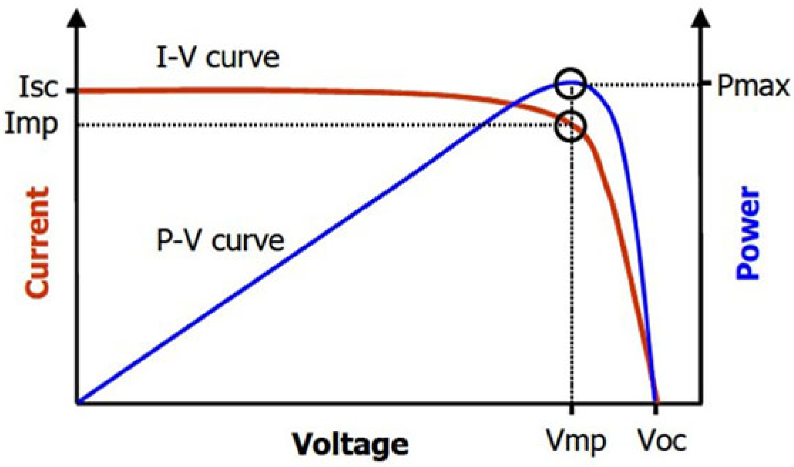

Figure 2.12 Characteristic Curve (Devis, 2015)

From the I-V curve shown in Figure 2.12, maximum power point (MPP) of the solar cell can be obtained. MPP is the point on a I-V curve that has the highest value of the product of its corresponding voltage and current, in short, it is the highest power output available (TeachEngineering, 2016). P_{max} is the maximum power point, I_{mp} and V_{mp} are the current and voltage at maximum power point (Devis, 2015).

2.6 Factors Affecting the Power Output

The conventional BIPV windows are using high efficiency non-transparent C-Si solar cells. The non-transparent solar cells limited the sunlight passing through the window and they made the building aesthetically unpleasant (Figure 2.13). Semi-transparent thin film solar cells are able to deal with these 2 problems but pay off very low efficiency for semi-transparent effect. The efficiency of thin film solar cells only 5-7% while the efficiency of C-Si solar cells up to 20%.

Figure 2.13 Limits the Daylight and Aesthetically Unpleasant

Secondly, the power output is affected by the sun altitude in Malaysia. Referring to Figure 2.14 (a) and Figure 2.14 (b), the sun altitude angle, α, in tropics is much higher than the non-tropics. Therefore, when the BIPV windows are installed vertically in Malaysia, the effective collecting area is less as illustrated in Figure 2.15. The effective collecting can be increased by tilting the solar cells upward.

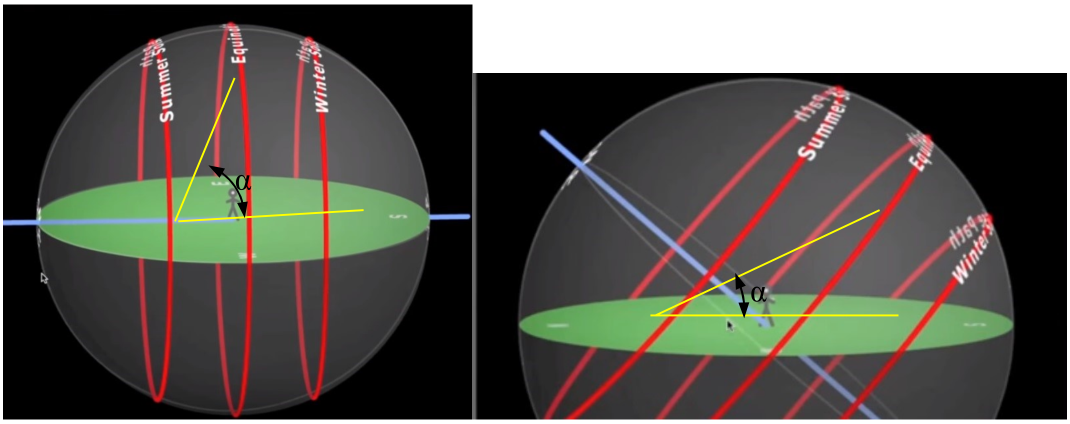

Figure 2.14 Sun Trajectories in (a) Tropics and (b) Non-tropics

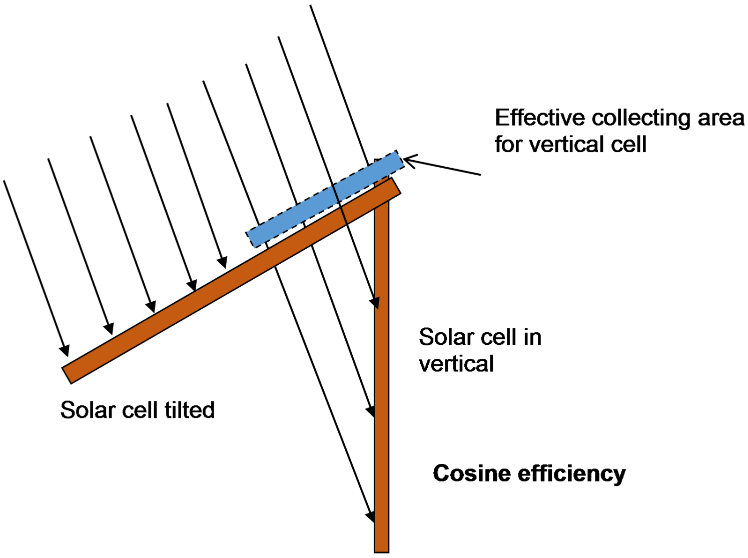

Figure 2.15 Cosine Efficiency

Another factor that will affect the power output is shading. One of the shading is known as temporary shading such as due to birds, falling leaves, dirt and haze. Presence of these elements will contribute random shading that can lower down the solar panels' output. Fortunately, these elements can be removed to restore the power output. Shading between the blades of the solar blind also reduces the amount of electricity generated. These mutual shading, for example, the upper piece of the solar panel will shade the lower piece if all the blades of the blind are installed with solar panels.

2.7 Types of Window Blinds and Shades

Sara Freitas and M. C. Brito of University London have done research on different building façade layouts that give the maximum solar photovoltaic yield. The result can be used as a reference for this project. In this paper, they compared the performance of flat façade, horizontal louvers, vertical louvers, ellipsoids and hexagonal pyramid shape façade. The façade that has the best performance is the horizontal tilted sunscreens (Sara Freutas, 2015). Therefore, the horizontal type of window blinds is included as the fundamental design for solar blind.

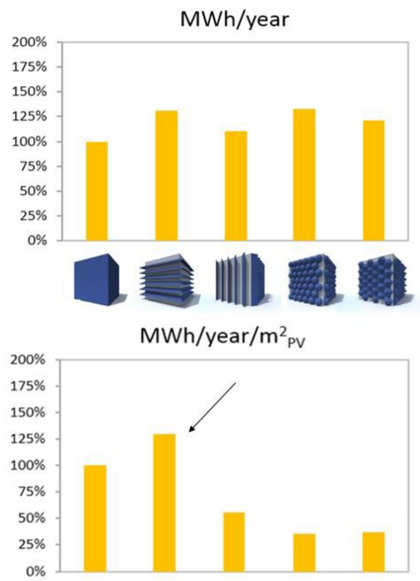

Figure 2.16 Comparison between 5 Types of Facade (Sara Freutas, 2015)

There are a few types of window blinds available in the markets. Three types of window blinds which are horizontally designed will be used as study material in this review, they are the cellular shade, faux wood blind and roman shades. The result of comparison is shown in table below (BaliBlinds, n.d.). The merits and weak point of each blinds are determine to get a good direction for the solar blind design. The table show that the cellular blinds have the best performance and can have different level of light control. Three of them can be control by using cord as standard method while the cellular blinds and Roman shades can also be controlled using motor.

The faux wood blinds can have complete privacy while the other two have moderate level of privacy. In term of cost, the Roman shades is the most expensive compared to the other 2. By comparing the working mechanism, the faux wood blind is the most suitable. Finally, the faux wooden blinds is chose to be the basic design of the solar blind as it meets the requirement of the solar blind. Modification is done to cater the requirement of a solar blind.

Table 2.3 Comparison of Different Window Blinds (BaliBlinds, n.d.)

Cost (based on average window size of 48" x 60")			
	Cellular Shades	Faux Wood blinds	Roman shades
Price	$$	$$	$$$-$$$$
Energy Efficiency			
Energy Efficiency	Best	Better	Better
Privacy			
Privacy Levels	Moderate to Complete	Complete	Moderate - Complete
Light Control			
Light Control Levels	Sheer, Light Filtering, Room Darkening, Blackout	Room Darkening	Light Filtering, Room Darkening, Blackout
Product Type			
Material	Fabric	PVC or Engineered Polymer	Fabric
	Neutral backing on select fabrics		Neutral backing on select fabrics or with privacy liners
Size Specifications (based on standard control type)			
Height: Maximum	144"	120"	86"
Height: Minimum	9"	10"	18"

Width: Maximum for Single Blinds/Shades	96"	96"	70"
Width: Maximum for Multiple Blinds/Shades on One Headrail	192"	120"	192"
Width: Minimum	9 3/8"	7 1/2"	16"
Minimum Window Casing Depth for Inside Mount	3/4"	3/4"	3/4"
Design Options			
Styles	3/4" or 3/8" Single Cell	2", 2 1/2" Slat	Custom Tailored, Classic
	3/8" Double Cell	2 1/2" Double Bevel Composite	Looped, Flat, Seamless
Finishing Touches	Wood Cornice	Paints, Stains, Cloth Tapes	Bead Trim, Braid Trim, Tassels
		Valance (standard), Wood Cornice	Scalloped Edges, Fabric Cut Yardage, Valance,
			Fabric-wrapped Cornice, Wood Cornice
Control Types	Cord (standard)	Cord (standard)	Cord (standard)
	Cordless		Cordless
	Continuous-loop Lift		Continuous-loop Lift
	Motorization		Motorization
Blind/Shade Types	Bottom Up/Top Down (Cord and Cordless)	Bay or Corner Window, Cut-outs	Bottom Up/Top Down (Cord)
	Top Down Only (Continuous-loop Lift)	Multiple Blinds/Shades on One Headrail	Bay or Corner Window
	Special Shapes (Angled, Arches, Geometric)		Multiple Blinds/Shades on One Headrail
	Bay or Corner Window, Cut-outs, Skylights		
	Multiple Blinds/Shades on One Headrail		

Special Features			
Safety	Safety Cord Cleats	Safety Cord Cleats	Safety Cord Cleats
	Cordless, Continuous-loop Lift		Cordless-loop Lift
	Motorization		
Green By Nature ™	Energy Efficient Solutions	NA	NA
Cleaning/Maintenance	Light Dust/Vacuum	Light Dusting	Light Vacuuming
	Spot Clean	Wipes Clean	Spot Removal

CHAPTER 3

METHODOLOGY

3.1 Introduction

In practical, the solar blinds were designed such that many small yet tilted able solar panels were connected to form blind like strips and attached to the existing window blinds. These solar blinds are suitable for retrofit cases. For example, they can be installed in high-rise building such as in UTAR Sungai Long Campus which the windows have already been installed or any other high rise buildings. These solar blinds were designed such that the angle can be tilted according to the customer preferences. On the other hand, they can be pre-tilted to the optimum angle for the whole year or with sun-tracking mechanism. The output of solar blinds can be optimized for maximum electricity yield, acceptable daylighting effect or the lowest heat penetration effect.

3.2 Research Method and Strategy

Window blinds or window shades are widely used around the world as they can choose to partially shade for filtering off the strong sunlight or fully shade to have privacy protection as well as total blocking of sunlight via adjusting the angles of the blinds and shades. Therefore, the design of the solar blinds must preserve the original concept and function of a common window blind and yet have minimum impact on their performance as solar blinds. For example, the mutual shading between the blades of the common window blinds is not a concern as they are designed in such way to block the sunlight. On the other hand, this mutual shading will affect the performance of the solar blinds because it decreases the power output as the solar panels are being shaded by each other. Therefore, the solar blinds must be carefully designed so that the solar panels will not shade among themselves while preserving the function as normal window blinds. Several types of window blinds are being used to compare in term of mechanical construction, shading effect, appearance and etc. The merits of these window blinds are adopted as the reference for the solar blinds design.

As mentioned previously, the main cause of low output in Malaysia is due to the cosine effect as the position of the sun in Malaysia is in high altitude most of the time thus cause large sunray incident angle to the common vertical placed solar cells. In this project, the solar blinds' angle are adjustable. This means that the solar blinds can gain relatively more output in Malaysia than the conventional vertical placed BIPV windows. Other problems occurred when using the high-efficiency non-transparent C-Si solar panels in the conventional BIPV windows are poor daylighting effect and aesthetically unpleasant. Although the semi-transparent thin film cells can tackle these issues, the power output is sacrificed as the efficiency of the semi-transparent thin film cells is lower than C-Si solar cells. The solar blinds are designed such a way that it uses high-efficiency C-Si solar cells but will not give rise to the aesthetic issue while the daylighting effect can be adjusted according to the user preferences.

At the beginning, all the necessary information were collected. For example, different types of window blinds were studied so that enough inspiration to come out with a novel design that was suitable for solar blinds. Different variety of solar panels in the market were studied to single out the appropriate one. The design of the solar blinds was drafted so that the necessary material can be purchase.

In this project, a 107x24mm, 0.2W monocrystalline solar panel was chosen as the material for solar blinds after comparing the price and size of existing solar panel on the market. The shading on the window blinds' blades cause by the sun azimuth angle, sun elevation angle and blade's tilting angle are carefully studied to ensure there are enough gaping between them for maximum electricity yield. The final product is an angle adjustable solar blind which does not affect the daylighting effect, causing an aesthetic problem and has enough gaping among the blades to minimize the mutual shading.

3.3 Apparatus and Material

1. Polycrystalline silicon cells
2. Horizontal type window blind
3. Wood
4. Rollers
5. Digital multimeter
6. Thermopile pyranometer
7. Protractor
8. Compass
9. Tabbing wire

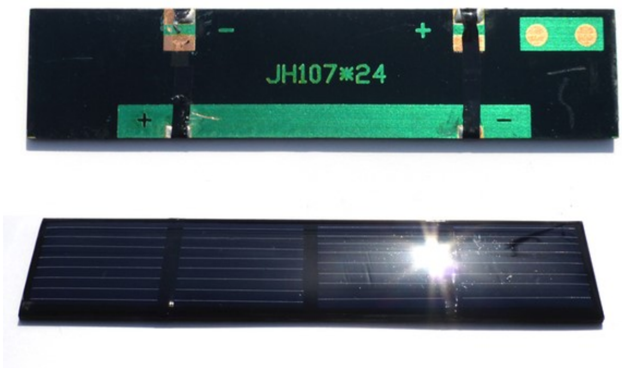

Figure 3.1 C-Si Solar Cell

Monocrystalline silicon cells were chosen for this project. The solar cell was 107 mm in length and 24 mm in width. The given rating of the solar cells was 5V, 40mA which capable of producing 0.2W. They were rectangular in size to suit the design of solar blinds. This solar cell were bought from Taobao.com which is a popular China-based online shopping platform. Purchasing solar cells from Taobao.com was much cheaper compared to local component shops as most of the solar cells are manufactured in China. A piece of solar cell cost RM1.90 including shipping fees. A piece of solar cell with the same rating can easily cost more than RM5.00 if purchase from local component shops.

A digital multimeter was used to test the voltage and current throughout the project. Digital multimeter was favoured over analogue multimeter because it had a more accurate result and the parallax error can be avoided. Thermopile pyranometer was used to measure the irradiance. Pyranometer better than irradiance sensor because pyranometer gave more accurate value slower compared to the irradiance sensor.

3.4 Prototype Design

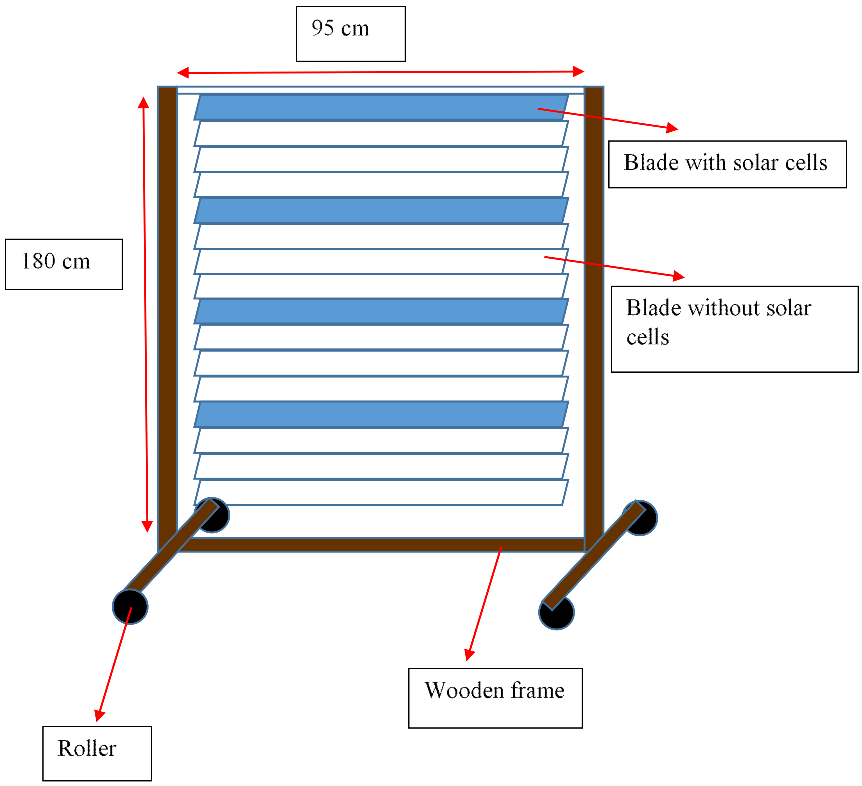

Figure 3.2 Prototype Design

Figure 3.2 above illustrated the prototype design. A wooden frame was built to act as a window frame so that the solar blind can fit on it. There were 4 rollers installed at the bottom to move the prototype effortlessly during data collection. The length of the whole structure is 180cm in height while the width is 95 cm. The figure above illustrated the solar blind that was placed in the normal way. One of the problem encounter when designing solar blind was mutual shading among the blinds. The solution for this problem was, attaching the solar panels alternatively as shown in Figure 3.2 and maintain some gaps between them as illustrated in Figure 3.3 below.

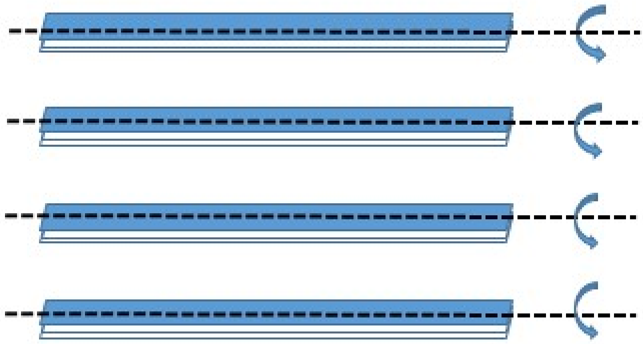

Figure 3.3 Gaps to Avoid Mutual Shading

In order to give some gaping between each strip of solar panels, those blades without solar panels had to be kept underneath those with solar panels. This can be achieved by introducing a new mechanism to the design. This new mechanism consists of 2 parts. The first part has a string that penetrates through all the blinds. This string is used to pull up those blades without solar panels attached to them assisted by additional knots as shown in Figure 3.6. With the help of a very simple knot, those blades without solar panels can be pull up easily. These knots are located beneath each of the last blades without the solar panels.

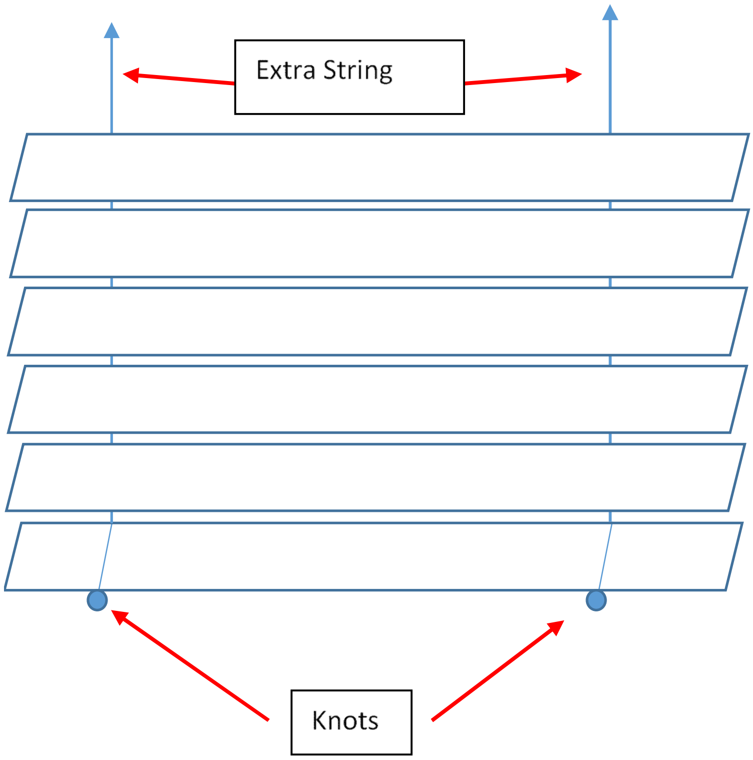

Figure 3.4 Blinds Detail

As shown in Figure 3.5, the normal window blinds hold the each of the blades by having two strings in horizontal. This is to limit the movement of the blinds while maintaining some gap in between them for sunlight to pass through. These 2 horizontal strings also responsible in angle adjusting of a blind. However, in this solar blinds design, the string had to be cut off so that the blinds can be pulled up without any resistance. Therefore an alternative method is needed to preserve those function. This come to the role of 2 part of the new mechanism. 2 Red circles in Figure 3.6 show the new strings that use to maintain the distance among the blinds. In order to tilt of angle, these strings are fixed to the blinds that have solar panels. On the other hand, the 2 original horizontal strings at the blinds that have solar panels attached remained uncut. Hence when the angle is tilted, they can also drive the angle of those without solar panels.

Figure 3.5 Limitation

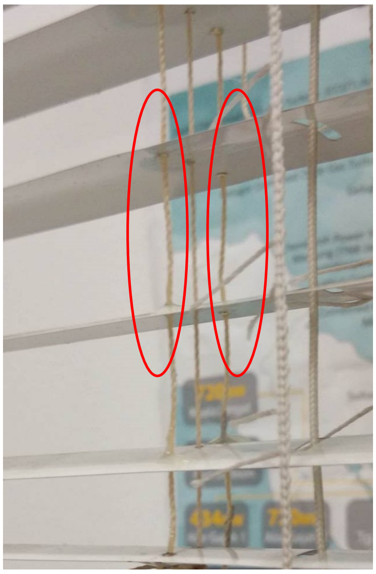

Figure 3.6 Strings to Maintain the Gap

This innovation design can let the consumer change the function of the solar blind according to his requirement. For example, if the consumer needs more sunlight to enter his room, he can pull up the blinds that without solar panels. On the other hand, if he looks for lowest heat penetration (as a normal window blind), the electricity yield need to be sacrificed because of the shading between the blinds. According to the calculation of shadow length based on the worst case scenario (section 4.3), total 7 blades need to bypass for maximum electricity yield.

3.5 Circuitry Design

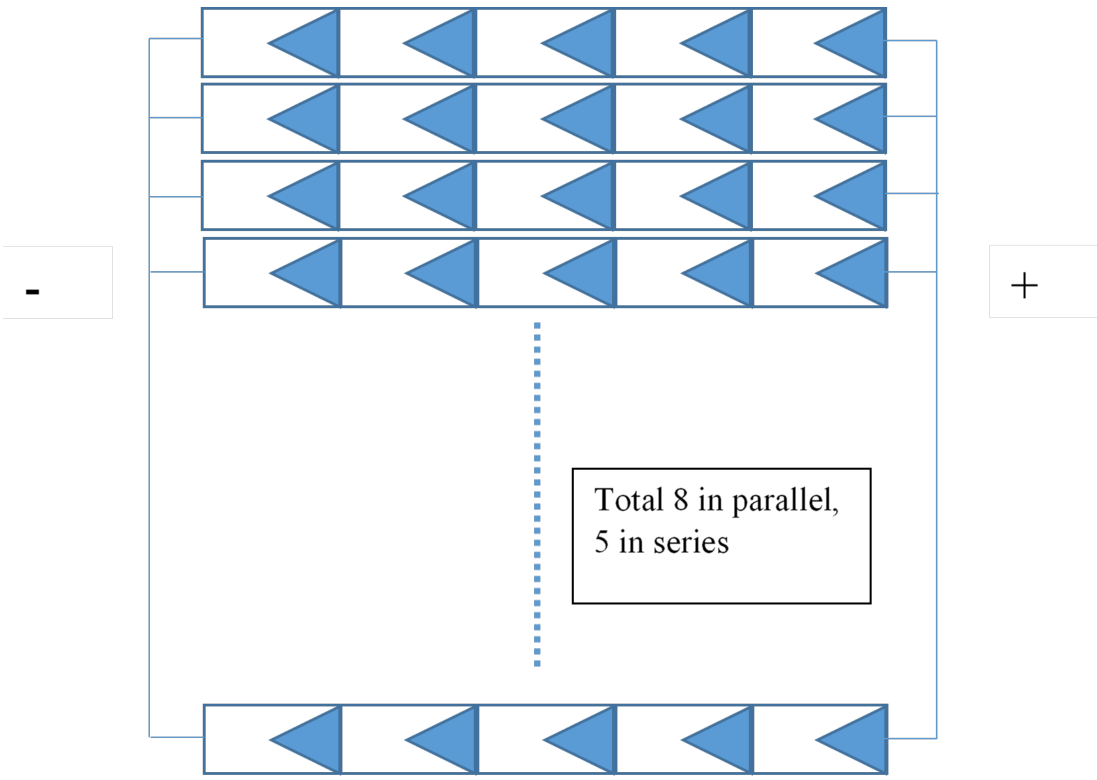

Figure 3.7 Circuitry Detail

The figure above shows the circuitry design of the solar blinder. 5 solar cells will be connected together in series with some spacing to let the string passed through/ Total 8 rows of solar cells will be connected in parallel as shown in the figure above. The solar cells rating for one row can be calculated by using equation 3.1 and 3.2.

$$Voltage = 5 \times V_{rated} \tag{3.1}$$

$$= 5 \times 5V$$

$$= 25V$$

$$Current = I_{rated} \tag{3.2}$$

$$= 0.04A$$

Where,
V_{rated} = open circuit voltage at 1000W/m^2 sun irradiance
I_{rated} = short circuit current at 1000W/m^2 sun irradiance

The solar cell rating given by the manufacturer are V_{rated} = 5V and I_{rated} = 40 mA. However, these values will not be constant due to the irradiance of the sun is inconsistent. The field factor of solar cell was assumed constant. Each series connection will have 5 solar cells connected together producing 25V and 0.04A. By using Power = Voltage*Current, the output power will be 1W for each row. The total output power is 8W since there are 8 rows of connections connected in parallel.

3.6 Experiment Procedure

Before undergoing any wiring of solar panels, a quick test was carried out to categorised the solar panels and also filter out the defects. In this quick test, each solar panels was placed under a light bulb. The categorized was done based on the output voltage. After the quick test, these solar panels were connected using tabbing wire according to the circuitry design.

The performance study of the solar blind was taken place on UTAR Sungai Long Campus rooftop. The solar blind was tilted in a few angles and placed facing the East direction during data collection. All the open circuit voltage and short circuit current were recorded. Different kind of experiments was conducted as listed below.

3.6.1 With Retracting the Blinds without Solar Panels at 30° Tilting Angle

1. The solar blind was set up on top of UTAR rooftop.
2. The solar blind was tilted at fixed angle of 30°.
3. The solar blind was placed facing the East direction.

4. The voltage, current and irradiance values were recorded from 8 a.m. till 5 p.m. using pyranometer and multimeter.
5. Each reading is taken at 15 mins interval.

3.6.2 With Retracting the Blinds without Solar Panels at 60° Tilting Angle

1. The solar blind was set up on top of UTAR rooftop.
2. The solar blind was tilted at fixed angle of 60°.
3. The solar blind was placed facing the East direction.
4. The voltage, current and irradiance values were recorded from 8 a.m. till 5 p.m. using pyranometer and multimeter.
5. Each reading is taken in at mins interval.

3.6.3 With Retracting the Blinds without Solar Panels at 5° Tilting Angle

1. The solar blind was set up on top of UTAR rooftop.
2. The solar blind was tilted at fixed angle of 5°.
3. The solar blind was placed facing the East direction.
4. The voltage, current and irradiance values were recorded from 8 a.m. till 5 p.m. using pyranometer and multimeter.
5. Each reading is taken at 15 mins interval.

3.6.4 With Retracting the Blinds without Solar Panels at 30° Tilting Angle

1. The solar blind was set up on top of UTAR rooftop.
2. The solar blind was tilted at fixed angle of 30°.
3. The solar blind was placed facing the North direction.
4. The voltage, current and irradiance values were recorded from 8 a.m. till 5 p.m. using pyranometer and multimeter.
5. Each reading is taken at 15 mins interval.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter introduced the prototype of this novel solar blind and its various forms. Besides that, the data that had been collected throughout this project was tabulated in this section. All the data was carefully studied and analysed. Finally, the results were discussed and a conclusion was made.

4.2 Prototype Design and Its Various Forms

After a few modifications, the final prototype is shown in Figure 4.1. It comprises 5 pieces of solar panels connected in series by using tabbing wire for each row. Total had 8 rows of blinds with solar panels which were connected in parallel using wires. The original blinds were replaced with aluminium strips and solar panels were attached to the strips. The replacements were done due to original blinds cannot support the weight of solar panels. Left-hand side and right-hand side solar panels have some gaps to the middle one to let the strings passing through the blinds. A wooden frame was built together with two aluminium hollow bar to hold the solar blind at the same time act as a window frame. 4 rollers were installed under the base of this frame for the ease of carrying around. This form of solar blind has the function exactly like a normal window blind. It can be fully opened or closed depends on user preferences. However, the power output in this form is lesser due to the mutual shading effect.

Figure 4.1 First Form of Solar Blind

Figure 4.2 and Figure 4.3 highlighted the innovative design of this solar blind. As shown in the figure, the blinds that without solar panels are able to be pulled up and keep underneath those with solar panels, leaving some gaps between each row of solar panels. Furthermore, the angle of the blind still able to be tilted, promising higher power output for Malaysia sun trajectory. In this form, the solar blinds can supply maximum power output as there are some gaps between solar panels to avoid mutual shading. Besides that, these gaps also allow more daylight to enter thus can cut down the used of indoor lighting. The length of the shadow was calculated based on the worst case scenario. The details of the shading analysis were further discussed in section 4.3.

Figure 4.2 Second Form of Solar Blind

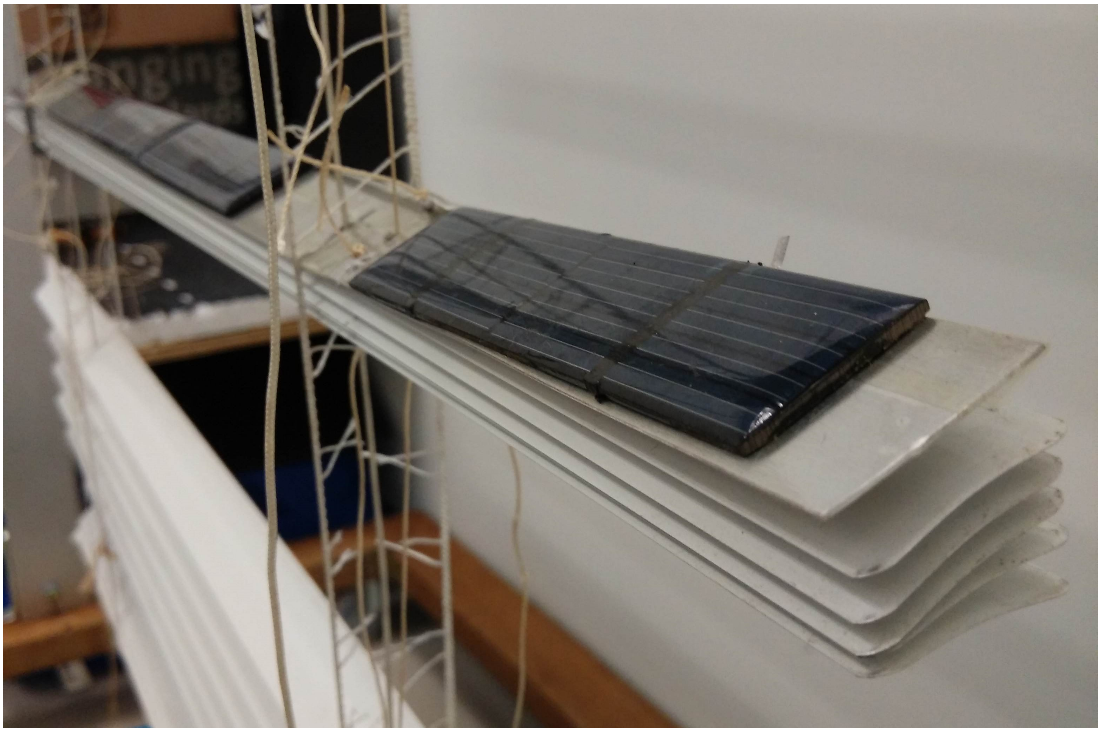

Figure 4.3 Gap to Minimize Mutual Shading

4.3 Shading Analysis

As mentioned in section 4.2, the length of the shadow was calculated based on the illustration below (Figure 4.4 and Figure 4.5):

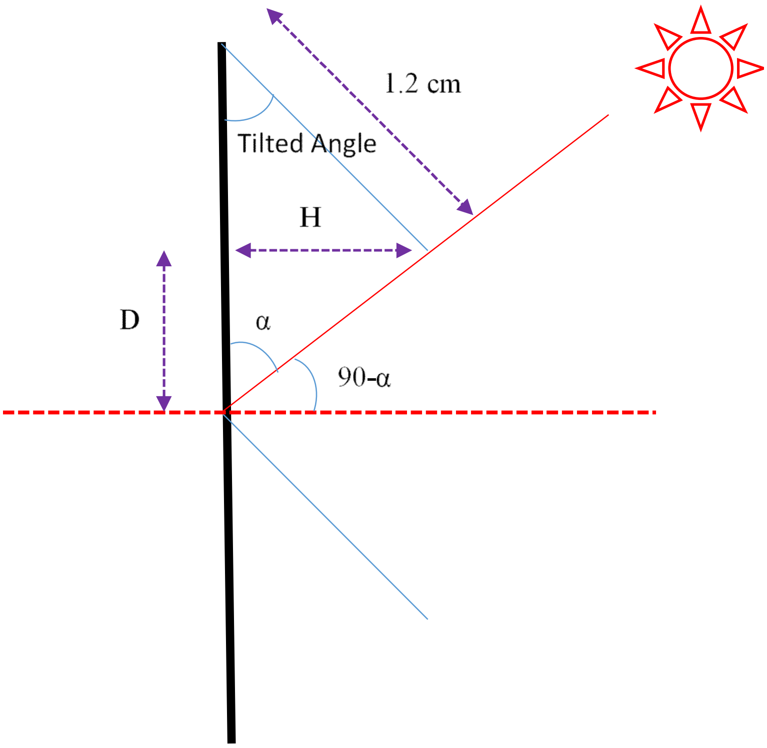

Figure 4.4 Illustration for Shading Analysis

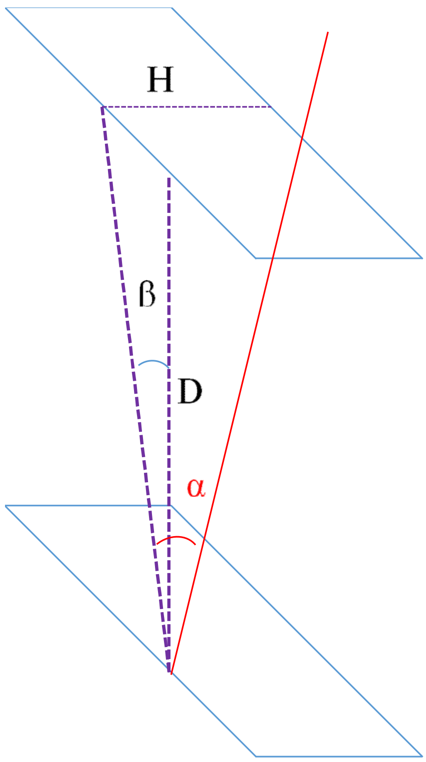

Figure 4.5 Illustration of Solar Blind Affected by Sun Azimuth Angle

The length D is calculated by equation (4.1) below:

$$D = \cos\beta \times L \tag{4.1}$$

Where,

$$L = \frac{H}{\tan(90 - \alpha)}$$

$$H = 1.2\cos(Tilted\ Angle)$$

$$\alpha = \arcsin(sin\,\varphi sin\delta + cos\varphi cos\delta cos\omega)$$

The calculation was calculated using Microsoft Excel and tabulated as shown in tables below. A few assumptions were made:

- Latitude angle, φ = 3 degree
- Sun declination angle, δ = 23 degree
- The hour angle, ω = 60 degree
- Sun altitude angle, α = 85 degree
- Sun Azimuth angle, β = 23.5 degree
- Length of solar panel, lpanel = 1.2cm
- Solar blind facing East direction

Table 4.1 Shadow length

Tilted Angle(°)	H/cm	L/cm	D/cm
0	1.2	13.71606	12.57845
5	1.195434	13.66387	12.53059
10	1.181769	13.50768	12.38736
15	1.159111	13.2487	12.14985
20	1.127631	12.88888	11.81988
25	1.087569	12.43097	11.39995
30	1.03923	11.87846	10.89326
35	0.982982	11.23554	10.30367
40	0.919253	10.50711	9.635654

45	0.848528	9.698721	8.89431
50	0.771345	8.816515	8.085274
55	0.688292	7.86721	7.214705
60	0.6	6.858031	6.289227
65	0.507142	5.796659	5.315884
70	0.410424	4.69117	4.302084
75	0.310583	3.549978	3.255543
80	0.208378	2.381769	2.184226
85	0.104587	1.195434	1.096284
90	7.35E-17	8.4E-16	7.71E-16

Based on the assumption made, the calculated shadow length is the length at worst case scenario. The sun Azimuth angle is assumed to be 23.5 degree where it is a maximum angle for Malaysia. The sun altitude angle is 85 degree. Sun altitude angles that more than 85 degrees are not practical as the shadow length is too large. Based on the calculations, the maximum shadow length is 12.6 cm. However, during the design, the gaps are maintained at 16 cm. This can be explained by referring Figure 4.2. As shown in Figure 4.2, when all the blinds without solar panels were kept beneath, they occupied some space which approximates 4 cm. Hence approximate 16 cm of gap was needed. One strip of a blind is 2.4 cm in width. Therefore, to achieve 16 cm gap distance, total need to bypass 7 strips. Following these calculations, 8 rows of solar panels can be installed in this solar blinds.

4.4 Tilted 30 Degree Facing East

The window blind was tilted to 30 degree, facing East direction. The data collected from 8 a.m. to 5 p.m. Date: 6-8-2016 and 13-8-2016.

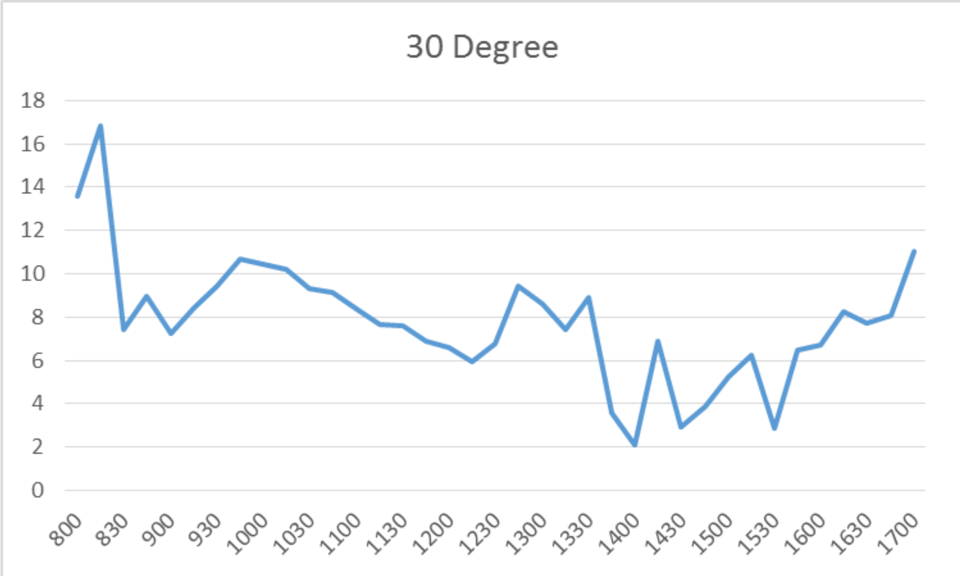

Figure 4.6 Power per 1000W/m^2 vs Time (6-8-2016)

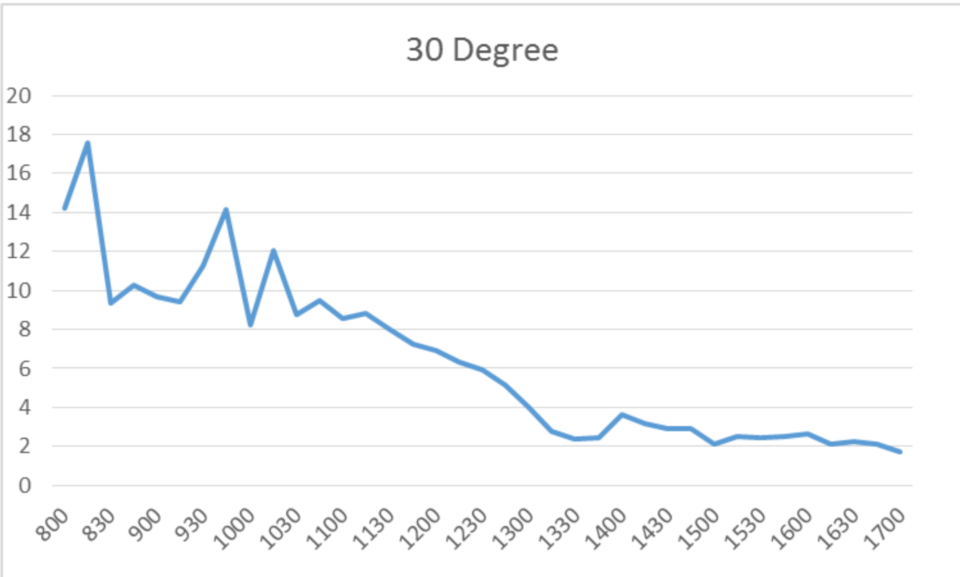

Figure 4.7 Power per 1000W/m^2 vs Time (13-8-2016)

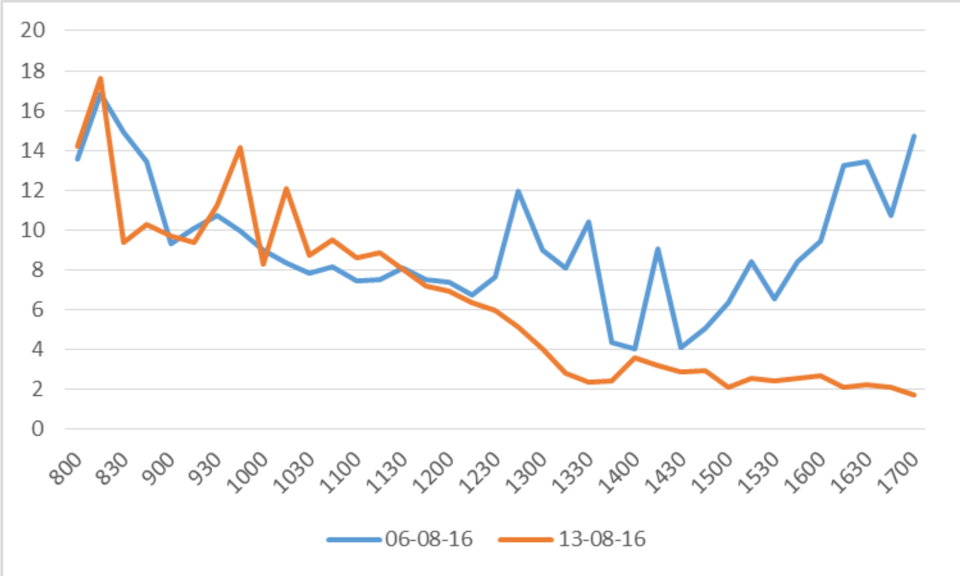

Figure 4.8 Data Comparison between Two Days

4.5 Tilted 60 Degree Facing East

The window blind was tilted to 30 degree, facing East direction. The data collected from 8 a.m. to 5 p.m. Date: 3-8-2016, 11-8-2016, 12-8-2016.

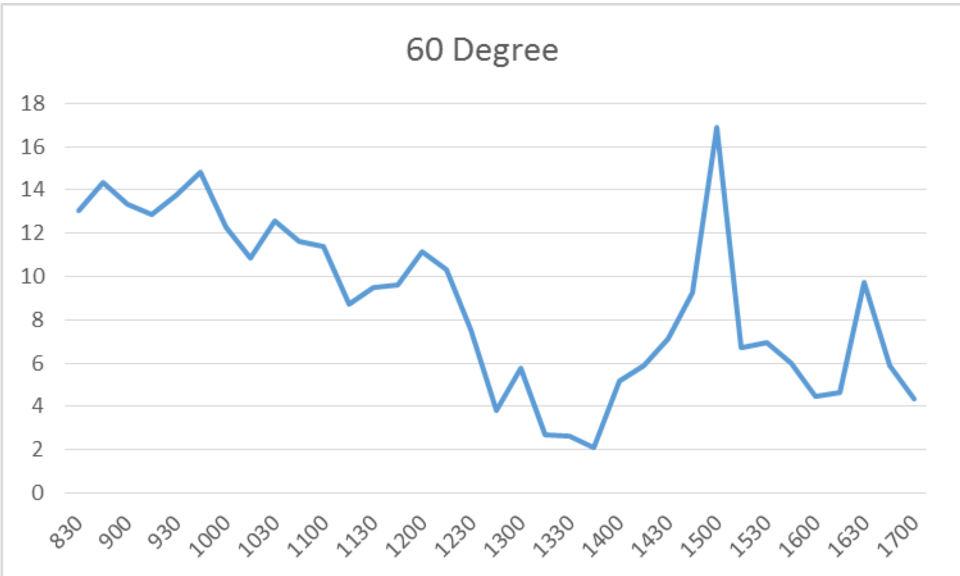

Figure 4.9 Power per 1000W/m^2 vs Time (3-8-2016)

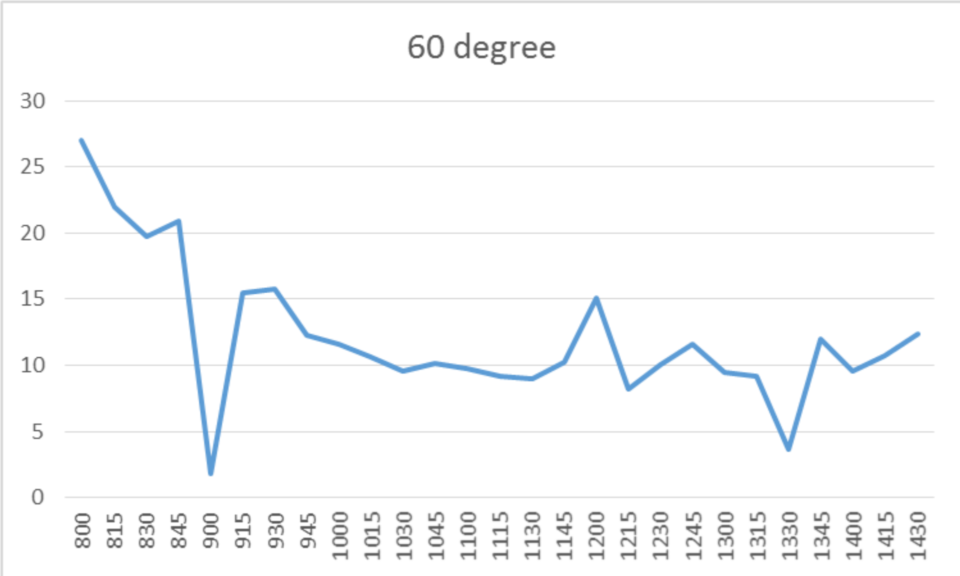

Figure 4.10 Power per 1000W/m² vs Time (11-8-2016)

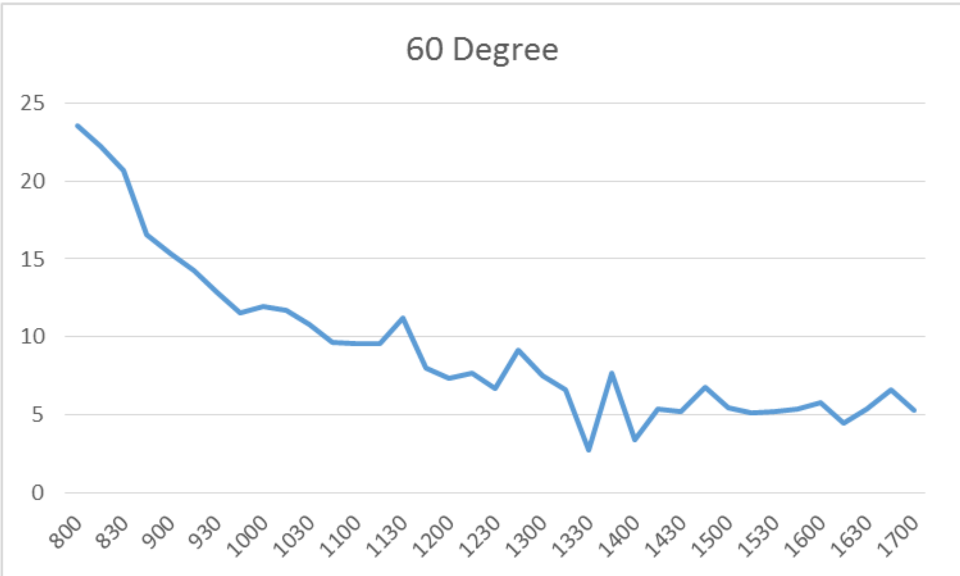

Figure 4.11 Power per 1000W/m² vs Time (12-8-2016)

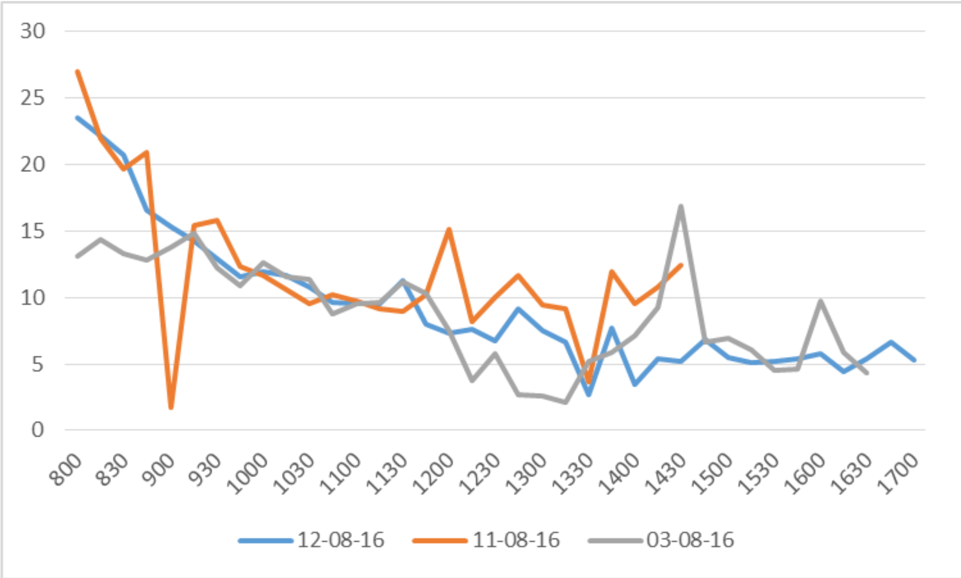

Figure 4.12 Data Comparison for 3 Days

4.6 Tilted 5 Degree Facing East

The window blind was tilted to 5 degree, facing East direction. This degree was the closest to the conventional BIPV window placed in vertical mean. The data collected from 8 a.m. to 5 p.m. Date: 10-8-2016.

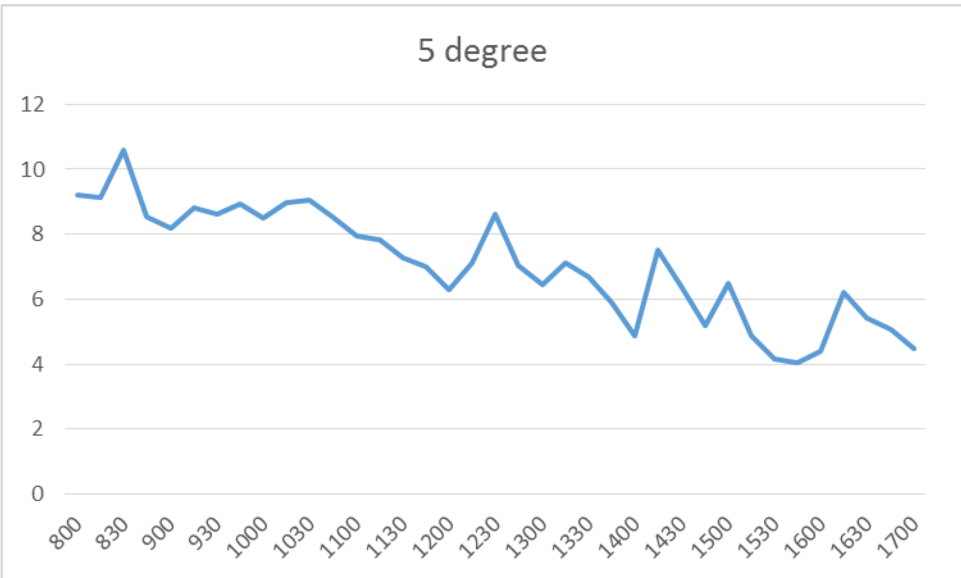

Figure 4.13 Power per 1000W/m^2 vs Time (10-8-2016)

4.7 Performance Comparison between 5, 30 and 60 Degree Facing East

The performance of solar blind tilted in 5, 30 and 60 degree was tabulated in a graph below. The best performance of solar blinds at each tilting angles were compared. The graph was analysed and the result was discussed.

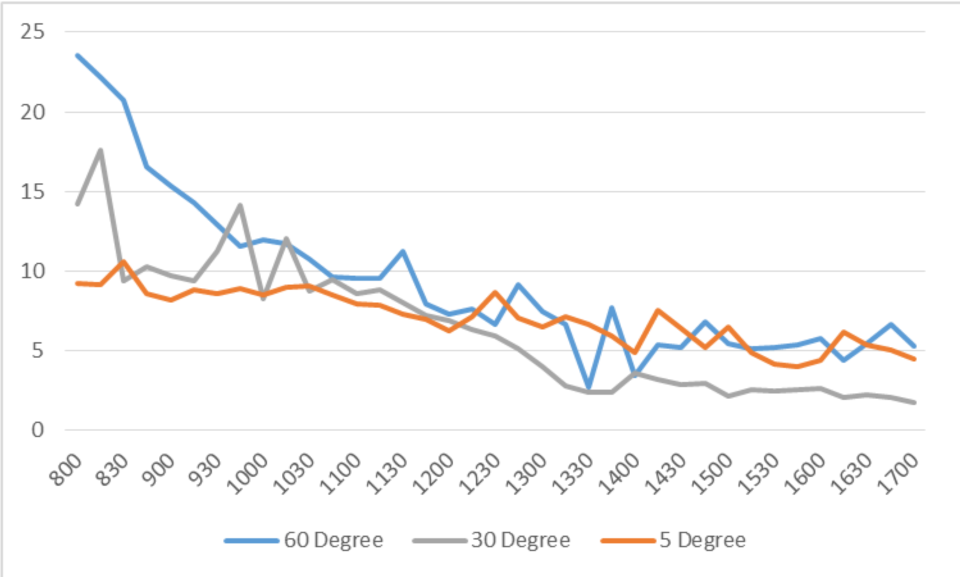

Figure 4.14 Performance Comparison of 3 Different Tilting Angles

4.8 Tilted 30 Degree Facing North

The solar blind was placed facing North direction to study the performance. During the data collection, North direction was preferred than south as the sun Azimuth angle was toward the south. The data was collected from 9 a.m. to 5 p.m. Date 23-8-2016.

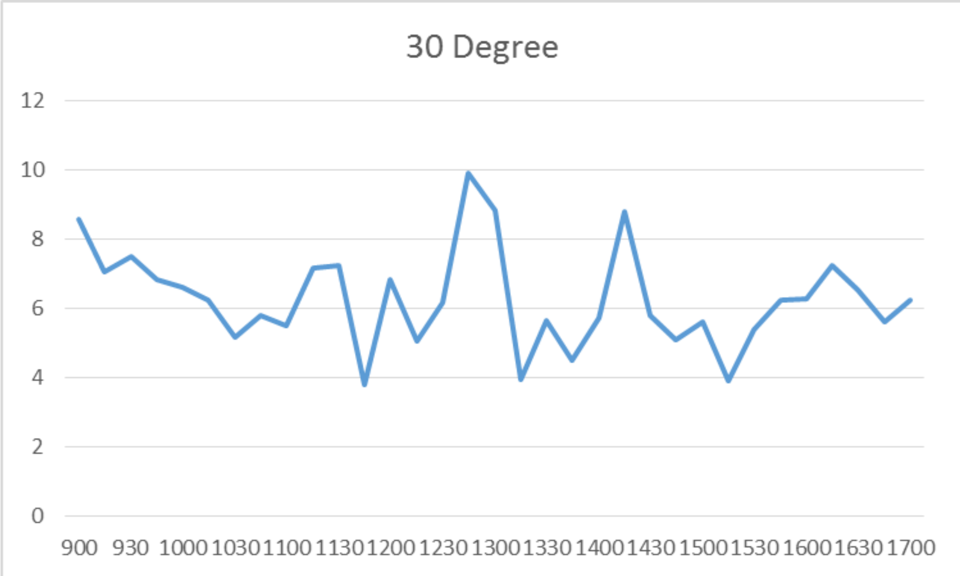

Figure 4.15 Power per 1000W/m^2 vs Time (23-8-2016)

4.9 Comparing East and North Direction for 30 Degree Tilting Angle

The data collected by tilting the solar blind at 30 degree facing East and North Direction was plotted into a graph for comparison.

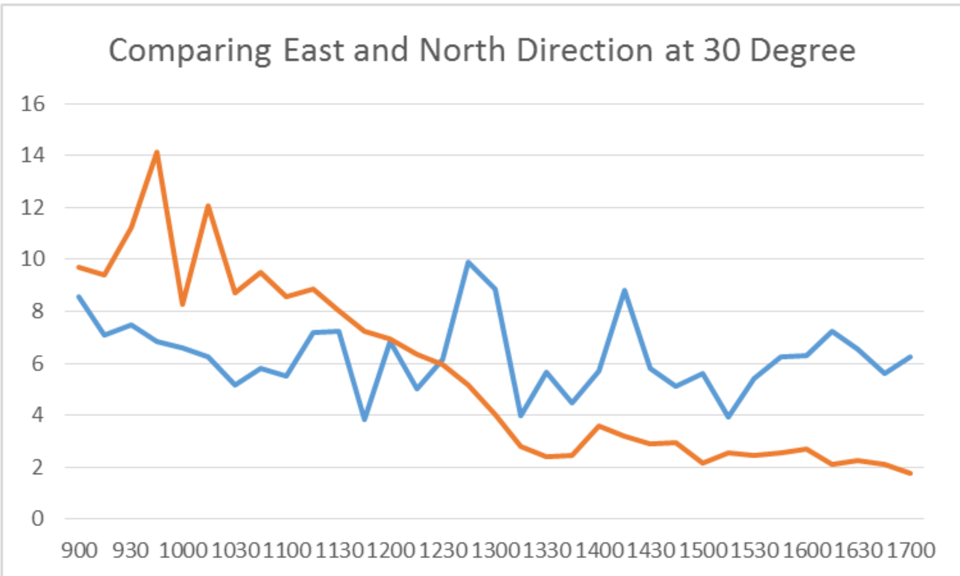

Figure 4.16 Comparing East and North Direction at 30 Degree

4.10 Electricity Generated in Different Tilting Angles and Directions

The graph below compared the electricity generated from the solar blind. The electricity generated was based on the data collected from 9 a.m. to 5 p.m. at different tilting angles and directions.

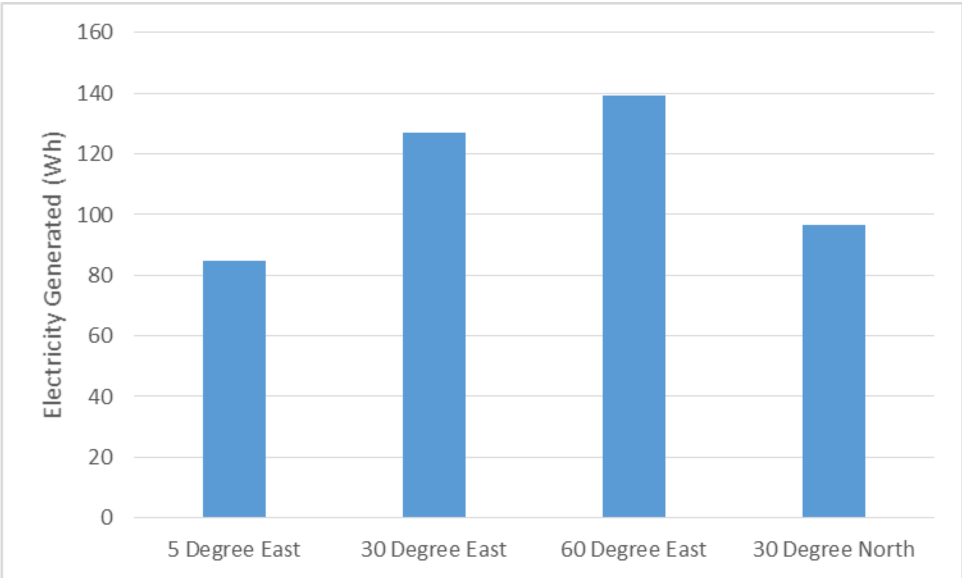

Figure 4.17 Electricity Generated in Different Tilting Angles and Directions

4.11 Discussion of Results

Theoretically, the performance of the solar blind will decrease after solar noon. This is because the sun passed the solar noon, it no longer at the Zenith and started to travel toward West direction. Section 4.4 showed the data collected from the solar blind tilted to 30 degree facing East. From the graph showed in Figure 4.7, the power output decreased significantly after 12.30 pm. However, the power output in the afternoon during 6-8-2016 was relatively higher compared to the power output on 13-8-2016. The wind on 6-8-2016 was strong. The solar blind was not fixed to the frame and it moved to and fro. Eventually, when the solar blind received more sunlight compared to the still solar blind. Due to this issue, the data collection was repeated on 13-8-2016. This time, the solar blind was tied to the frame by using nylon string. In this case, the results were more convincing. The sudden spikes that appear in the graph above were caused by the fault during data collection. The irradiance changed rapidly when there were a lot of clouds. Therefore, the irradiance when recording the open circuit voltage and short circuit current from the multimeter connected to the solar blind was not telly with the irradiance when recording the data from pyranometer.

In section 4.5 showed the data collected from tilting the solar blind to 30 degree. This experiment was repeated 3 times because first experiment result was not ideal and the second experiment came across a thunderstorm in the afternoon. The third result was ideal. The graph showed that the performance of the solar blind was the best in the morning. However, the output power started to decrease towards the noon. After the sun passed solar noon, the output power maintained at the same level. Not much fluctuation occurred to the output power in the afternoon.

Section 4.6 showed the data collected from the solar blind where it was tilted to 5 degree. Due to some imperfection occurred to the prototype, this solar blind cannot be fully closed. 5 degree tilted angle is the closest to the actual BIPV window where the window is placed in a vertical direction, where the tilting angle is zero. In the morning, the output power was relatively low compared to 30 and 60 degree (Figure 4.14). At 8 a.m. the performance of the solar blind at 60 degree was approximately 200% better while approximately 100% better at 30 degree compared to 5 degree tilting angle. However, toward the solar noon, the power output at 5 degree tilting angle did not fluctuated as much as 30 degree and 60 degree. The graph in Figure 4.14 section 4.7 showed the performance comparison of solar blind at 5, 30 and 60 degree tilting angles, facing East direction. As discussed before, in the morning the performance of 30 and 60 degree tilted solar blind was better than 5 degree. However, in the afternoon, the performance of 5 degree tilting angle was better. It was because when the solar blind was tilted toward vertical, it can absorb more diffuse sunlight compared to 30 and 60 degree. Hence the power output was higher.

The last experiment of this project was conducted by placing the solar blind facing the North and tilted to 30 degree. Theoretically, the performance of the solar blind will almost the same during morning and afternoon. The performance is the best during solar noon as the sun is highest in altitude. The graph showed in Figure 4.15 showed the data collected during 23-8-2016, the performance of the solar blind during morning and afternoon did not have significant difference. However, during 1.15 p.m. there was a significant drop in performance, which was contradicted to the theoretical explanation. By studied the data on that day, the error was determined. The short circuit current during this period should have a higher value than 143.1 mA as the irradiance was 961 W/m2. This was due to the irradiance already changed when the short circuit current value was recorded. Overall, the results were convincing.

Figure 4.16 in section 4.9 showed the performance comparison of solar blind facing East and North direction while tilted to 30 degree. In the morning, the performance of the solar blind was better at East direction compared to North direction. This showed that the solar blind receive more directly sunlight in the morning at East direction. During the noon, where the sun was highest in altitude, the performance of solar blind at North direction was way better than that in East direction. This is due to the cosine effect was greater in East direction. In the afternoon, the performance of solar blind at North direction was better as in this direction, it received more direct sunlight. Solar blind in East direction only received indirect sunlight in the afternoon as the sun in another side of the solar blind. However, the overall performance of solar blind at North direction was quite constant, it did not fluctuate as much as in East direction.

In section 4.10, the Figure 4.17 showed the electricity generated (Wh) from 9 a.m. to 5 p.m. by the solar blind at different tilting angles and directions. The first 3 bar graphs showed the electricity generated by placing the solar blind at East direction. The results showed that at 60 degree tilting angle, it generated the most electricity, approximately 139 Wh. On the other hand, 5 degree tilting angle only had 84 Wh of electricity. In 60 degree tilting angle, it was able to generate 65% more electricity than 5 degree and 10 % more electricity than 30 degree. Besides that. it was estimated that the solar blind was able to generate approximate 50kWh of energy for 1 year if placed at East direction with 60 degree tilting angle. For 30 degree tilting angle at North direction, the generated electricity was lower than 30 degree tilting angle at North direction.

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 Conclusion

Existing BIPV window technology is flourishing in the western countries like Germany. Since the technology is well developed in their countries, it suits them the most. When other tropical countries like Malaysia adopted their technology, it would not end well. The reason is the sun altitude in tropics is relatively higher than the non-tropics, causing great cosine loss. Since the sun altitude in non-tropics is lower, vertically placed BIPV window is suitable for them as the sun rise slower toward Zenith. Besides that, the use of high-efficiency non-transparent C-Si solar cell as the basic of a BIPV window will scale down the amount of daylight passing through the window and it makes the building appearance displeasing.

A novel solar blind was introduced in this project to tackle the problems faced by the tropical Countries. Cosine loss can be reduced by adjusting the angle of the solar blind. The daylighting effect can be controlled according to the user preference. Furthermore, solar blind is aesthetically better. This solar blind is targeted to be installed in high rise building. The rooftop of high rise building normally packed with compressors and generators, so space is limited to install solar panels. On the other hand, high-rise buildings have plenty of windows. This solar blind is particularly suitable for retrofit cases as well as new building. Hence a great amount of money can be saved from the installation.

Based on the results discussed in chapter 4, a few conclusions can be made. Comparing the performance of the solar blind in 5, 30 and 60 degree tilting angles, facing East direction, it showed that the performance the solar blind was the worst at 5 degree. By tilting the solar blind at 60 degree angle, facing East, the electricity generated was 65% more than that in 5 degree tilting angle. This result concluded that the conventional BIPV windows which are placed in vertical position, not suitable in Malaysia. In East direction, tilting the solar blind to 60 degree promised the best performance. Therefore, to optimize the solar blind, it can be pre-tilted to 60 degree. By placing the solar blind toward the North direction during summer, the time of solar blind exposes to direct sunlight was more than the East direction. As a conclusion, the vertically placed BIPV windows are not suitable in Malaysia and other tropical countries.

5.2 Recommendation

In order to deliver more significant outcomes, a few improvement and modification can still be made. Further study on the window blind working principle would be a benefit to produce better results.

The first solar blind prototype is not perfect. One of the flaws is the solar blind cannot be fully closed like a normal window blind. This might due to the extra mechanism does not have enough strength to drive the blind. Further research needs to be done to solve this problem. Secondly, when the blinds without solar panels are kept beneath those with solar panels, the end result is not good. As shown in Figure 4.2, some are perfectly fit underneath while some are not. Therefore, the knots position must be very precise determined so that all can fit perfectly. The blinds with solar panels can be replaced with a self-made solar cell that is cut into same shape and length as a normal blind. The frame needs to be redesign to exactly fit the length of the blind

The length of the shadow is not necessary to calculate in worst case scenario. More rows of solar panels can be installed to increase the power output. More experiments have to be conducted to obtain more convincing results. Suggested procedures are including more direction when conducting the experiments, taking the data in 5 minutes interval from 8 a.m. to 5 p.m. and construct more solar blinds conduct experiments at the same time. One transparent glass can be put in front of the solar blind and non-transparent at behind to mitigate real case scenario.

CHAPTER 6

ACHIEVEMENT AND AWARDS

6.1 Novel Research and Innovation Competition 2016 (NRIC)

This competition was organized by Universiti Sains Malaysia (USM) from 16-18 August 2016. Bronze was awarded in this competition with the project titled "A Novel Solar Blind/Window to Improve Building Energy Efficiency in Malaysia", team up with Peggy Lee Siau Wei.

6.2 UTAR FYP Poster Competition (May Trimester) 2016

This was a final year project poster competition organized by UTAR LKC FES on 25 August 2016. This competition also team up with Peggy Lee Siau Wei with the project title "Angle Adjustable Solar Window Blinds and Solar Window" in track Materials, Manufacturing, Green & Sustainable Technologies. We won 1st runner up in this competition.

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APPENDICES

APPENDIX A: Photos of NRIC 2016

Photos taken during NRIC 2016.

Figure A.6.1 Group Photo of NRIC Participants and Supervisors

Figure A.6.2 Medal and Certificates

APPENDIX B: UTAR FYP Poster Competition

Figure B.1 Track 3 Winners

Figure B.2 Certificate and Trophy