HIGH ACCEPTANCE ANGLE OPTICAL FIBER BASED SOLAR DAY-LIGHTING SYSTEM USING TWO-STAGE REFLECTIVE NON-IMAGING DISH CONCENTRATOR

CHUA TIONG CHUAN

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

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2016

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 : ______________________________

ID No. : ______________________________

Date : ______________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"HIGH ACCEPTANCE ANGLE OPTICAL FIBER BASED SOLAR DAY-LIGHTING SYSTEM USING TWO-STAGE REFLECTIVE NON-IMAGING DISH CONCENTRATOR"** was prepared by **CHUA TIONG CHUAN** 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 : ______________________________

Date : ______________________________

Specially dedicated to
my beloved father, mother and brothers

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my greatest gratitude to my research supervisor, Prof. Chong Kok Keong for his invitation to this project, invaluable advice, guidance and his enormous patience throughout the development of the research.

Besides, I would certainly like to express the sincere appreciation and deepest gratitude to my project seniors, Dr. Pua Chang Hong and Mr. Wong Chee Woon who providing me important guidance, navigation, precious opinions and suggestions during the process of this project.

In addition, I would like to thank to all the lab assistants and officer who offer an appropriate place to keep the project's prototype and giving us as much as help they could provide during the conduction of the project. Furthermore, I would also like to take this opportunity to thank to my partner, Lee Zhe Kai, Wong Chong Chiat and Ooi Wai Cheng who are willing to discuss and give opinions regarding this project.

Lastly, I would like to thank to my friends and family for supporting me, both mentally and physically, in order to assist me to accomplish the project.

HIGH ACCEPTANCE ANGLE OPTICAL FIBER BASED SOLAR DAY-LIGHTING SYSTEM USING TWO-STAGE REFLECTIVE NON-IMAGING DISH CONCENTRATOR

ABSTRACT

Electricity consumption for day-lighting system in buildings is increasing drastically over years. In fact, during the day time, there is unlimited sunlight outdoor and it can be used to fulfil the lighting requirement inside the building. Solar day-lighting system is an essential technology to reduce the lighting consumption inside the building. This can be accomplished by channelling the concentrated sunlight via bundles of optical fiber. In this research, the lighting system proposed for the indoor is hybrid day-lighting which combines both the sunlight and artificial light to provide better illumination level. A sun tracking mechanism integrated with two-stage reflective non-imaging dish concentrator (NIDC) is used to track the sun and focus the light using flat mirrors and guiding the light into the building via fiber optic bundles. The sunlight undergoes a two stage reflection so as to focus the sunlight onto the fiber optic. With that, day-lighting plays a significant role in reducing the energy consumption by utilizing the sunlight and illuminates the interior part of the building. The performance of this system was verified through experiment and testing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

A	Area of 80 mirrors, m^2
I	Solar radiation, W/m^2
L	Length of optical fiber, m
α	Attenuation for transmission loss, dB/m
Θ_{max}	Acceptance angle of optical fiber
Px	Power at optical fiber output end, W
Py	Power at optical fiber input end, W
R	Resistance, Ω
V	Voltage, V
I	Current, A

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Briefing of the background

In the 21th century, energy demand and consumption is getting higher and this leading to a severe global warming problem to the world. The global warming is mainly caused by the greenhouse effect due to the extensive emission of carbon dioxide. This is due to the source of energy is produced from burning of fossil-fuel like coal and natural gas. Daylighting is definitely the solution to this problem. Daylighting is an important feature to reduce the energy demand which it utilize the sunlight and light up the interior of building by guiding the sunlight through bundles of optical fibers. It provides natural lighting that can reduce the electricity demand due to lighting system in the building during day time.

Recently, there are many research and development project on this day-lighting system. The examples of conventional concentrators that use the optical fiber to guide the sunlight are Fresnel lens, parabolic concentrator and heliostat. The non-imaging dish concentrator which is claimed to have better acceptance angle. The two stages reflective non-imaging dish concentrator was introduced in order to reduce the bending angle of optical fiber. The optical fiber provides a good transmission and propagation medium for and it is recommended to use in day-lighting system. A Hybrid Solar lighting (HSL) is a system which enables energy efficient lighting as it is the combination of both the sunlight and artificial light together for the illumination of interior building.

1.2 Problem statement

There are many designs for the solar day-lighting system and different choices of mechanical tracking structure and light transmission media. Therefore, a depth research and comparative studies have to be conducted on the performances and characteristics of different sun tracking mechanism, day-lighting system and optical fiber transmission media so as to determine which mechanism are more suitable. A hybrid lighting system should also be considered due to the possibility of insufficient illumination in buildings where the light is guided by optical fiber.

1.3 Aims

The aim of this study is to design a non-imaging planar concentrator and guided the sunlight into interior room using optical fiber.

1.4 Objectives

In this project, the objectives are listed below:

- To design double stage reflective non-imaging dish concentrator for day-lighting system.
- To analyse the performance and characteristic of optical fiber as transmission system.
- To develop a hybrid lighting system.

1.5 Report Outline

The arrangement of this thesis is stated below.

Chapter 1 is about the introduction and background on day-lighting system. It also covers the problem statement, aim and objectives.

Chapter 2 is about the literature review. The review is about design and performance of different type of solar concentrator. It also includes the some comparison between plastic optical fiber and glass optical fiber.

Next, in chapter 3, it will include the methodology in designing the solar day-lighting system which consists of design mechanism of non-imaging dish concentrator, optimization of plastic optical fiber design and hybrid solar lighting system.

Then, chapter 4 will discuss the result of hot mirror transmission performance, optical transmission and attenuation, optical fiber surface and the result from lighting system.

Last but not least, chapter 5 will analyse some problems encountered in the project and suggestions or improvements will be discussed. The conclusion and future research for the two-stage non-imaging dish concentration was discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Basics of day-lighting system

In the past, different researches were done to fully utilize the light from the sun to reduce the electric power consumption and illuminate interior building. A new strategic known as day-lighting was introduced so as to direct and lead the sunlight to interior spaces of the building. By implementing a suitable day-lighting system, the electrical lights in the building can be lowered. Conventional day-lighting systems involve the problems of significant loss and difficulty of guiding the sunlight efficiently to achieve a standard illumination to the whole building due to blocking of some objects. The new solar day-lighting system is using optical fiber as the guidance of sunlight to all rooms in the building.

Optical fiber has been reviewed as one of the most efficient method in guiding the sunlight into the building so as to reduce the electricity consumption for indoor lighting systems. In order to guide sufficient sunlight to provide standard illumination, a focused sunlight will be required. The sun tracking solar concentrators will be used to get the maximum sunlight by keeping track with the sun and focused the sunlight to a common point by using flat mirrors. Non-imaging dish concentrator can provide uniform concentrated sunlight and it is important when dealing with the heating issue encountered at the aperture of optical fiber that is coupling to the sunlight. The double-axis solar concentrator system will generally mount on the roof of the building for the ease of sun tracking and maximizing the collection of sunlight.

2.2 Benefits of day-lighting system

Day-lighting is and energy saving approach because artificial light consume large amount of electric power, and this day-lighting system which utilize the sunlight to provide interior illumination at day time. Therefore, the electric light that needed to be installed in the building can be greatly reduced. The sunlight transmitted to the building has a much similar characteristic and it match up well with the human eye making a comfortable environment for the indoor lighting.

2.3 Types of Solar Concentrator

Solar concentrator is an important consideration when designing the day-lighting system. It ensures a good amount concentration of sunlight can be collected and transmitted via the bundles of optical fiber. It is important because the illumination level inside the building must be maintained at a standard levels, this will then require a strong focused sunlight to be acquired at entrance of the optic fiber.

2.3.1 Heliostat

Heliostat is a solar concentrator that consists of plane mirror used to reflect the sunlight to a targeted point and the light will be guided into the building. The heliostat is usually fixed in position and it is used for large scale that reflects the sunlight to a focusing mirror where a high intensity of sunlight is required.

For a small scale day-lighting, it is not preferable due to the whole system cost which is higher. The disadvantages of heliostat are that it needs a relatively large space which is less viable to be implemented on the roof of the building. The cost for implementing this system is higher compared to others system. For the light to be effectively transmitted and distributed to fulfil the illumination level, a high accurate sun tracking system is an issue for heliostat as it is required to reflect the sunlight to a target point continuously.

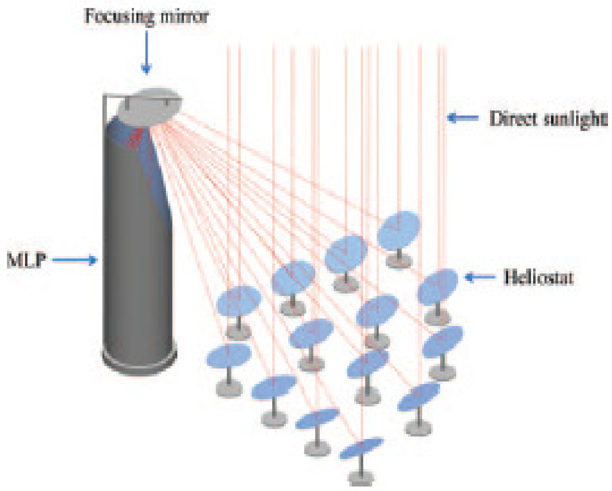

Figure 2.1: Reflection of sunlight using heliostat

Figure 2.2: Heliostat structure

2.3.2 Parabolic Reflector

Parabolic reflector has a very special curve shape known as parabola and they are used to collect the light at a fixed point. They collect the light sources from a far distance and reflect it to a fixed focal point where the light will be focused. Basically, any incoming light will reaches the parabolic reflector will be reflected to a focusing point due to its geometric properties.

Figure 2.3: Parabolic Reflector

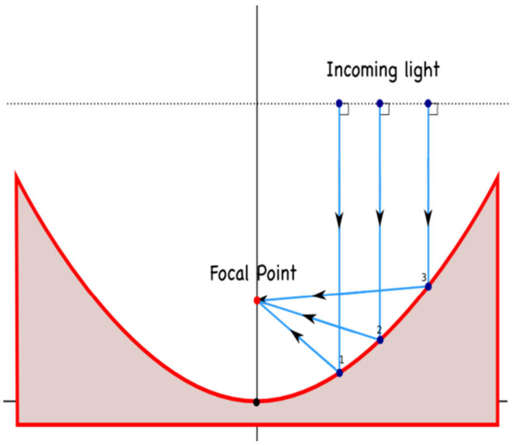

Figure 2.4: Idea of Parabolic Reflector

This kind of structure is difficult to achieve especially when a high concentration of light is required. Therefore, in order to achieve a strong focusing light, a high accuracy of parabolic reflector is needed and it has to be symmetrical and a material that have a constant thickness. It is costly due to the fabrication of such special mirror.

2.3.3 Fresnel Lens

The Fresnel lens is one of the approaches for day-lighting and it basically concentrates the sunlight which passing through the lens to a target point. It is easy to install and the Fresnel lens designs enable larger aperture and thus allow more light to pass through and focused at the target point. The Fresnel lens bends the incident sunlight to a common target where the optical fiber will install. In order to achieve a collimated light at the focusing point onto optical fiber, the combination of both Fresnel lens and plano-concave lens is needed. The performance of the Fresnel Lens is lower due to the relative low transmission efficiency and lower light concentration. However, to fulfil a large illumination area, a rather bigger size of Fresnel lens will be required.

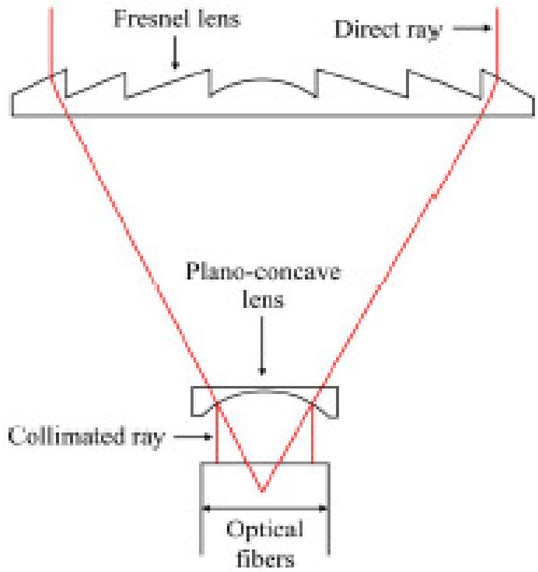

Figure 2.5: Concept of Fresnel Lens

2.3.4 Non-imaging dish concentrators

A non-imaging dish concentrator is a solar concentrator formed by large number of flat square mirror which act as a platform to collect the sunlight and transfer it to a target. The incident sunlight onto the mirrors will be reflected to a target point by the mirrors. To focus the light to a fixed point, the flat mirrors are tilted with some angles so to achieve a high concentration of sunlight. Besides, small spacing spaces between the mirrors are required to solve the shadowing effect and the blocking of sunlight. The height of the mirrors is expected to place correspond to the gradually increased in height following the idea of dish shape. This type of concentrator can produce a more uniform of sunlight at the focusing point and higher concentration ratio. It also provides a large surface area and wide acceptance angle for sunlight, thus improving the concentration of sunlight. The use of flat mirrors in this design allows a lower fabrication cost and simpler structural and construction. Therefore, the idea is more suitable in the implementation of daylighting system.

Figure 2.6: Non-Imaging Dish Concentrator

2.4 Optical Fiber

The two commonly used materials are silica glass and plastic as the core for the optic fiber. Optical fiber is normally used for the transmission of data, electrical signal and light along the medium over a relatively long distance. The operation of optic fibre transmission is through the occurance of total internal reflection. Total internal reflection principle states that as the light travel in a medium, the reflection of light occurs when the incident angle of the light is larger than critical angle. The optic fiber is very fragile and easily break therefore extra attentions is required when handling with it.

2.4.1 Plastic Optical Fiber (POF)

The core material of POF is polymethylmethacrylate (PMMA) which is also called as acrylic that allows the transmission of light. The light is generally transmitted through this fiber core. The refractive index of POF is usually given as 1.49 which is used to indicate the propagation of the light in the fiber. It describes the behaviour of light in travelling along the optical fiber. Besides, the POF have a relatively high numerical aperture which is used to determine the acceptance angle of the optic fiber to receive light. A high value of numerical aperture indicates a better acceptance angle for optic fiber. Moreover, the POF also have relatively low and better flexibility. Compared to glass fiber, POF have higher attenuation loss and the performance in transmission of light is lower. Due to the high concentration of light received at the focusing point by reflection, the heating problem on the optic fiber has always been an issue leading to high temperature which changes the properties of optic fiber. Therefore, a heat dissipation system had to be introduced to reduce the excess heating. So, POF is more preferable in the implementation of daylighting system compared with glass optical fiber because of the more flexibility in bending and lower cost. The specification of the different POF is referred to the table shown below.

Table 1 Techinical specification of POF provided by Mitsubishi Rayon Co., Ltd.

Product Line-up							
Application	Lighting	Sensing	Industrial Data Com	High Bandwidth	Heat Resistance	Tight Bending	Home Network
Grade	ESKA™	SUPER ESKA™	ESKA PREMIER™	ESKA MEGA™	ESKA™ for high temperatures	ESKA™ bend	ESKA™ Optohome
Fiber Code	CK	SK	GK	N/A	N/A	N/A	N/A
Cable Code	N/A	SH	GH	MH	BH	LH	RH
Refractive Index	1.49	1.49	1.49	1.49	1.49	1.492	1.49
Numerical Aperture	.05	.05	.05	.03	.058	.05	.05
Temperature Range	-55°C ~ 70°C	-55°C ~ 70°C	-55°C ~ 85°C	-55°C ~ 85°C	-55°C ~105°C	-40°C ~ 70°C	-55°C ~ 70°C
Sample Item	CK40	SK40	GK40	MH4001	BH4001	LH4001	RHVV 4002-CMR
Attenuation	<0.20dB/m	<0.15dB/m	<0.15dB/m	<0.16dB/m	<0.20dB/m	<0.45dB/m	<0.19dB/m

2.4.2 Glass Optical Fiber (SOF)

The performance of glass fiber is much better than POF as its transmission rate is higher than that of POF and glass optic fiber has lower attenuation .Compared to the POF, glass optical fiber achieves a lower loss during propagation which leading to a better performance for a longer distances transmission. Although there have been many advantages, it is relatively costly and more fragile than POF. For the day-lighting system, the optic fiber is required to have a more flexibility in bending. A POF with PMMA core materials is more suitable than glass optic fiber for day-lighting system. The graph below compares the attenuation for each types of fiber.

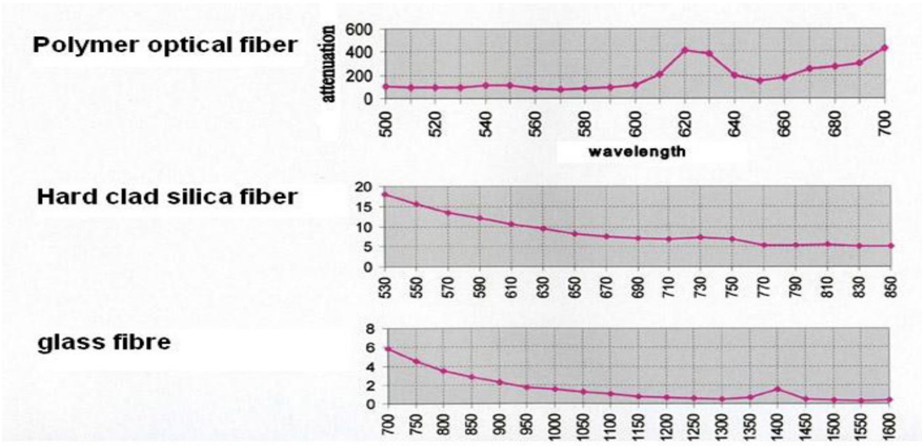

Figure 2.7: Attenuation vs Wavelength of fiber optic

2.5 Hybrid Solar Lighting

To reduce the electricity consumption during the day time, the day-lighting system was introduced. As the light sources from the sun is not consistent and concentration of sunlight is changing along the day, so fully rely only on the sunlight guided by the optic fiber is definitely insufficient. To make sure the human have the maximum visual comfort and maintain the illumination level in a predetermined range, the use of electrical light is required. Combination of both the sunlight guided via optic fiber and the electric light is called hybrid solar lighting, this feature ensures a maximum illumination can be achieved and provided to those interior spaces by controlling the electrical light during day time.

The working principle of this system is basically compares the illumination provided by the light sources guided by optical fiber using photosensors. If the natural light is sufficient for the illumination level for indoor lighting, then the electrical light will be switched off or adjusted at a dimmer level. In contrast, if the natural light provided did not reach the predetermined illumination level, electrical light will be turned on and combine the natural light so as to provide maximum lighting effect in indoor throughout the daytime. This system will help to lower the energy consumption of lights and provide a better illumination to the interior spaces.

CHAPTER 3

METHODOLOGY

3.1 Design of two-stage Non-Imaiging Dish Concentrator Mechanism

The purpose of this solar concentration design is to develop a day-lighting system using optic fiber as the transmission media for sunlight. The non-imaging dish concentrator is designed to have a two-axis sun tracking mechanism which is azimuth and elevation tracking. By taking the idea of non-imaging planar concentrator (NIPC), some modifications have been done by converting the one stage reflection into a two stages reflection system. The basic concept of this solar concentration is to reflect the incident sunlight using flat mirrors into secondary reflector, and then focus the sunlight to optical fibre by secondary mirrors.

3.1.1 Simulation of reflection of light ray

Before the construction of this solar concentrator for day-lighting purpose, some studies and simulations were done to inspect the behaviour of reflection of light using square flat mirror. The demonstration and simulation on reflection of light is done by using the software simulator known as OpticalRayTracer 9.1. From the simulation, the distance between the optical fiber and the second stage mirrors can be determined and whether or not it will generate a maximum focus onto the optical fiber. There is a need to place the both first and second stage mirror with some tilted angle so that the light can be reflected toward the target.

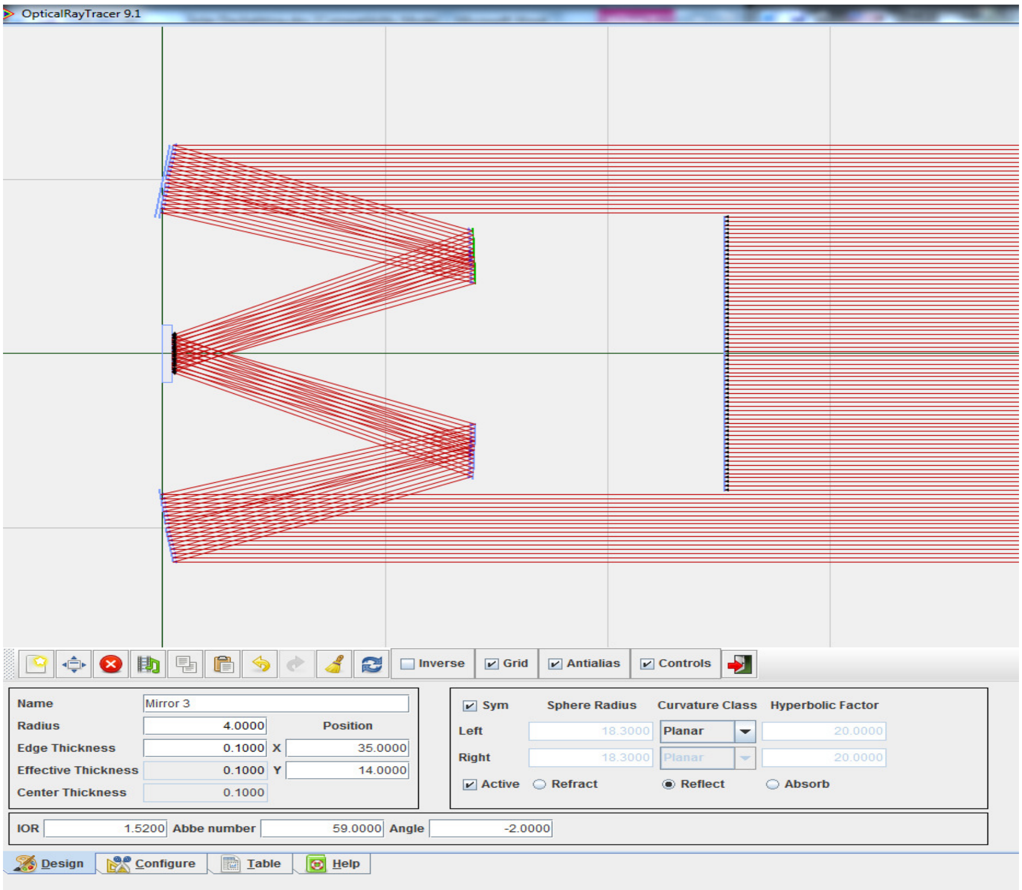

Figure 3.1: 2D-Simulator Software OpticalRayTracer 9.1

3.1.2 Hardware design of the concentrator by using Solidworks

This solar concentrator design consists of a two-stage reflection by using large number of flat square mirrors and bundles of optical fiber to perform focusing and guiding of sunlight respectively. In first stage of reflection, four mirrors will be treated as one assembly set and mounted on a small frame of steel. A total of twenty assembly sets of this model consisted of 80 flat mirrors with 5cmx5cm each were required to form a square frame acting as primary reflector. A demo unit of the 4 mirrors was built for the testing of sunlight reflection. In this unit, 3 screw points was attached to a mirror using silicon paste and four mirrors were mounted onto a frame.

It has 3 point attachment and small spaces reserved between the mirrors to ease the adjustment of mirror angle.

Figure 3.2: Single assembly set of flat mirror as first stage of reflector

At second stage, the mirror used is of slightly bigger size than that used in first stage. Instead of four mirrors, a single mirror will be treated as a unit now. Twenty units of 8x8 cm mirrors were placed at the top frame acting as a secondary reflector. The second stage mirrors were designed to form at inner part of square frame in order not to blocking the sunlight that passing to the first stage mirrors. Thus, this design forming a light coupling between four mirrors at the bottom frame and one mirror at the top frame. Steel bars will be used as a frame support and the mounting for the first stage mirrors and support materials for the second stage of mirrors. There is an empty slot existed in the centre of this design used for the installation of optic fiber and guidance of the sunlight to illuminate the interior spaces.

The drawings of the two stage reflection mirrors and the supporting materials were done by using the SOLIDWOKS. The whole dimensions of the system were shown in figure below.

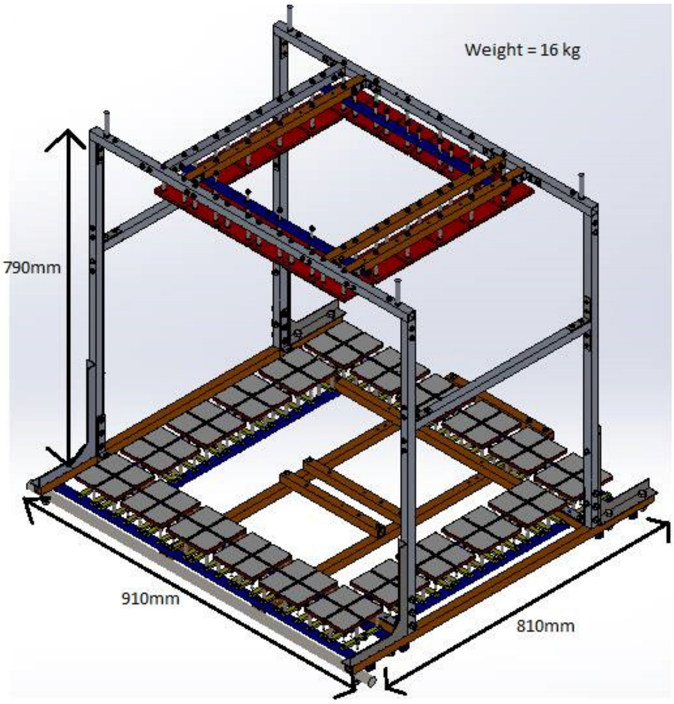

Figure 3.3: Two-stage reflection using SOLIDWORKS

This design also consists of two-axis sun tracking system. This is done by the linear actuator, motors and gears. The completed design schematic drawing was done by using SOLIDWORKS and is shown in figures below. The total weight of this solar concentrator is 42.2kg.

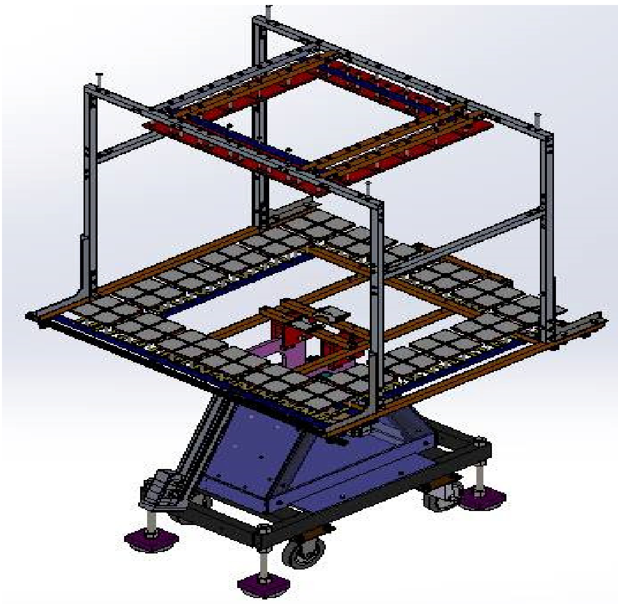

Figure 3.4: Isometric view of the solar concentrator

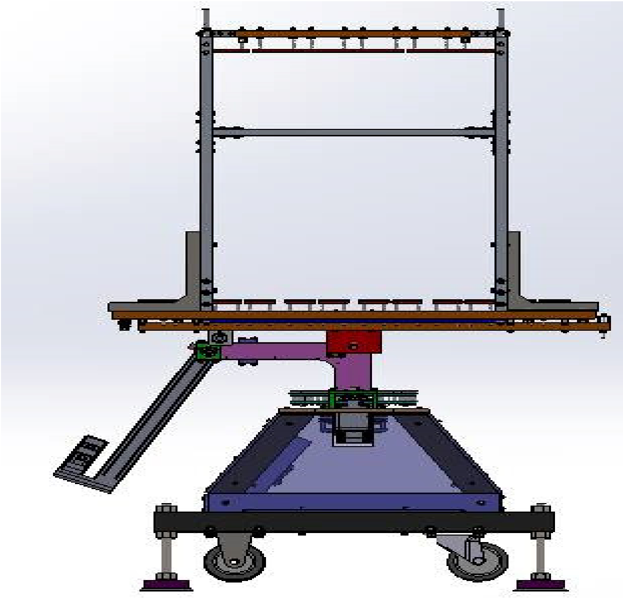

Figure 3.5: Side view for the completed design

3.2 Optimization of plastic optical fiber design

First, it is very important to understand properties of the optical fiber and the how the optical fiber operated in order to fit into the system and maximize the efficiency of the system. In the following parts, the overall design and the installation of the optical fiber in guiding the concentrated sunlight into an interior space will be explained. The study on the optical fiber characteristics and the technical issues will be revealed one by one.

3.2.1 Specification of plastic optical fiber

The material of optical fiber and the appropriate diameter is carefully chosen so that it is most suitable for this solar daylighting application. The optical fiber used in this system is of high performance plastic optical fiber and the model is CK-120. The specification is important to help us in designing the optical fiber system. This core material of this optical fiber is Polymethyl-Methacrylate Resin (PMMA) and with the cladding made of Fluorinated Polymer. The refractive index profile is step index and the core refractive index is 1.49. In order for the light rays to be reflected in the core, the refractive index of the cladding must be lower than the refractive index of the core. The refractive index leads to the numerical aperture (N.A.) of the fiber.

The numerical aperture of this POF is 0.5 and this will give us the acceptance angle of the optical fiber by the following equation. Thus, it was calculated that the acceptance angle, θmax is 30°.

$\mathrm{N.A.} = \sin(\theta\mathrm{max})$, θmax is the acceptance angle.

This acceptance angle is defined as the maximum angle that the light rays could enter into the optical fiber and are all transmitted through it. It is also indicated that the maximum emitting angle would also be the same as the acceptance angle when the light rays exit from the optical fiber. The 2θmax is referred to the acceptance cone and it is 60 ° which the light entered the optical fiber at an angle smaller or within acceptance cone will travel to other end. The description of the acceptance angle and acceptance cone was shown in figure 3.6 and figure 3.7 respectively.

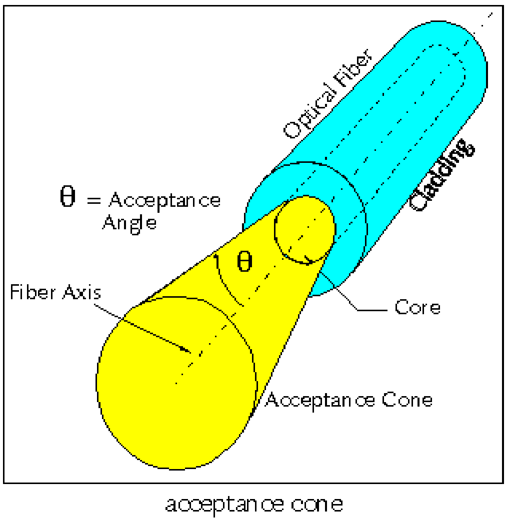

Figure 3.6: Acceptance angle for the optical fiber

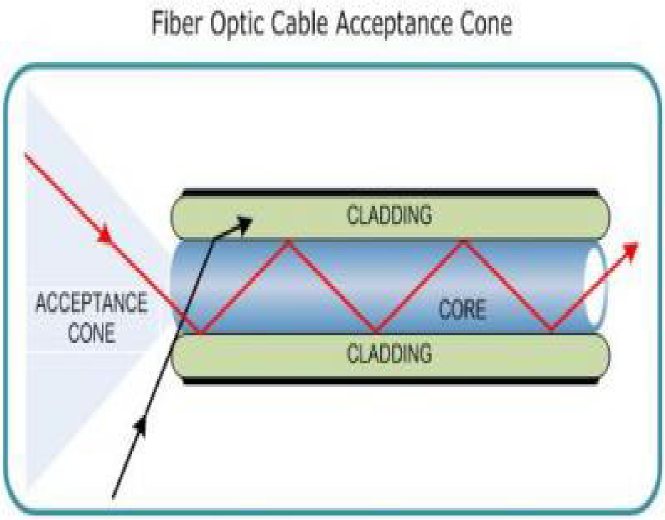

Figure 3.7: Description of the acceptance cone on the light rays

The diameter of the optical fiber is crucial because this diameter is responsible in guiding the light through its medium. A larger core diameter will result in transmitting more light through the plastic optical fiber compared to the glass optic fiber which has a much smaller core diameter. In this case, the core diameter of the POF is 2.945mm and the overall diameter is 3mm including the cladding. This is considerably good and the largest diameter among the same grade of plastic optical fiber from the manufacturer, which is Mitsubishi Rayon Co., Ltd. The CK grade fibers are typically used for illuminating the environments and lighting applications. With both large core diameter and large N.A., it gives the advantage of better light coupling and large acceptance angle.

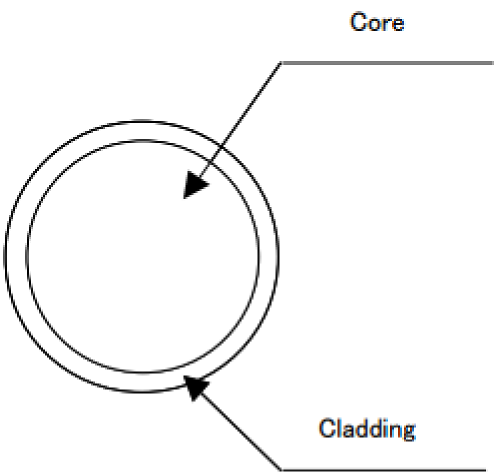

Figure 3.8: Sectional view of POF

3.2.2 Optical Fiber Operating Condition

There are some technical issues in the guidance of sunlight due to the properties of optical fiber which are transmission and coupling loss, excessive heating effect and degradation problem. As the sunlight is reflected by mirrors into a focus point, it will involve highly concentrate sunlight and the temperature at the focus point will be shot up to a much higher temperature. Thus, it would certainly exceed the maximum operating temperature of optical fiber which the maximum rating is in the range of -55 ˚C to 70 ˚C.

3.2.2.1 Optical Fiber heat problem

To solve the heating problem, an understanding of the behaviour of sunlight is necessary. As mentioned before, the sunlight spectral involved from ultraviolet light to visible to infrared. While the flat mirrors used in the dish concentrator are sliver coated mirrors, and they will reflect all wavelength above 300 nm. The specular reflectivity of the sliver-coated mirrors was shown in the figure 3.10 and as seen from the graph, the specular reflectivity of that mirrors, *pm* is roughly equal to 0.94.

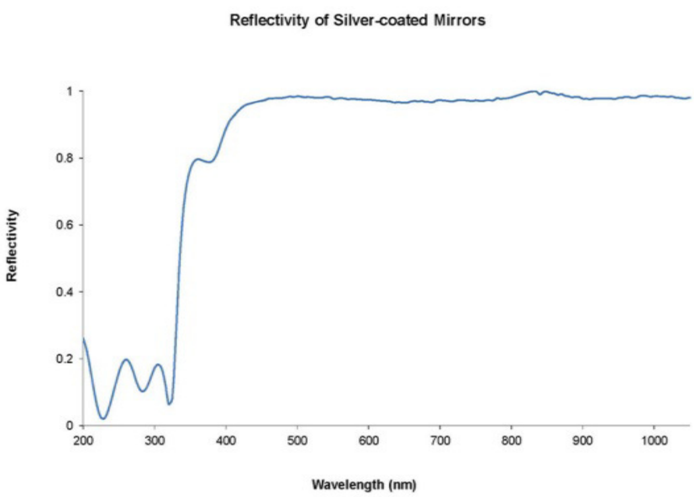

Figure 3.9: Reflectivity of sliver-coated mirrors

A high performance hot mirror is necessary to protect the optical fiber and reduce the heat which mostly comes of infrared. This hot mirror is designed to transmit the visible light from 400nm to 690nm and reflect the infrared from 750nm to 1150nm. This filter is crucial as it reduce most of the heat in the system without immolate the visible light output in the system. The maximum operating temperature for the hot mirror is 400 ˚C.

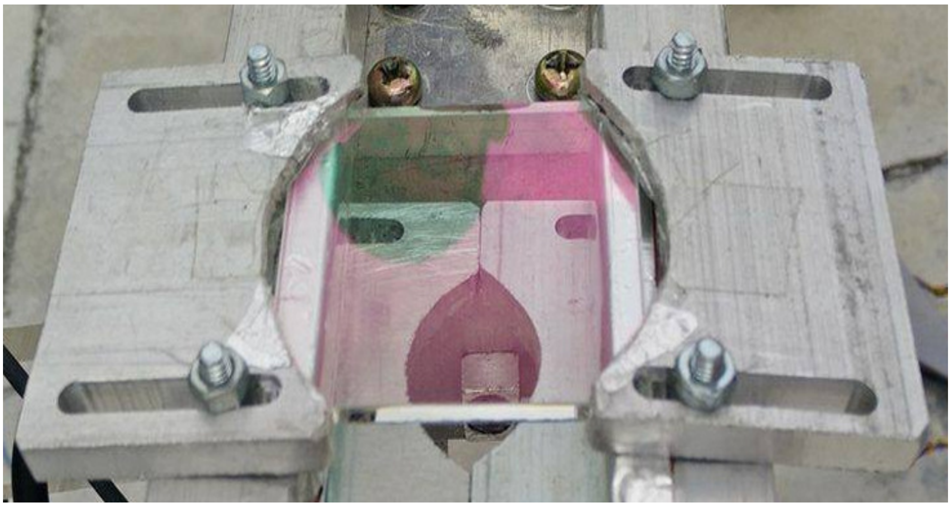

Figure 3.10: High performance Hot Mirror used in the prototype testing

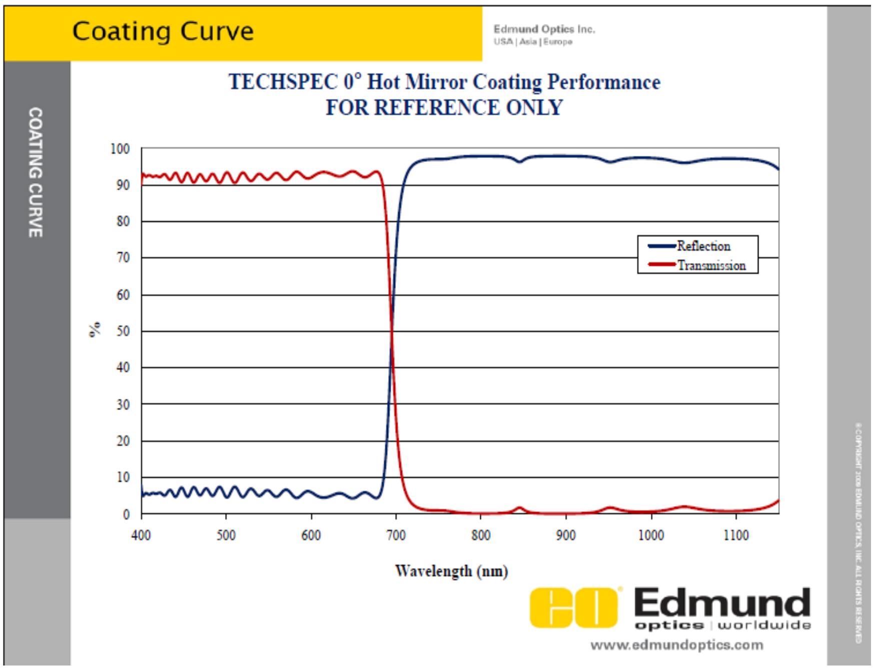

Figure 3.11: Coating specification of the hot mirror

An experiment was carried out to study the performance of the hot mirror by using Avantes NIR spectrometer shown in figure below. The detector was held on a tripod stand and facing directly to the sun as shown in figure. Lastly, with the help of the Avasoft software, the sunlight intensity was measured and plotted for different wavelength ranging from 200nm to 1753nm. The experiment was done on the rooftop of UTAR sungai long campus KB block.

Figure 3.12: Avantes NIR spectrometer

Figure 3.13: Setup of NIR spectrometer

Figure 3.14: The Avasoft software used to plot the spectrum of sunlight

3.2.2.2 Optical fiber degradation problem

The optical fiber is susceptible and sensitive towards the UV because the UV can cause the degradation problem to the polymer fiber. This means that if the UV is not filtered out from the optical system, the performance of the optical fiber can be decreased and downgraded along the time or period. The hot mirror above can also filter out the UV below 400nm which in turn prevents the degradation of polymer fiber.

Because this dish concentrator is placed at outdoor, there is a lot of dust or dirt. If the optical fiber is contaminated with dust or dirt or exposed in dusty environment for a long period, this will significantly reduce the optical transmission efficiency of fiber.

To counter the dirty environment, bundles of optical fiber are placed inside the cleaned PVC pipes that are joined together by a PVC connector to form a roughly 10m long. This will act as a protection layer for optical fiber from dusty environment and minimize the dirt or dust effects. The PVC pipe also prevents the optical fiber from friction with the ground, thus keeping the optical fiber in a good condition.

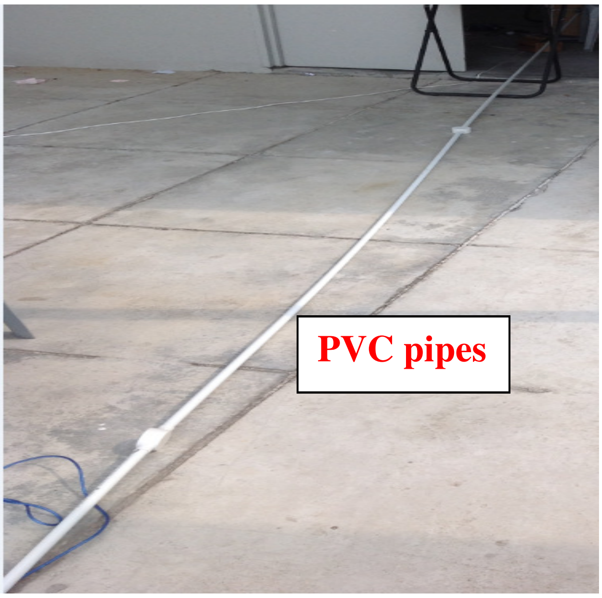

Figure 3.15: PVC pipes

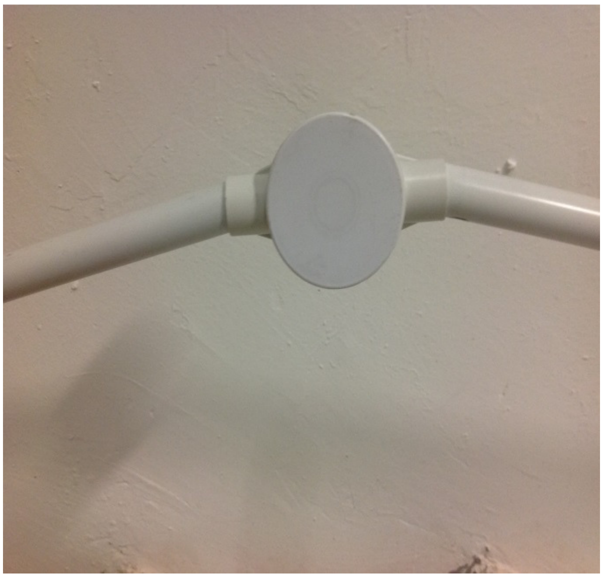

Figure 3.16: PVC Connector

3.2.3 Optical Fiber Arrangement

The two-stage reflection allows bundles of optical fiber to be installed at a much better position and the bending of the fibers can be minimized. The arrangement of the optical fiber is shown below. The sunlight focused at the target is roughly 5cmx5cm. With a 3mm optical fiber, seven optical fibers will be arranged like hexagon shape into one bundle. So this bundles which consist of 7 optical fibers will be an exact duplicate for the other bundles and the overall arrangement is shown below. The drawings were done by using Solidworks.

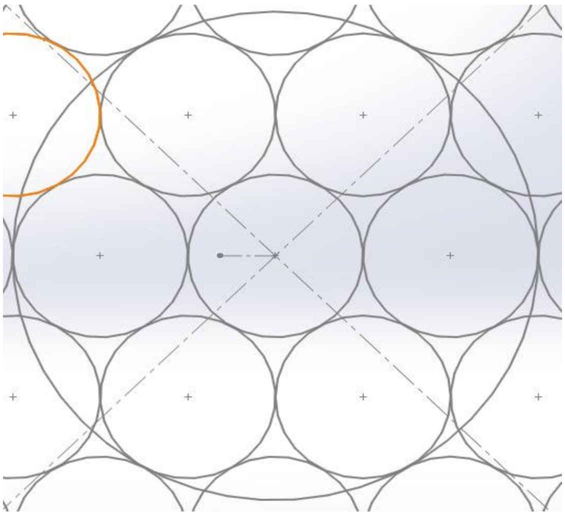

Figure 3.17: A bundle consist of seven optical fiber

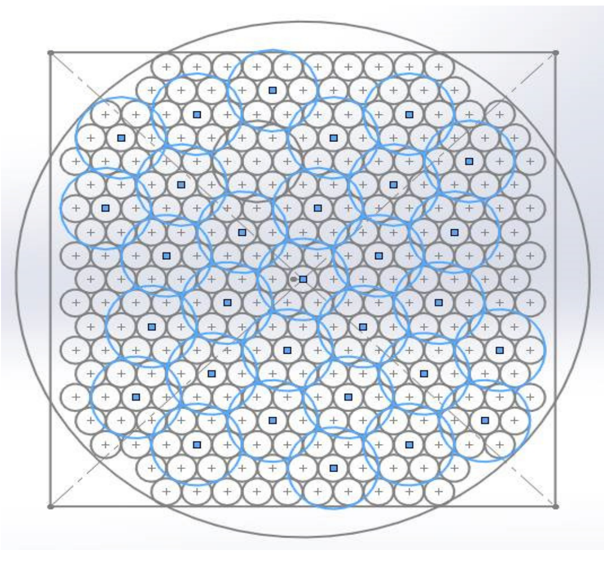

Figure 3.18: Bundles of optical fiber for 5x5cm target

3.2.4 Optical fiber testing

One of the most important parameter for optical fiber is the transmission and coupling loss. An experiment for the finding the transmission loss or attenuation is carried out and it is called the cutback method. The transmission loss from the datasheet given is to be compared with the result of the testing. A fixed length of 10 meter fiber is used in the experiment.

The formula to calculate the attenuation is given below.

$$\alpha(dB/m) = \frac{10\log_{10}(Px/Py)}{L}$$

Where α = attenuation in dB/m
Px = power at optical fiber output end
Py = power at optical fiber input end
L = length of the optical fiber.

The procedure for this cutback method is by providing a constant and un-interrupt white light source at beginning end of the optical fiber. This end of the fiber is clamped tight by using a retort stand and an optical fiber is coupled perpendicular to the white light source which is white led.

Figure 3.19: Un-interrupt white light source at one end

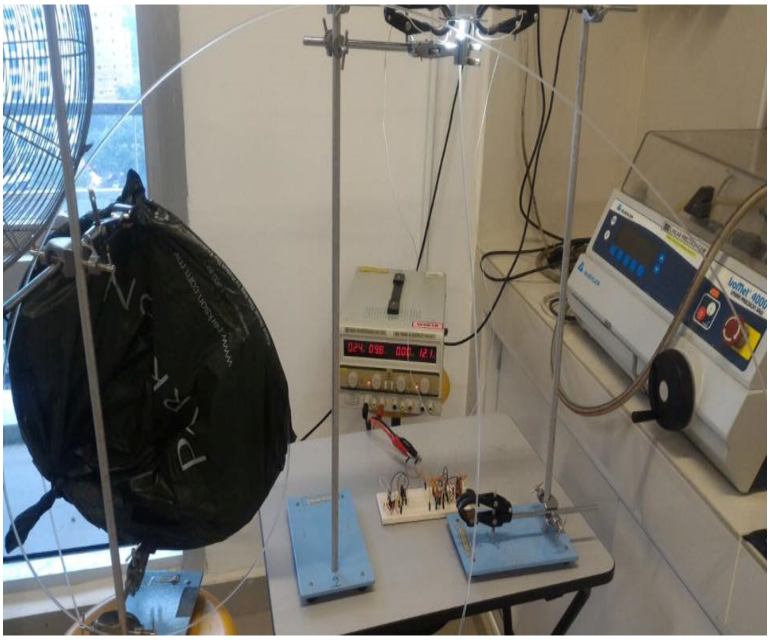

Figure 3.20: Setup experiment

The light intensity coming out at the other end of optical fiber was measured using a solar cell by taking both the short circuit current and open circuit voltage. These result will generate a power by multiplying them using the formula P=VI.

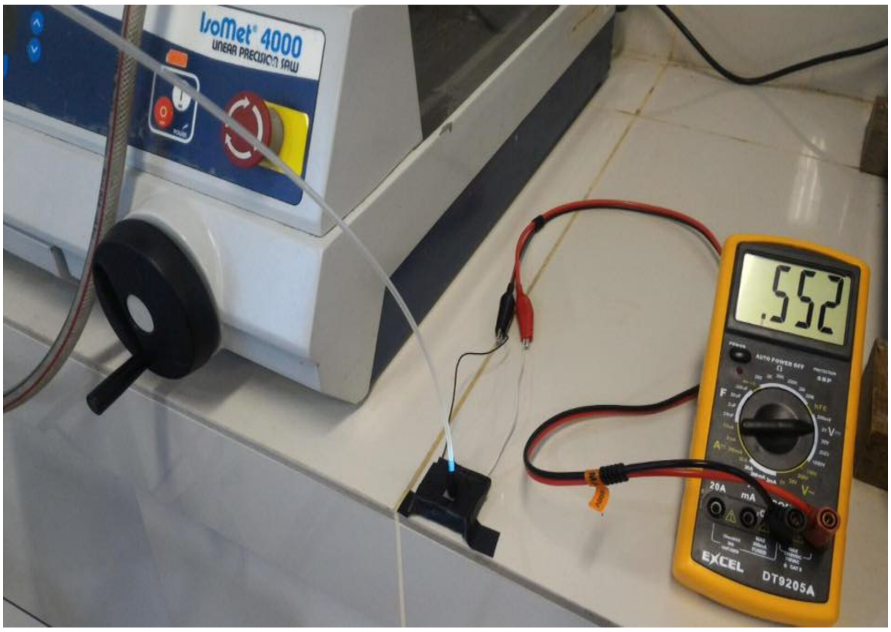

Figure 3.21: Measurement taking using solar cell and multi meter.

After measuring the power, 2 cm of optical fiber is cut at the measuring end. The cutting of optical fiber is first make a crack on the optical fiber using cutting blade and then apply a tension force to break it. After cutting the optical fiber, it is required to polish the surface of optical fiber at the end in order to ensure it has a flat surface and take the measurement again. In this experiment, different grades of sandpaper were used to polish the surface of optical fiber using polishing machine and the experiment is done for each grade of polishing which is 400, 800, 1200, 1500, 2000 grades.

The surface of the optical fiber was inspected under a microscope to see the effects of polishing after cut the optical fiber. The result was taken for unpolished, polishing with 1000 grade sandpaper and 2000 grade of sandpaper for different magnification.

3.3 Hybrid Lighting System: Daylight and Artificial Light

For the daylighting design, a lighting control system for artificial light is implemented so as to provide a suitable lighting level for interior space and as a compensation for the daylighting system using optical fiber. Photodiode is used in this design to make a measurement of detected light guided from optical fiber. Thus, an artificial light such as LED is used to compensate the natural daylight when the illumination level from optical fiber achieved is less than required level. The dimming and switching on or off of a LED can be done by an electronic control circuit with the help of closed-loop feedback system. The photodiode will keep track the illumination level from optical fiber with the desired level for a room so that it can make adjustment to the output of LED light. Any changes in the illumination will instead generate an error signal to the system and the system will immediate make a response by adjusting the power supplied to the LED.

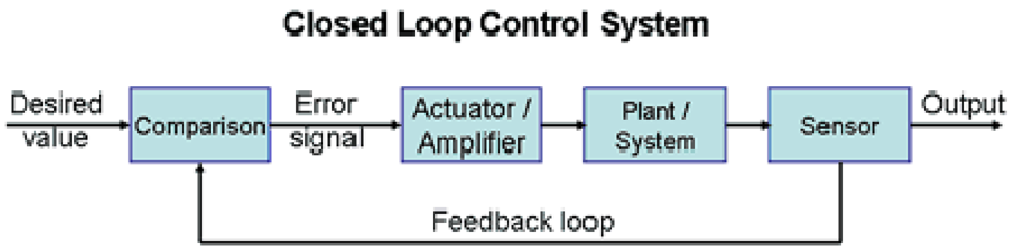

Figure 3.22: Block Diagram of the Lighting control

3.3.1 Lighting controller system/platform (Arduino)

The controller board or the driver for the lighting system used in the project is Arduino Uno. Arduino was chosen to be used in this system due to its lower cost compared to other controller such as Raspberry Pi. Besides, Arduino is easy to operate and the hardware and software implementation is much simpler because they are open-source to the end user. The Arduino input and output pins is operated at 5V and the maximum current it can draw from the Arduino's pins is 40mA current per pin.

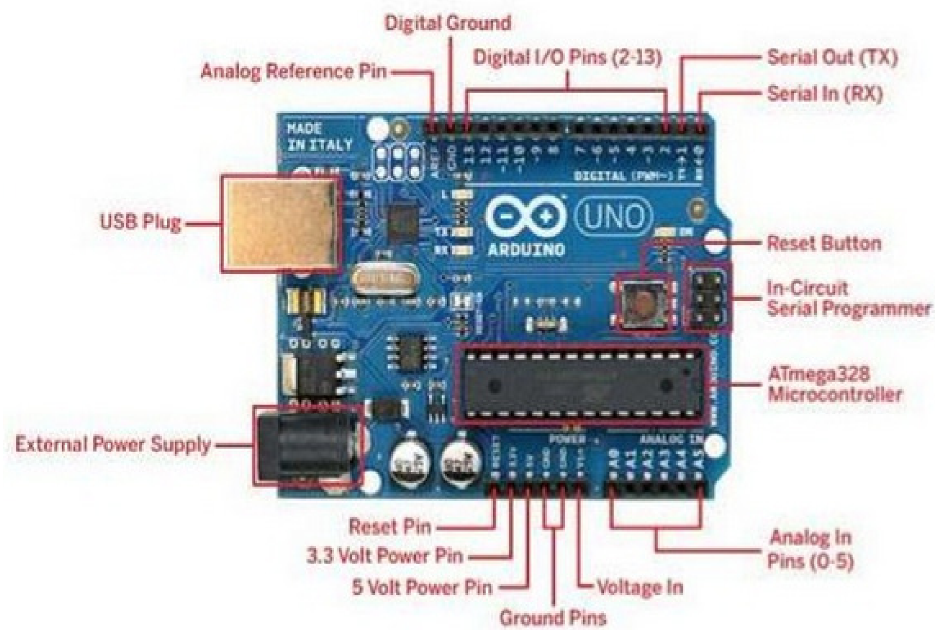

Figure 3.23: Arduino Uno R3 and the pin mapping

The Arduino programs could be written in the interface provided by the Arduino integrated development environment (IDE). The programming language used in the project is C++ language.

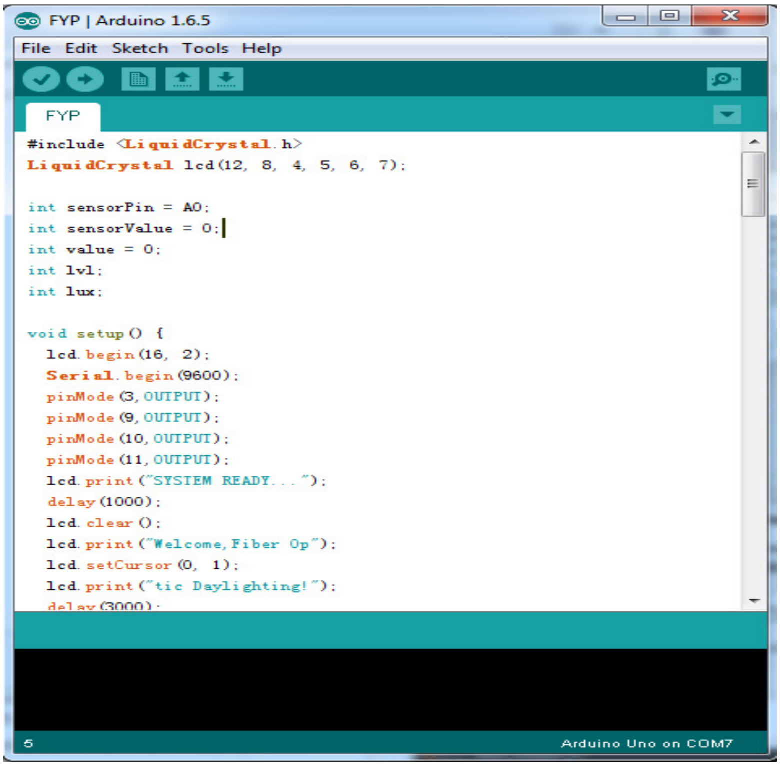

Figure 3.24: Screenshot of the Arduino IDE

3.3.2 LCD display

A 2x16 LCD display is used to show the value of light intensity in the room and also the light level provided by the LEDs. This is implemented to show the room light intensity and the LED light level at every interval. The pinout for 2x16 LCD module is shown below. In this project, the data pin used in only 4-bit which is DB4 to DB7 pins.

Pin No	Function	Name
1	Ground (0V)	Ground
2	Supply voltage; 5V (4.7V – 5.3V)	Vcc
3	Contrast adjustment; through a variable resistor	V_{EE}
4	Selects command register when low; and data register when high	Register Select
5	Low to write to the register; High to read from the register	Read/write
6	Sends data to data pins when a high to low pulse is given	Enable
7	8-bit data pins	DB0
8		DB1
9		DB2
10		DB3
11		DB4
12		DB5
13		DB6
14		DB7
15	Backlight V_{CC} (5V)	Led+
16	Backlight Ground (0V)	Led-

Figure 3.25: Pin description of 2x16 LCD module

The schematic circuit for connecting both the Arduino Uno and LCD display is shown below.

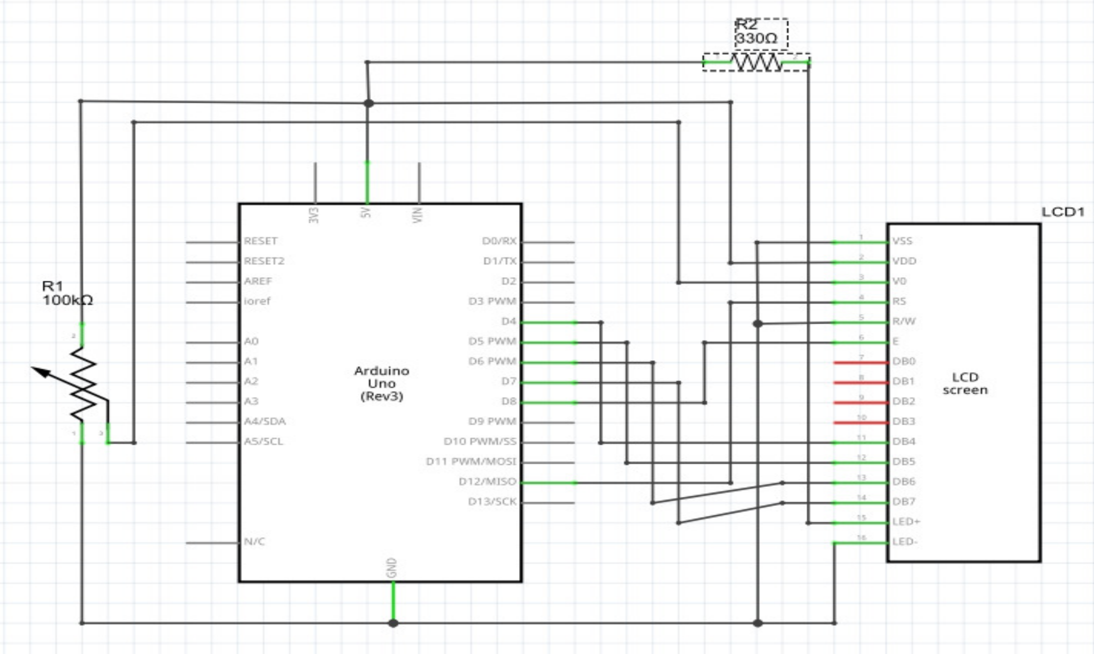

Figure 3.26: Schematic circuit for LCD with Arduino Uno.

3.3.3 Photodiode Light Sensor

In order to detect the light intensity from the optical fiber, a photodiode sensor which is a light sensor is used. The model of photodiode chosen for the system is BPW21, which acts as an exposure meter for both the daylight and also artificial light. This BPW21 is a silicon photodiode which is especially suitable for the applications in visible spectral range which can measure from 350nm to 820nm.

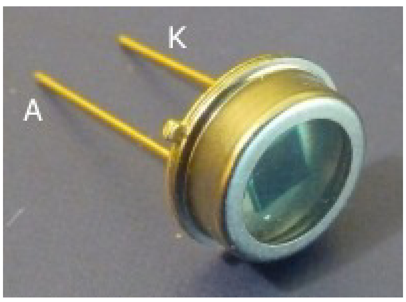

Figure 3.27: BPW21 silicon photodiode for visible spectrum.

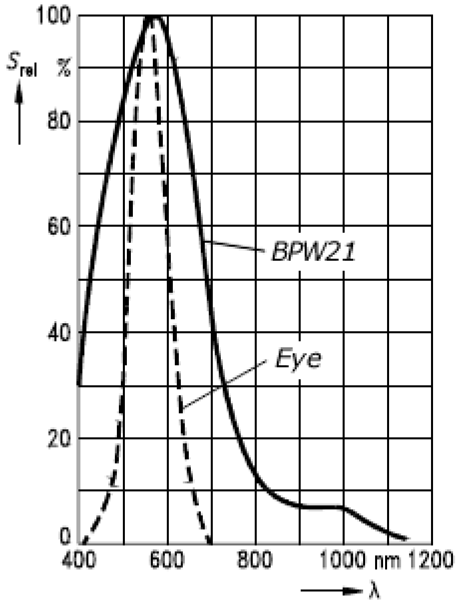

Figure 3.28: Relative Spectral Sensitivity of bpw21

The light intensity in term of lux can be obtained from the graph below. Every single value of light intensity will give a specific current or voltage in respective unit. Since the photocurrent has a linear characteristic versus the light intensity, the light intensity could be obtained given the current. However, because the current given is so small that the multi-meter would not able to measure, so an amplifier circuit is done to amplify the signal.

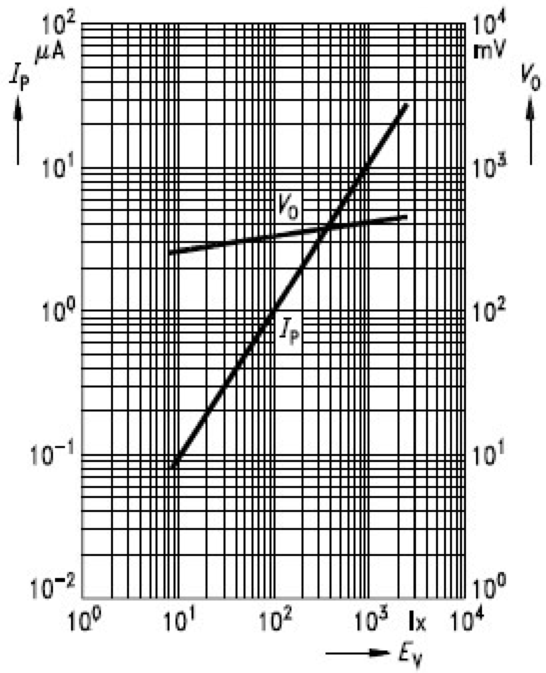

Figure 3.29: Transfer Characteristic of BPW21

The precision zero-drift LTC1050 operational amplifier has an excellent performance and provides low noise, so it is chosen to be used in amplifying the signal.

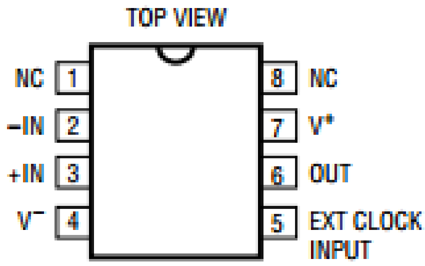

Figure 3.30: LTC1050 operational amplifier and its pinout

The photodiode first generated certain value of current when exposed to the certain light intensity, then this amplifier circuit act as an trans-impedance amplifier will convert the current into voltage by the following equation.

$V_{out} = I_{photo} \times R$,   R = feedback resistance.

The output voltage will be feed into Arduino's analog input so that it can perform analog to digital conversion which the digital value are useful in controlling the brightness of led. The feedback resistor, R value determines the amplification and also the sensitivity of the photodiode. The capacitor placed in parallel to the resistor plays an important role in stabilize the amplifier.

According to the specification of bpw21 photodiode, it has the spectral sensitivity of 10nA/lux. In this case, a normal room condition would require 500 lux but the R value is chosen as 500k so that it could detect wider range of light intensity from 0-1000 lux. This 1000 lux will in turn give a voltage of 5V which is the maximum voltage the Arduino's analog input can receive. The output voltage, Vout will be connected to the analog input, A0 pin of the Arduino board. This photodiode will be placed beneath of the room so that it can keep track the light intensity of the room.

3.3.4 Artificial Light

Artificial light plays an important role in make up the light intensity of an interior space to a required level whenever the daylight coming out from the bundles of optical fiber is not enough to fulfil the light level due to cloudy day and eventually at night time. For this, Light Emitting Diodes (LEDs) are chosen to be used as artificial light and the model used is LUW W5AM-KYLX-4E8G, a high power led with white light source at colour temperature of 5700k which is in the similar range of daylight that is from 5000k to 6000. It provides a high brightness illumination and allows the design of small and limited space applications which is suit for the testing box used in this system. This LED is used for general lighting purpose and application such as resident and commercial architectural lighting.

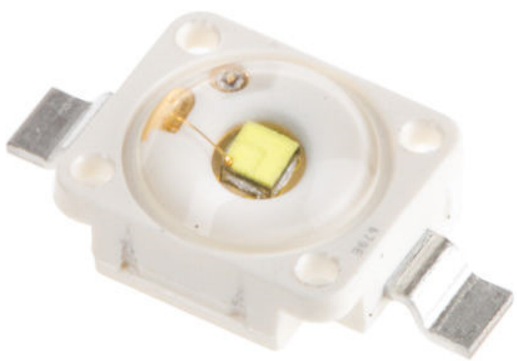

Figure 3.31: LUW W5AM High Power white Led, 5700K

3.3.4.1 LED driver

To operate the LED, a driver is used so that it can provide a constant current and thus brightness for illumination. Considering that the Arduino can only supply up to 40mA per pin, thus an external amplification system is needed to supply more current to the LEDs. In the lighting system, four LEDs will be used to compensate the light from optical fiber. They are placed at four corners surrounding the bundles of optical fiber at center. They were drived by using the PWM pins on the Arduino.

Figure 3.32: Led placement

Figure 3.33: Led placed at four corners.

These LEDs need more currents in order to have brighter illuminance. Therefore, the current supply from the Arduino Uno is further amplified using 2N2222 transitor with a power supply. The resistance value in the circuit is calculated so that it will provide roughly 0.2A current to four LEDs. The schematic drawing is shown below.

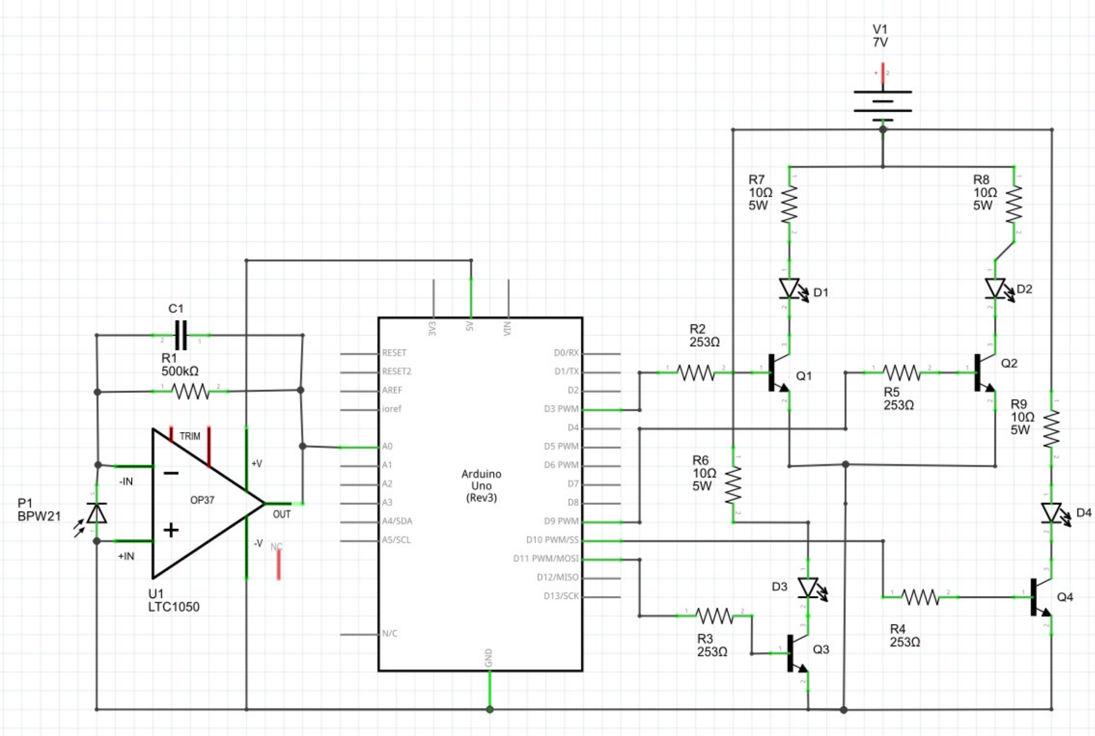

Figure 3.34: Schematic drawing for the transistor amplifier circuit and photodiode sensor.

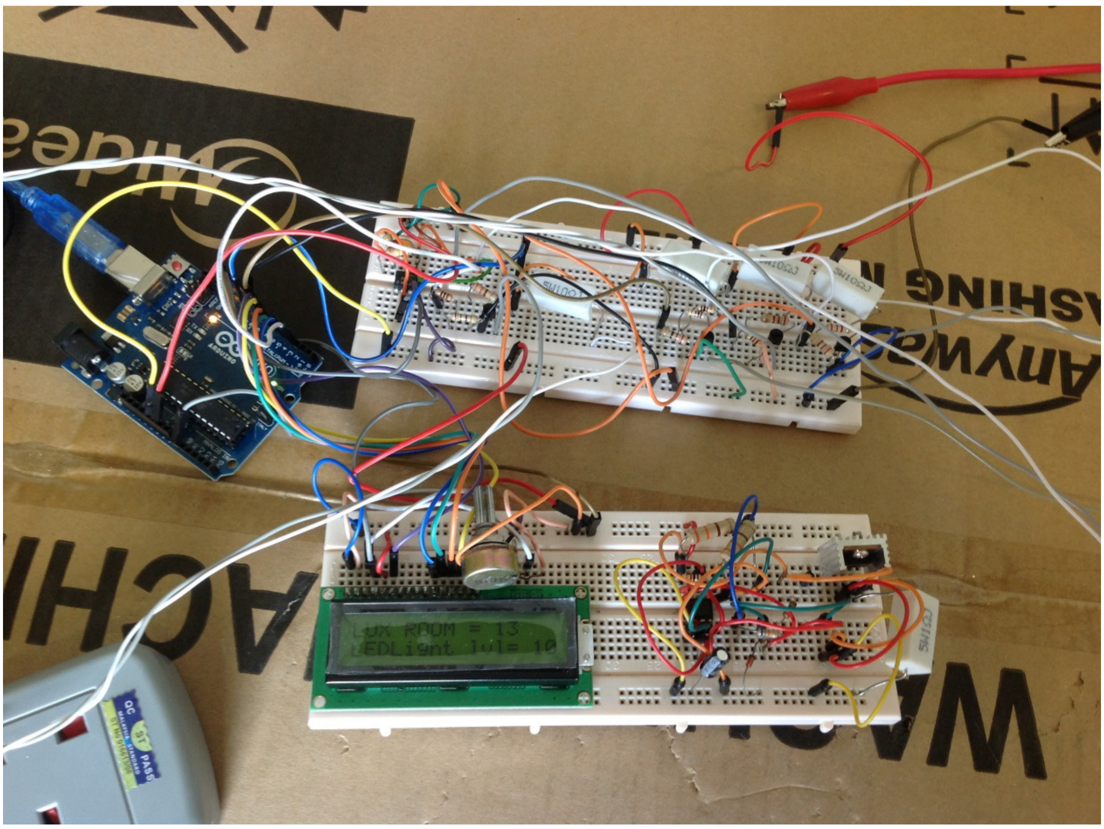

Figure 3.35: Completed construction of the circuit.

3.4 Methodology calculation

A rough estimation of the light intensity collected and also the illuminance needed to light up an office and testing box was calculated. It would give a rough figure of how many bundles of optical fiber or LEDs needed.

Table 2 Two-stage non-imaging dish concentrator parameters

Parameters	Value
Dimensions of a primary mirror : length x width (m)	0.05 x 0.05
Area of a primary mirrors (m^2)	0.0025
Number of primary mirrors	80
Area of 80 primary mirrors, A (m^2)	0.2
Specular reflectivity of sliver coated mirrors, *p*m	0.94
Hot Mirror transmissibility of visible light	0.98
Core reflective index of POF	1.49
Numerical aperture of POF	0.5
Maximum operating temperature of POF ˚C	70
Plastic optical fiber, POF length L (m)	10
Diameter of POF (mm)	3
Transmission loss of POF (dB/km)	200
Typical solar radiation, I (W/m^2)	1000
Visible light (%)	47
Infrared ray (%)	46
Ultraviolet light (%)	7
Luminous efficacy for direct (beam) component (lm/W) in Subang	104

The following calculations are used to find out how much energy presented at the target point:

The power captured by all the primary mirrors = I x A $=1000W/m^2 \times 0.2m^2 = 200W$

The power after two-stage reflection = 200W x 0.94 x0.94 = 176.72W

The visible light power as 47% of total spectrum = 176.72W x 0.47 = 83.06W

The visible light after the hot mirror filter = 83.06W x 0.98

Thus, the illuminance = luminious efficacy x power of visible light

=104lm/W x 81.389W = 8464.45 lm.

A target point of $2500mm^2$ will have approximate 8464.45 lumens and thus the lumen that a bundle of optical fiber can carry is calculated.

Area of a bundle of optical fiber was done by the Solidworks.

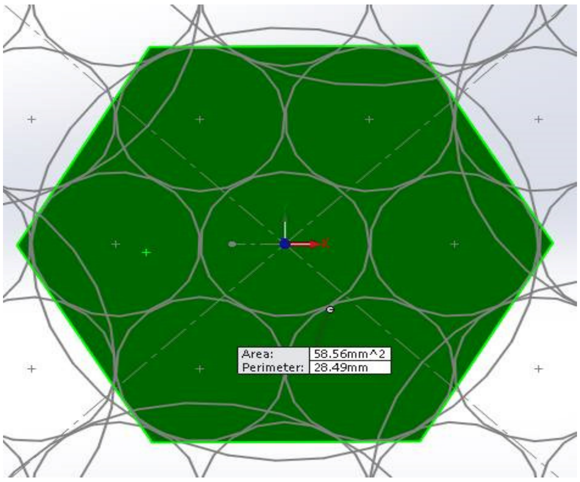

Figure 3.36: Area of a bundle of optical fiber.

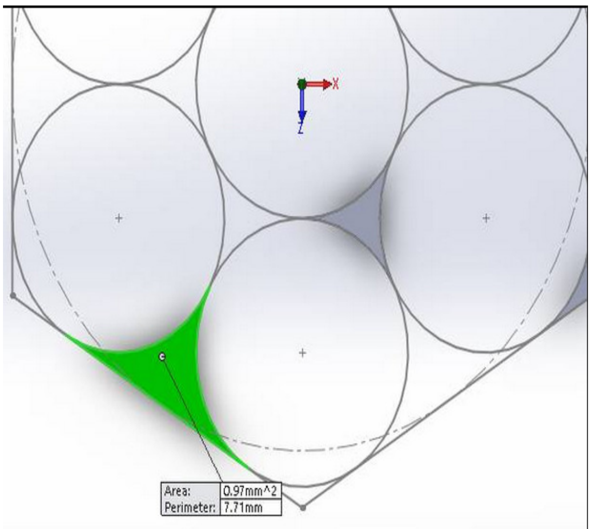

Figure 3.37: Gap area 1

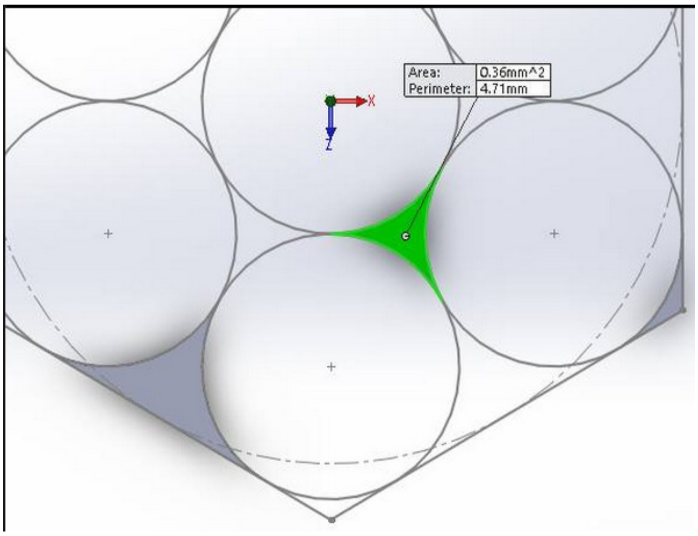

Figure 3.38: Gap area 2

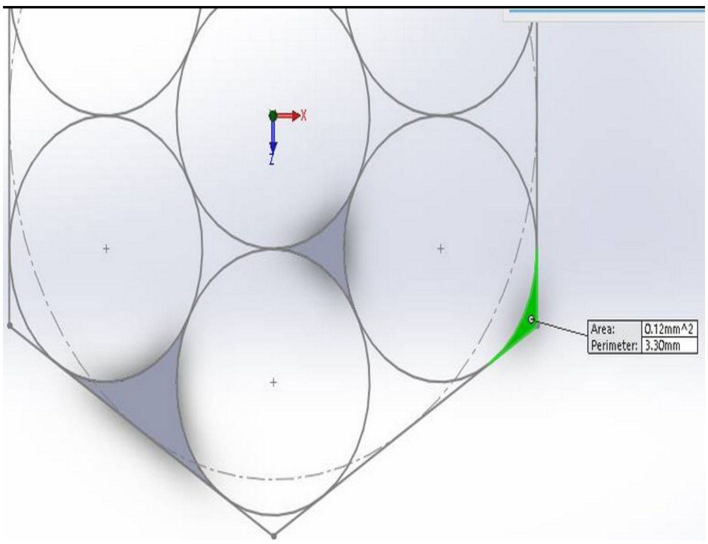

Figure 3.39: Gap area 3

With the gaps area listed, an effective area for a bundle of optical fiber was calculated.

Effective area = $58.56\text{mm}^2 - (0.36\text{mm}^2 \text{x}6) - (0.97\ \text{mm}^2\ \text{x}6) - (0.12\ \text{mm}^2\ \text{x}6)$

$= 49.86\ \text{mm}^2$ which is equal 85%.

This area will in turn give 168.8 lumens when compared with the 2500 mm^2 target area based on the ratio. Since the optical fiber used is 10m, the total loss incurred that calculated from calibration of cutback testing is 45.7%. Therefore, the lumen produced at the other end of a bundle of optical fiber is expected to be 76 lumens.

It is recommended that standard office which is used for the purpose of reading, typing and writing to have the illuminance of 500 lux. A standard office room will have an area of $6.5m^2$ ($70ft^2$). The dimensions and plan of the office were shown below.

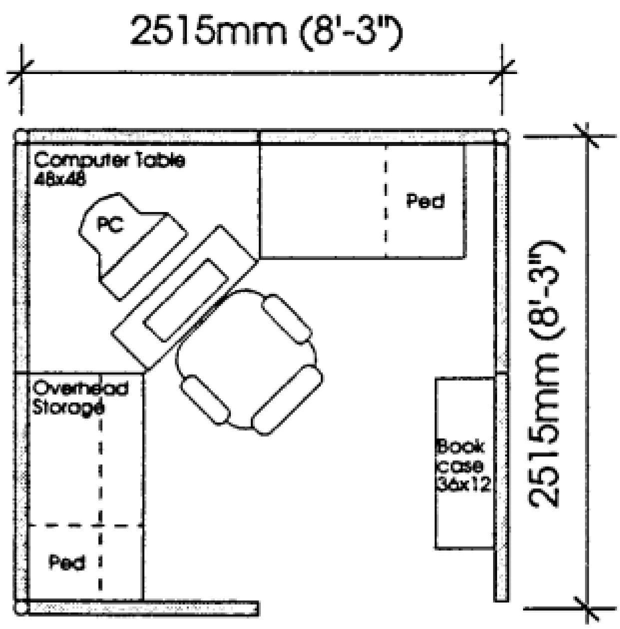

Figure 3.40: Dimension and plan for standard office (6.5m2).

For the testing purpose, a box with dimensions of 57cmx58cmx125cm was constructed and used in the testing.

Figure 3.41: Replacement of room by a box.

The following formula is used to convert the unit of light intensity from lumen to lux.

$$\text{Illuminance (lux)} = \frac{luminous\ flux(lumen)x\ coefficient\ of\ utilizationx\ light\ loss\ factor}{Total\ Area}$$

Coefficient of utilization = measure of how well the light emitted onto a particular area which is assumed to be 0.8 for this case.

Light loss factor = light loss due to the degradation of product or fixture of luminaire and it is not encountered in the optical fiber. The typical factor for led is assumed to be 0.9.

The lumen required is calculated below.

1) For daylight from optical fiber in standard office:

$$500 = \frac{lumen\ x\ 0.80}{6.5}$$

lumen = 4062.5 lm needed to achieve 500lux

Therefore, the bundles of optical fiber needed is 4062.5/76 ≈ 53 bundles.

2) For daylight from optical fiber in box of area 0.3306 m^2:

$$500 = \frac{lumen\ x\ 0.80}{0.3306}$$

$$\text{lumen} = 206.625 \text{ lm needed to achieve 500lux}$$

Therefore, the bundles of optical fiber needed is 206.625/76 ≈ 3 bundles.

The LEDs used in the project will produce a 104 lumen per watt with the forward voltage, V_f of 3.2V at 350mA current.

1) For LEDs in standard office:

$$500 = \frac{lumen\ x\ 0.80x\ 0.9}{6.5}$$

$$\text{lumen} = 4513.8 \text{ lm needed to achieve 500lux}$$

Therefore 44 LEDs given at 350mA will be needed.

2) For LEDs in box of area 0.3306 m^2:

$$500 = \frac{lumen\ x\ 0.80x\ 0.9}{0.3306}$$

$$\text{lumen} = 229.58 \text{ lm needed to achieve 500lux}$$

Therefore 2 LEDs given at 350mA will be needed.

CHAPTER 4

Result and Discussion

4.1 Hot mirror transmission performance.

Although the transmission of hot mirror was specified in the datasheet, a confirmation of the result was done by doing another experiment using Avantes NIR spectrometer. This NIR spectrometer is used to detect the irradiance of the sunlight with spectrum range from 200nm to 1753nm. The result has been taken in a day with good condition of sunlight. The result before and after placing the hot mirror was collected and plotted in excel graph is shown below. The absorption of the hot mirror was also plotted.

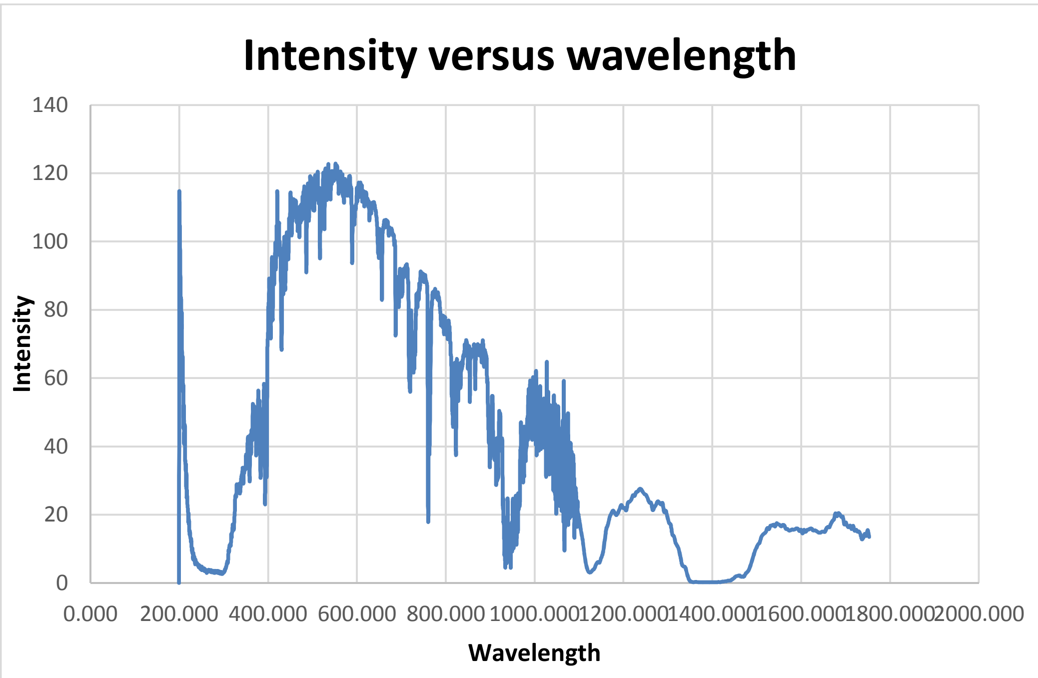

Figure 4.1: Intensity of sunlight before hot mirror.

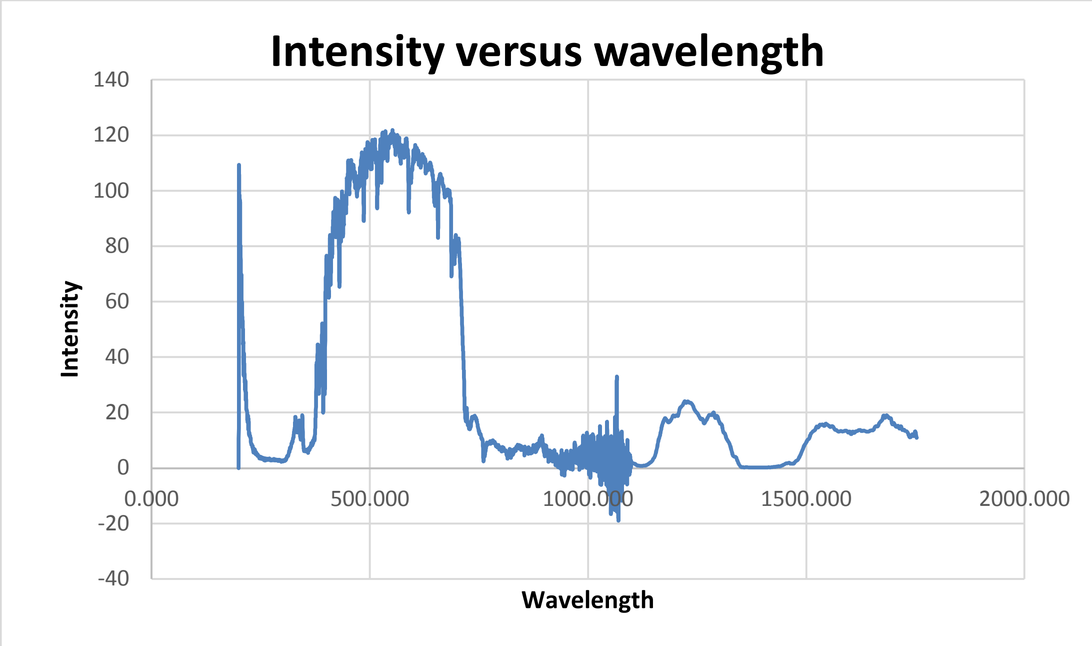

Figure 4.2: Intensity of sunlight after the hot mirror

It can be seen from the graph that the hot mirror filtered out most of the intensity below 380nm and above 710nm, passing average of 98% of the visible light.

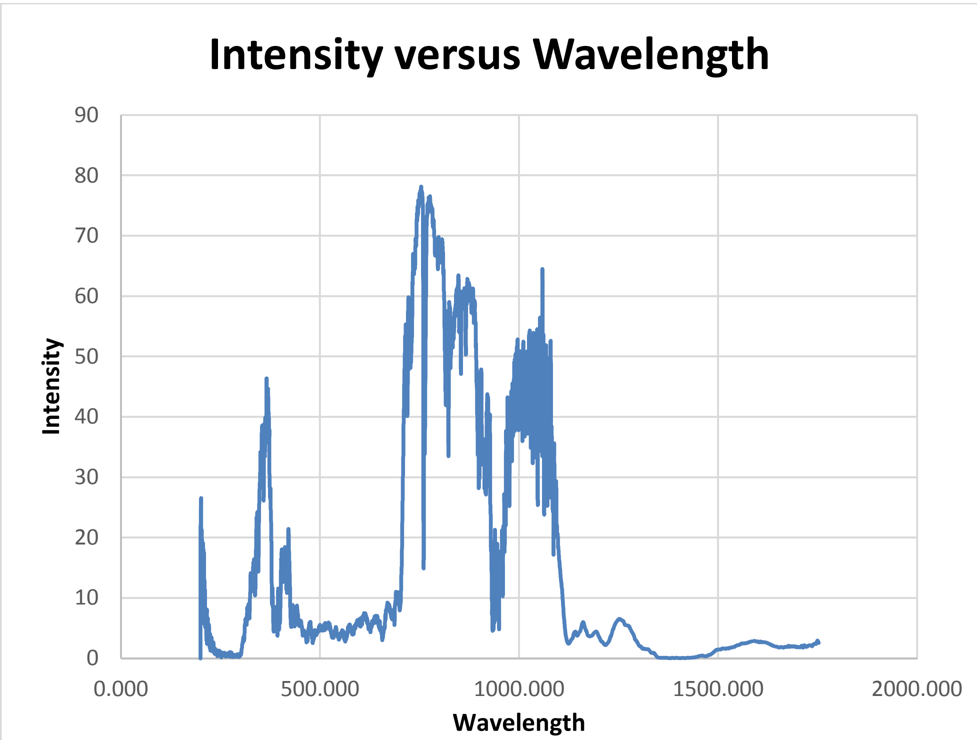

Figure 4.3: Reflection of Hot mirror

For the reflection of the hot mirror from the data collected, after comparison, it reflected an average of 98% of infrared ray and average of 70% of ultraviolet light. Thus, after utilize the hot mirror, total energy transmitted by thermal radiation will be cut down almost by half. The hot mirror could significantly reduce the heat problem suffered by optical fiber.

4.2 Optical transmission loss and attenuation

The calibration for the transmission loss of optical fiber was carried out in Mechanical lab. The equipment used in this experiment involves the polishing machine as shown below.

Figure 4.4: Polishing Machine

The polishing is done by placing the sand paper onto the polishing machine. This experiment is also to find out the difference for each sand paper grade and their effect on the optical fiber surface. The rotating speed will be adjusted to 250 rpm speed and the some water is allowed to flow in the process of polishing to ease the polishing process. The result for the polishing was tabulated in the table below.

Cutback testing

Light onto the hole of solar cell				Surrounding light			
V =	0.932V	I=	58.5uA	V=	3.14mV	I=	0.04uA

Table 3: Before polishing for 10m optic fiber

Length of fiber optic (Cut) (m)	Current (uA)	Voltage(V)
9.91	15.32	0.523
9.89	15.44	0.527
9.87	15.59	0.532
9.85	15.68	0.536
9.83	15.80	0.540
9.81	15.87	0.540
9.79	15.92	0.539
9.77	16.13	0.541
9.75	16.16	0.540
9.73	16.20	0.541
9.71	16.22	0.542

Table 4: Polishing (current)

Length of fiber optic (Cut) (cm)	Sand paper grade				
	400	800	1200	1500	2000
	Current(uA)	Current(uA)	Current(uA)	Current(uA)	Current(uA)
9.91	15.31	15.48	15.65	15.95	16.19
9.89	15.35	15.56	15.68	15.98	16.21
9.87	15.37	15.59	15.73	16.00	16.22

9.85	15.39	15.61	15.76	16.03	16.24
9.83	15.44	15.62	15.78	16.05	16.27
9.81	15.45	15.66	15.82	16.10	16.30
9.79	15.50	15.69	15.88	16.12	16.32
9.77	15.54	15.71	15.93	16.18	16.37
9.75	15.56	15.76	16.00	16.20	16.39
9.73	15.59	15.78	16.04	16.23	16.40
9.71	15.60	15.81	16.07	16.26	16.42

Table 5:Polishing (voltage)

Length of fiber optic (Cut) (cm)	Sand paper grade				
	400	800	1200	1500	2000
	Voltage(V)	Voltage(V)	Voltage(V)	Voltage(V)	Voltage(V)
9.91	0.527	0.532	0.536	0.543	0.549
9.89	0.527	0.530	0.538	0.543	0.549
9.87	0.527	0.531	0.537	0.543	0.550
9.85	0.528	0.532	0.537	0.543	0.550
9.83	0.527	0.532	0.537	0.544	0.550
9.81	0.527	0.531	0.537	0.544	0.550
9.79	0.526	0.53	0.536	0545	0.550
9.77	0.526	0.531	0.537	0.543	0.549
9.75	0.527	0.530	0.536	0.543	0.549
9.73	0.527	0.531	0.537	0.543	0.550
9.71	0.528	0.532	0.538	0.544	0.550

In this experiment, the value taken from the multi meter had encountered some errors which the voltage reading given by multi meter is ± 0.001V and the current reading having the errors of ± 0.03 uA. As seen from the data above, when the optical fiber is polished with more fine or higher grade of sand paper, the light intensity or the current of the solar cell increases. In the case where we uses 2000 grade sandpaper for polishing all the optical fiber, a graph of length of optical fiber versus the power was plotted to examine the attenuation.

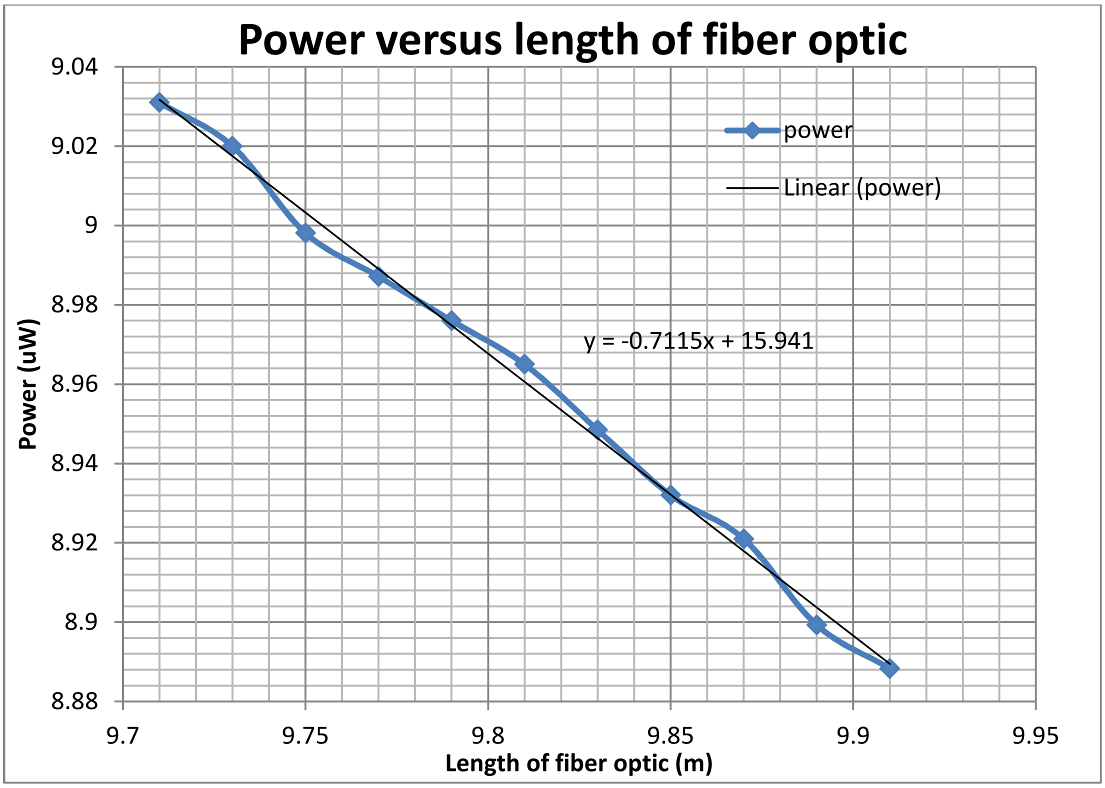

Figure 4.5: Power versus length of fiber optic

A linear equation of $y = -0.7115x + 15.941$ was generated by taking the averaging point. By substitution any two length of optical fiber to the above equation to get the power for each length, the attenuation can be calculated from the equation given.

Because the Py which is the input power into the optical fiber which is unknown, so by having two Px value from substituting the length into the new equation $y = -0.7115x + 15.941$ with length to get the power and equating them together and solve using the equation.

$$\alpha(dB/m) = \frac{10\log_{10}(Px/Py)}{L}$$

It would give the Py. Thus, the attenuation,α can be calculated. From the calculation, the attenuation was found to be 0.3618dB/m. This value is slightly higher than the attenuation specified in the datasheet, which is 0.2dB/m. This is because the light source used is of white light LED and the testing used a single wavelength 650nm collimated light. The source used in the experiment is a broadband light source comprised of different wavelength, thus having different index and give a higher error. The loss calculated is the total loss from both the transmission loss and the coupling loss. So a 10 meter long optical fiber is expected to have 45.7% loss.

4.3 Surface of optical fiber

The surface of optical fiber is very important in order to ensure a better coupling of light and better light capturing. In this part, three different surface of optical fiber which is unpolished, polished with grade of 1000 and 2000 sand paper were study and examined under the microscope of different magnification. The result was shown in the figures below.

The microscope's magnification scale of 50x is shown below:

Figure 4.6: Unpolished

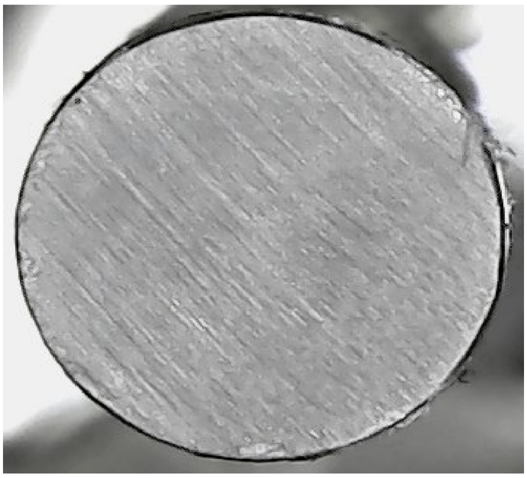

Figure 4.7: 1000 grade sandpaper polish

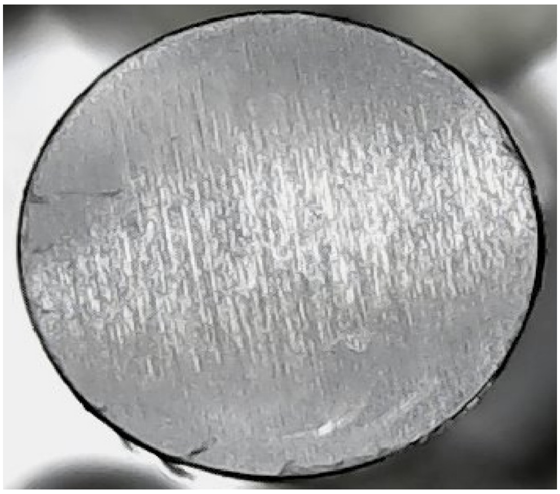

Figure 4.8: 2000 grade sandpaper polish

The microscope's magnification scale of 500x is shown below:

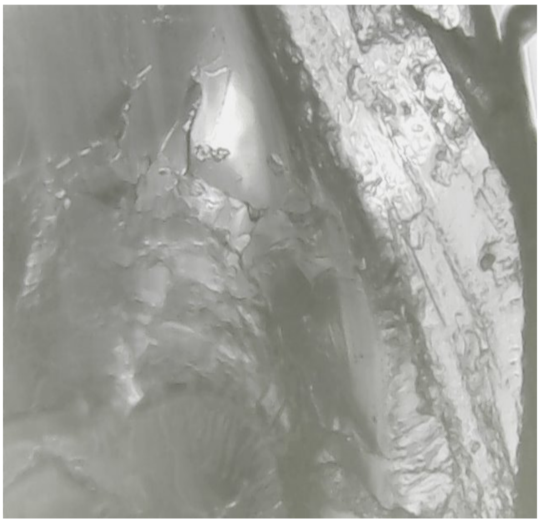

Figure 4.9: Unpolished

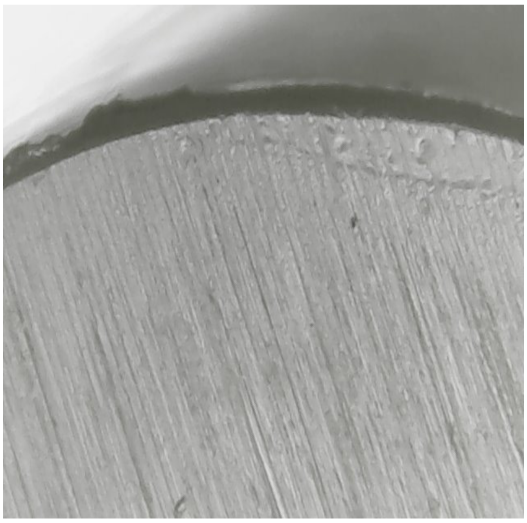

Figure 4.10 1000 Grade sandpaper polish

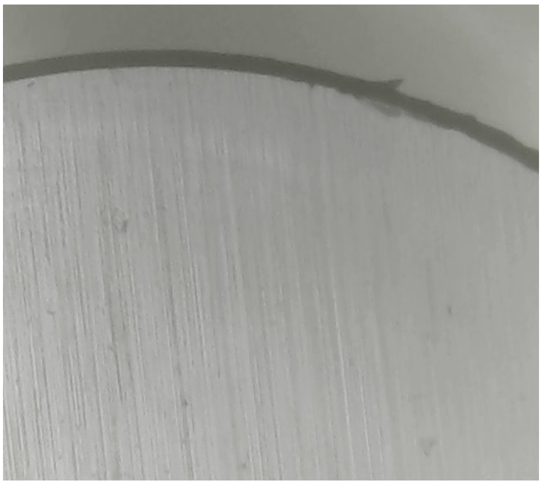

Figure 4.11: 2000 Grade sandpaper polish

The microscope's magnification scale of 1000x is shown below:

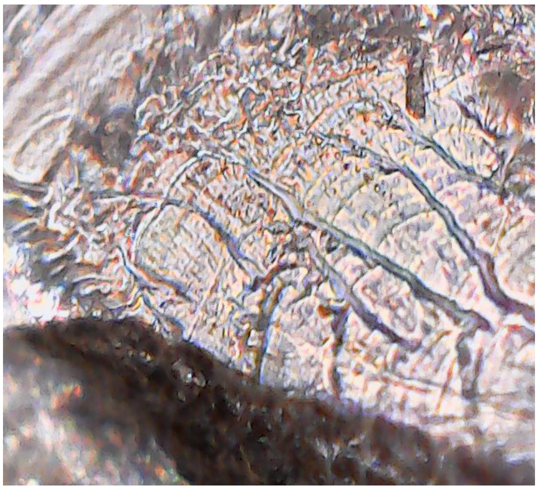

Figure 4.12: Unpolished

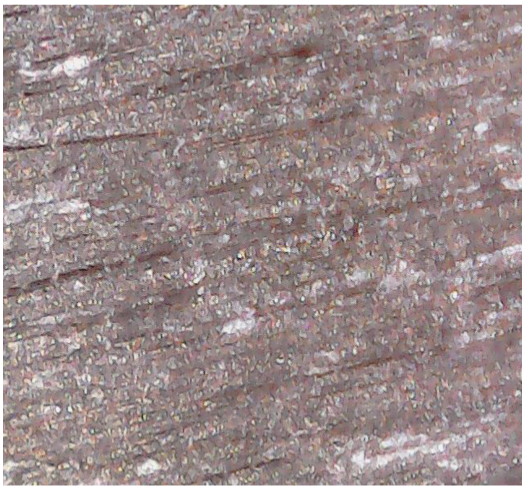

Figure 4.13: Grade 1000 polish

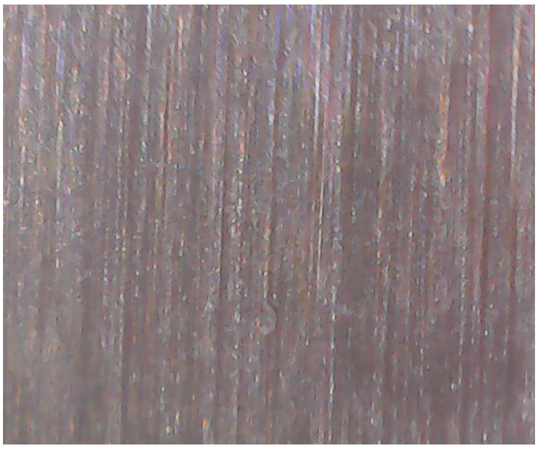

Figure 4.14: Grade 2000 polish

The figures above clearly show that whenever the optical fiber is polish with fine sandpaper, the surface become more uniform and smooth. Thus, it will have a better outcome and effect in capturing the sunlight. Therefore, polishing has to be done in order to increase the efficiency of the optical fiber.

4.4 Lighting system

4.4.1 LCD Display result

The LCD display will display the operation taken by the lighting system.

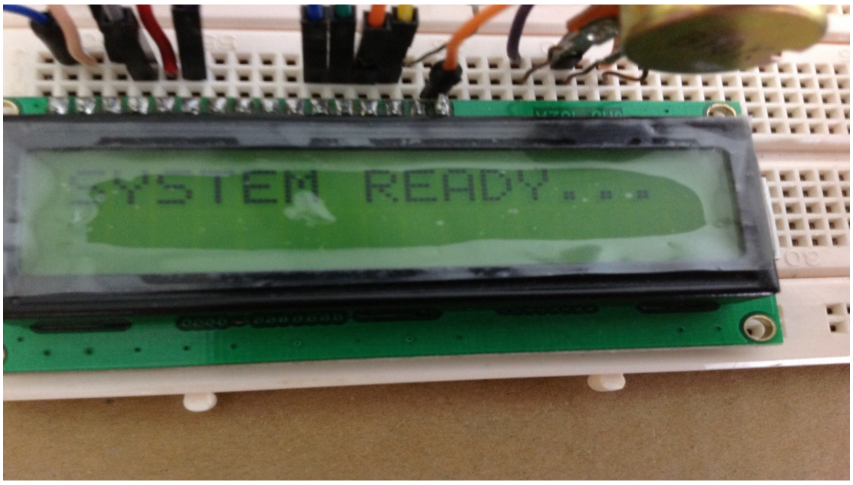

Figure 4.15: Indication of system setting up

Figure 4.16: LCD display

The LCD will display the light intensity measured by the photodiode and also the LED brightness level. For instance, the illuminance of the room is low, it will turn on the LEDs to fulfil the light intensity of 500lux.

Figure 4.17: LCD showing the lux of a room and led bright level

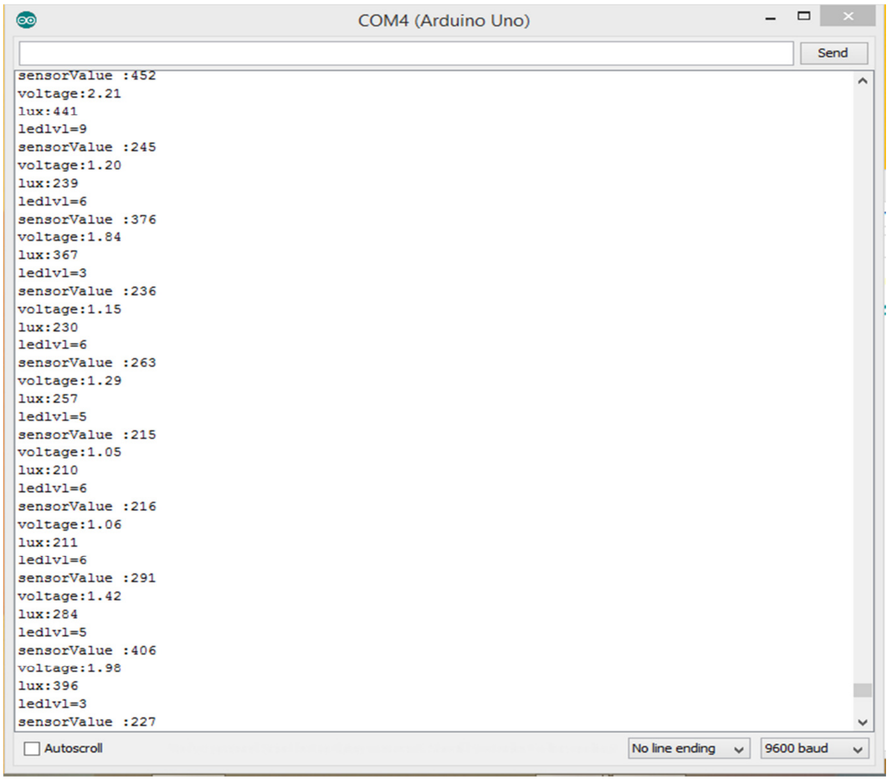

Figure 4.18: Arduino interface showing the result for the lighting system.

4.4.2 Prototype testing

Figure 4.19: one bundle of arranged in a hexagon like shaped.

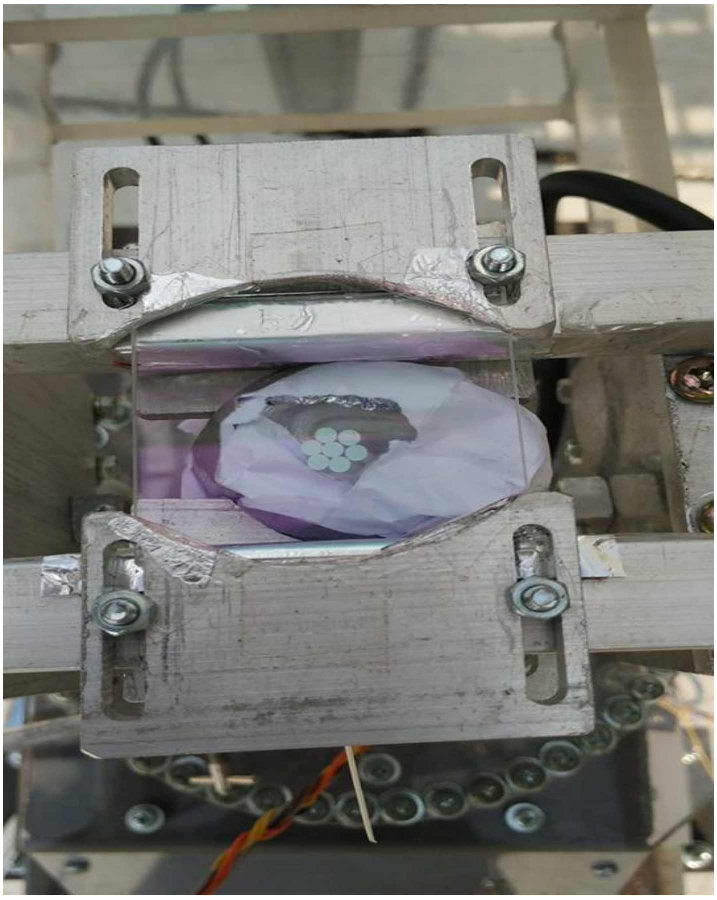

Figure 4.20: the mounting of a bundle of optical fiber after Hot Mirror

The lighting system was tested on the rooftop of KB block.

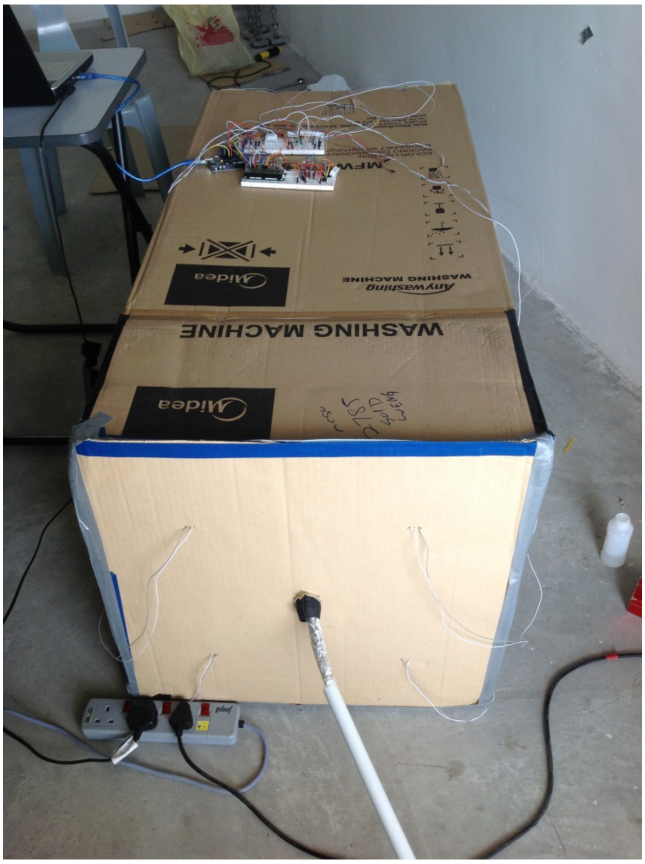

Figure 4.21: Testing process for lighting system

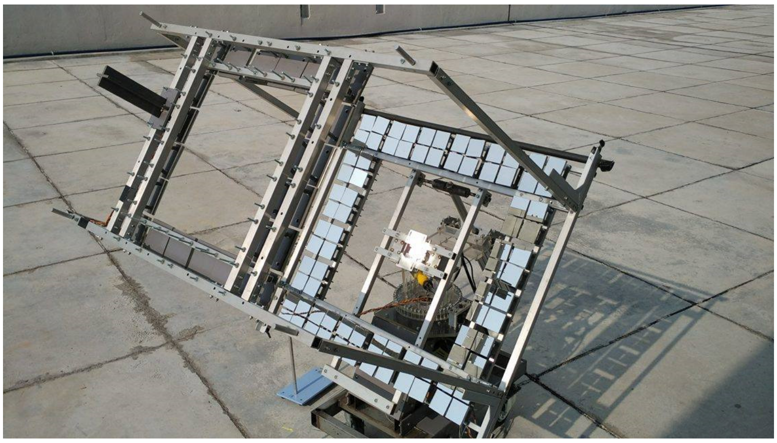

Figure 4.22: working prototype of two-stage dish concentrator

Figure 4.23: The optical fiber was clamped with a retort stand to fix the position.

The four LEDs were mounted at 4 corners and the bundles of optical fibers at middle.

Figure 4.24: Indoor condition of the room

Figure 4.25: Lux meter for measuring light intensity

CHAPTER 5

Conclusion and Recommendations

5.1 Discussion and Improvements

In this project, many problems have been encountered and there are still some room for the improvements or modifications can be done. The improvements and the overall performance will be discussed to fine-adjust the system to achieve a better efficiency.

5.1.1 Mechanism design

In the design of this two-stage non-imaging dish concentrator, there are many spaces not being used in the system in collecting the sunlight. If these wasted spaces could be used, it could have generated a more concentrated sunlight onto the target point and thus achieve a better efficiency for the system. To collect more sunlight, a larger area of mirror or more number of mirrors maybe implemented.

5.1.2 Dusty environment

Because this system involving the outdoor condition, it is rather difficult to maintain the efficiency because the dusty environment will cause the dirt to stick on the mirrors, the hot mirror, and also the optical fiber at the surface end. It would need a regular maintenance by cleaning them with alcohol in order to maintain the efficiency.

5.1.3 Heat and Degradation problem

For the outdoor usage, the optical fiber is vulnerable to dusty environment even bundles of optical fiber are installed inside a PVC pipes. Besides, the efficiency of Hot mirror used in this experiment to resist the ultraviolet is lesser, so the optical fiber will be undergoes degradation after a certain period. Although the hot mirror was used to remove most of the infrared, it only cut down the total intensity by half. As a significant amount of energy is still in the visible region, no filter can remove or reduce that without directly making it darker. Therefore, a well-designed cooling system such as active cooling should be implemented so that the optical fiber can be operated at its comfort temperature.

5.1.4 Surface of optical fiber

When doing the cutting and polishing of the optical fiber, there is still some imperfection on the surface because it was done by human being and that contribute some man-made errors. As seen under the microscope, the surface of the optical fiber is not completely smooth and there are some epoxy residue existing on the surface after being polished.

5.1.5 Lighting system

The photodiode used in this project may encounter some problem such as the limitation in the detection zone for light intensity. The photodiode was proposed to be put at the side of bundles of optical fiber instead of putting at the bottom of the room. In this way, it would not be blocking any light coming out to the room as there is some light at emitting end of the optical fiber. A calibration has to be done by comparing the light coming out from the emitting end and at the side of the optical fiber. Besides, the light emitting from optical fiber is of small angle and a light dispersing element such as acrylic lens diffuser can be used to spread the light to illuminate to all angles of the room.

5.2 Conclusion

The prototype of this two-stage non-imaging dish concentrator (NIDC) with the use of 5cm x5cm primary mirror was successfully developed with basic requirements. It was able to collect highly concentrated sunlight onto the target point and the guidance of sunlight into interior room through plastic optical fiber for solar day-lighting system was completed. A hybrid lighting system was also implemented t compensated the light from the optical fiber. However, the fine adjustment to the light compensation system by LEDs was not yet completed. In short, this project was very interesting and definitely challenging to me.

5.3 Future Research and development

A fine adjustment onto the lighting compensation system can further be done to provide a much more satisfy outcome. Moreover,the evaluation and feasibility report of this daylighting system using two-stage non-imaging dish concentrator to be studied. Some indoor lighting simulation software can be used to verify with the data collection of the daylighting system. The overall performance of this system could be compared with other conventional design.

REFERENCES

Alata, M., Al-Nimr, M. and Qaroush, Y. (2005). Developing a multipurpose sun tracking system using fuzzy control. Energy conversion and management, 46(7), pp.1229--1245.

A. Cziker, M. Chindris and Anca Miron. (n.d). Fuzzy controller for a shaded daylighting system.

M. Amin, N. Ken. (2014). Photovoltaic generation power improvement using freshnel condenser lens. International Confession on Advanced Mechatronic Systems.

J. F Song, Y. Zhu, J, Zhou and Y.P. Yang. (2014). Daylighting system via fibers based on two-stage sun tracking model. Solar Energy, 108, pp. 331-339.

J. Gu, F. Qing, L. Hua, X. Guo, L. LV, and Y. Yuan. (2011). The design of one controlling circuit for solar lighting system. International Conference of Information Science and Technology.

J. K. Kim, and J. James. (1993). A conceptual framework for dynamic control of daylighting and electrical lighting systems.

K. K Chong, C. W. Wong, F. L. Siaw, and G.S. Wong. (2008). Design and construction of non-imaging planar concentrator photovoltaic system. Renewable Energy. 34(5).

K. K. Chong, C. W. Wong, F. L. Siaw, and T. K. Yew. (2010). Optical Characterization of Nonimaging Planar Concentrator for the application in concentrator photovoltaic system. Solar Energy.

M. H. Tan, K. K. Chong, and C. W. Wong. (2014). Optical Characterization of nonimaging dish concentrator for the application of dense-array concentrator photovoltaic system. Solar Energy.

M. Xu, X. Cao, and S. Weng. (2011). Daylighting system controller and software design.

T. Li, F. Yang, and C. Yuan. (2013) A novel parabolic trough solar lighting and thermal system for building energy efficiency. IEEE International Conference on Automation Science and Engineering.

T. Lerdlekha, and S. Kumar. (2008). A simple control method for daylighting in passive solar design: A case study of Bangkok, Thailand.

Ullah, I. and Seoyong, S. (2013). Concept of solar tower for daylighting in multi-floor buildings. Green science and technology.

Ullah, I. and Seoyong, S. (2013). Development of optical fiber-based daylighting system with uniform illumination. Optical Society, 16(3), pp. 247-255

Ullah, I. and Seoyong, S. (2012). Development of optical fiber-based daylighting system with collimated illumination. 17th Opto-Electronics and Communication Conference.

Ullah, I. and Seoyong, S. (2013). Uniformly illuminated efficient daylighting system. Smart Grid and Renewable Energy, 4, pp. 161-166

L. Sedki. And M Mohamad.(2016). Performance assessment of installed low cost solar daylighting system via optical fiber.

X. Zhang, T. Li, L. Hou, X. Song, and J. Chuan. (2010). Research of fiber optic lighting system of solar energy.

APPENDIX

APPENDIX A: CODING

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(12, 8, 4, 5, 6, 7);

int sensorPin = A0;
int sensorValue = 0;
int value = 0;
int lvl;
int lux;

void setup() {
  lcd.begin(16, 2);
  Serial.begin(9600);
  pinMode(3,OUTPUT);
  pinMode(9,OUTPUT);
  pinMode(10,OUTPUT);
  pinMode(11,OUTPUT);
  lcd.print("SYSTEM READY...");
  delay(1000);
  lcd.clear();
  lcd.print("Welcome,Fiber Op");
  lcd.setCursor(0, 1);
  lcd.print("tic Daylighting!");
  delay(3000);
  lcd.clear();
}

void loop() {
   sensorValue = analogRead(sensorPin);
   float voltage = sensorValue*(5.0/1023.0);

   Serial.print("sensorValue :");
   Serial.println(sensorValue);
   Serial.print("voltage:");
   Serial.println(voltage);
   lux = voltage/0.005;
   Serial.print("lux:");
   Serial.println(lux);
   adc();
   Serial.print("ledlvl=");
   Serial.println(lvl);

   lcd.setCursor(0,0);
   lcd.print("                ");
   lcd.setCursor(0,0);
   lcd.print("LUX ROOM = ");
   lcd.setCursor(11,0);
```

```
    lcd.print(lux);
    lcd.setCursor(0,1);
    lcd.print("                ");
    lcd.setCursor(0,1);
    lcd.print("LEDLight lvl= ");
    lcd.setCursor(14,1);
    lcd.print(lvl);
    delay(1000);
}

void adc(){
  if(lux >=0 && lux <=50)
    {
       lvl=10;
       analogWrite(3,216);
       analogWrite(9,216);
       analogWrite(10,216);
       analogWrite(11,216);

    }
    else if(lux >50 && lux <=100)
    {
      lvl=9;
       analogWrite(3,192);
       analogWrite(9,192);
       analogWrite(10,192);
       analogWrite(11,192);

     }
    else if(lux >100 && lux <=150)
    {
      lvl=8;
       analogWrite(3,168);
       analogWrite(9,168);
       analogWrite(10,168);
       analogWrite(11,168);

     }
     else if(lux >150 && lux <=200)
    {
      lvl=7;
       analogWrite(3,144);
       analogWrite(9,144);
       analogWrite(10,144);
       analogWrite(11,144);

     }
     else if(lux >200 && sensorValue <=250)
    {
      lvl=6;
       analogWrite(3,120);
       analogWrite(9,120);
       analogWrite(10,120);
       analogWrite(11,120);

     }
     else if(lux >250 && lux <=300)
    {
      lvl=5;
       analogWrite(3,96);
```

```
     analogWrite(9,96);
     analogWrite(10,96);
     analogWrite(11,96);

   }
   else if(lux >300 && lux <=350)
  {
    lvl=4;
     analogWrite(3,72);
     analogWrite(9,72);
     analogWrite(10,72);
     analogWrite(11,72);

   }
   else if(lux >350 && lux <=400)
  {
    lvl=3;
     analogWrite(3,48);
     analogWrite(9,48);
     analogWrite(10,48);
     analogWrite(11,48);

   }
   else if(lux >400 && sensorValue <=450)
  {
    lvl=2;
     analogWrite(3,24);
     analogWrite(9,24);
     analogWrite(10,24);
     analogWrite(11,24);

   }
  else if(lux >500)
  {
    lvl=1;
     analogWrite(3,0);
     analogWrite(9,0);
     analogWrite(10,0);
     analogWrite(11,0);

  }
}
```