# UTILIZATION OF DIRECT SOLAR RADIATION FOR INDOOR LIGHTING


By

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12899


Dissertation Submitted to the Department of Mechanical Engineering in Partial Fulfilment of the Requirements for the Degree Bachelor of Engineering (Hons) (Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

________________________________________

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TRONOH, PERAK

SEPTEMBER 2013

**CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken nor done unspecified sources or persons.

Produced by,

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YASHADINI ANANDARAJAH

# ABSTRACT

This study focuses on the development of an optical fibre based indoor lighting system through utilization of direct solar radiation. Using the approach of renewable energy which is the sun, this paper discusses the concept of the manifestation of solar radiation for indoor lighting. The study proposes a design of this system and also highlights the fabrication besides testing process. The design of the daylighting system is focused on. Parabolic design for the solar collector is discussed. A design of the overall working system is presented using AutoCAD software. Alternative approach using light refraction method is also focused on. The working principle of the optical fibre based indoor lighting system through light refraction method is highlighted. The efficiency of the system is also included in this study. Efficiency will be evaluated through monitoring and testing procedures. Tabulation of gathered data will also be displayed. An analysis on the optical fiber based day lighting system in Universiti Teknologi PETRONAS is also executed.

# ACKNOWLEDGEMENT

First and foremost, I would like to thank the almighty for making this dissertation a reality. Other than that, I take immense pleasure in thanking my direct supervisor Dr. Syed Ihtsham Ul Haq Gilani for his guidance throughout the progress of the final year project.On the other hand, I would also like to express gratitude to my co supervisor Dr. Hussain Hammud Ja'afer Al Kayiem for his continuous support in ensuring the completion of the final year project.Besides that,  I would also like to extend a note of acknowledgement to my family and peers for their moral support in the completion of the final year project. It would have been an impossible feat without the help I've been blessed with throughout the completion of this final year project. Last but not least, I am highly indebted to every party that has been responsible for the contribution towards the completion the final year project.

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# CHAPTER 1 INTRODUCTION

## 1.1 Background of Study

At present time, ever increasing demand for energy around the world has been a vital concern. Fossil fuel is hugely relied on as the main power generating source and the unsustainable feature of the fossil fuels has encouraged researchers to explore new ways of generating power through alternative energy.

It has been researched that about 30% of energy consumption at residential and commercial areas are used for lighting. In Malaysia itself, the yearly energy consumption is about Thus, this study focuses on reducing the energy consumption through the application of the direct solar radiation for the use of indoor lighting. By definition, lighting or illumination is the deliberate use of light to achieve a practical or aesthetic effect[1].There are two main types of lighting, mainly artificial and natural. Artificial lighting is the usage of lamps and bulbs to illuminate light through the use of electricity. Natural lighting is the direct lighting from the sun,which does not require electricity. Natural lighting is closely related to daylighting, which the use of solar radiation to illuminate the indoor of a building is known as daylighting which carries a similar definition. This study proposes the usage of optical fibres to transmit the sunlight for indoor lighting, once the light is collected through a parabolic dish collector. Once fabrication is completed, luminance of light will be monitored,throught the lux meter.

The primary source of the universe, the sun is an element of radiation. Solar radiation is defined as the electromagnetic radiation and particles (electrons, protons, alpha particles, and rarer heavy atomic nuclei) emitted by the Sun. The electromagnetic radiation covers a wavelength range from x-rays to radio waves, that is, from about 0.01 nanometer to 30 km[2].There are three types of solar radiation , namely direct solar radiation, diffused solar radiation and also reflected solar radiation (refer figure 2). The focus for this project will be on direct solar radiation.When the radiation reaches the atmosphere, particles such as air, dust and pollutants cause the radiation to be absorbed, scattered and reflected. Beam radiation refers to the direct radiation which reaches earth’s surface without being scattered. The scattered radiation from the beam radiation is known as diffuse radiation whereas the radiation reflected back from the ground is known as reflected radiation. Global radiation which is approximately 1000 W/ m2 at noon at sea level is the sum of the beam radiation, diffuse radiation and reflected radiation. Solar radiation intensity outside the atmosphere is about 1353 W/m2 and the value varies throughout the year due to the apparent trajectory of the earth on its orbit [3] . Malaysia is a country that benefits from abundant amount of solar energy. The annual The annual average daily solar irradiations for Malaysia have a magnitude of 4.21–5.56 $kWhm^{-2}$, and the sunshine duration is more than 2,200 hours per year[13]. Malaysia also receives sunlight all year round.

Sunlight in this case is part of electromagnetic radiation by the sun. Direct solar radiation that avoids blockage of clouds are called sunshine, which is composed of bright light and radiant heat This light range has three major components:

• Ultraviolet (UV) light with wavelengths between about 1 nm and 390 nm,

• Visible light with wavelengths between 390 nm and 760 nm,

•Infrared radiation (IR) with wavelengths exceeding 760 nm but shorter than $10^6$ nm.

Average direct sunlight is about 93 lumens per watt of radiant flux. Infrared is about 45% of the spectrum, visible is about 46%, and ultraviolet about 9%. Factors that affect the variation of these numbers include altitude, Earth's position relative to the sun, and environmental conditions[4]. This sunlight will be a significant element in this study as it will be primary source that will propel the system that will be designed.

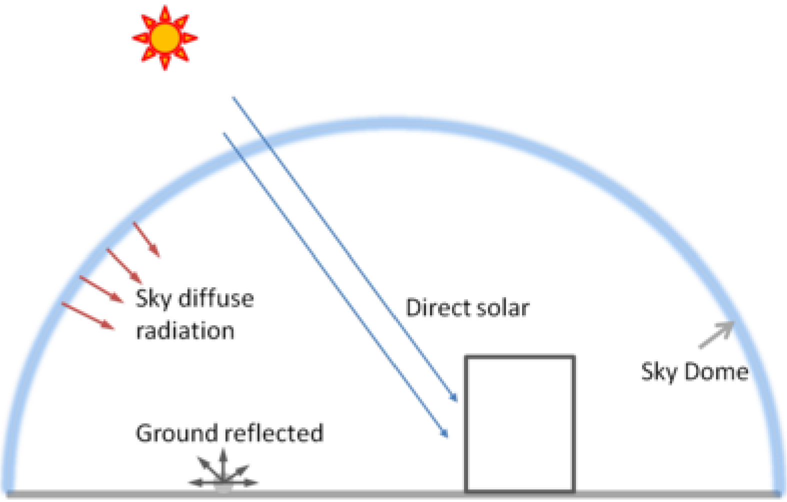



**Figure 1 The Three Types of Solar Radiation**

*Retrieved from http://www.bembook.ibpsa.us/index.php?title=Ground_Reflectance*

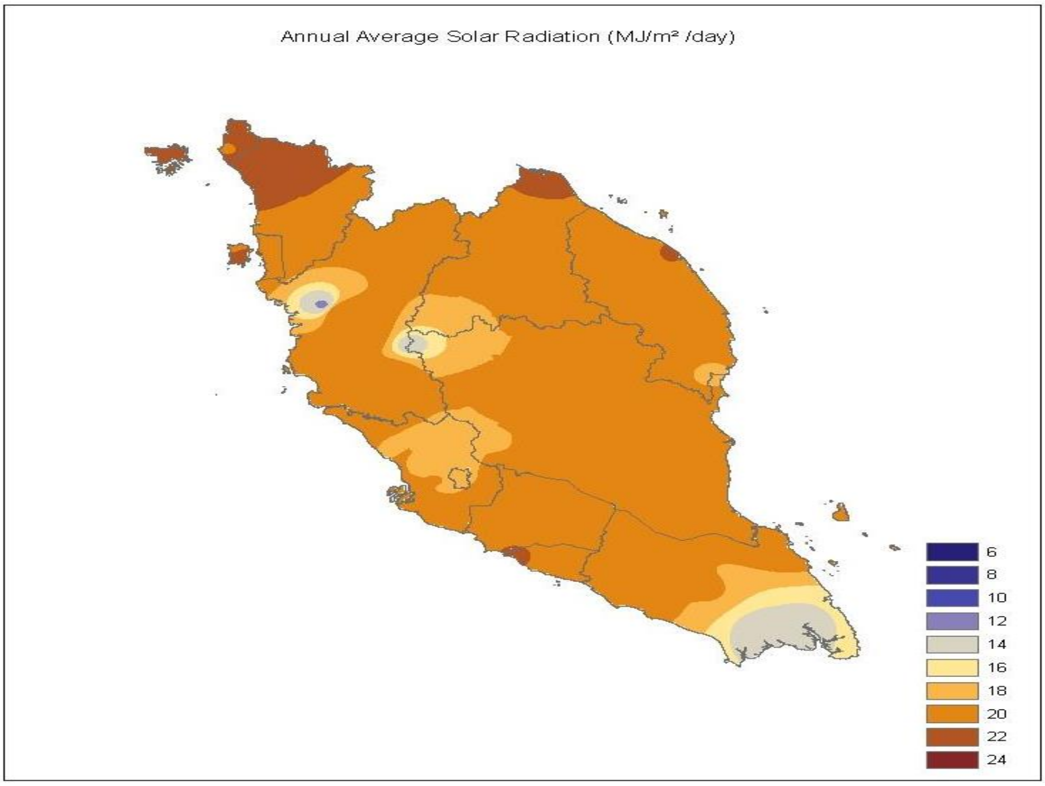



**Figure 2 Annual Average Solar Radiation in East Malaysia**

*Retrieved from http://161.142.139.60/solar/menu.html*

Daylighting is the use of natural sunlight to illuminate the interior of a building or in other words, this can be known as indoor lighting. Indoor lighting consists of natural lighting and artificial lighting[5]. The usage of windows are example of daylighting. In this project, a system is to be designed based on guiding natural light into the interior. The system includes optical fibres as a mode of transportation for the natural light from the sun. An optical fibre is a light transporting element or rods that are able to transmit light. It works through the principle of total internal reflection.It usually comes in single mode or multimode with the latter being the commonly used type. It collects light at one end and emits the collect light at the other. It is either made of plastic or silica with the latter being more costly. The basic concept of an optical fibre based indoor lighting system to be optimized in this project is where a parabolic dish/mirror is used to collect sunlight and then directs it into the optical fibre.

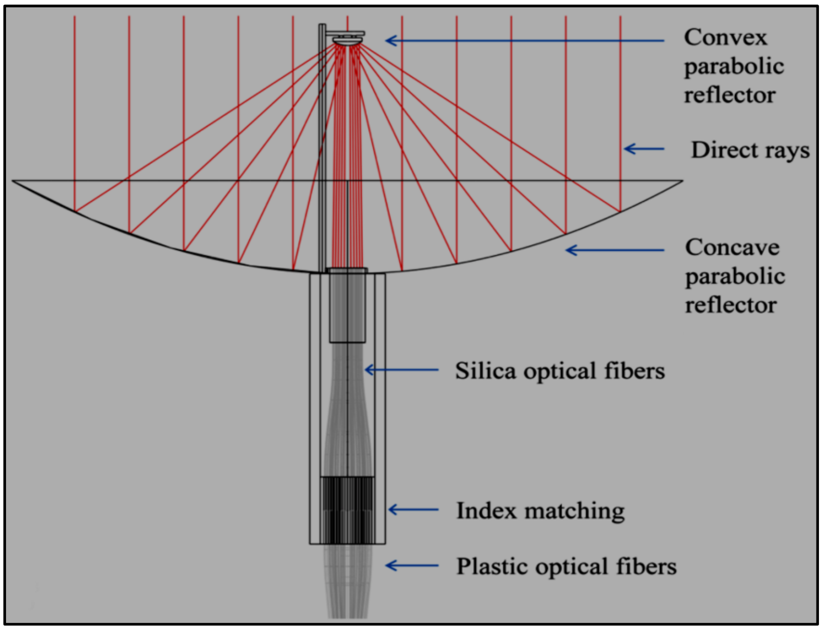



**Figure 3 Layout of the system using a parabolic mirror to collect light and directing it to the optical fibres[6]**

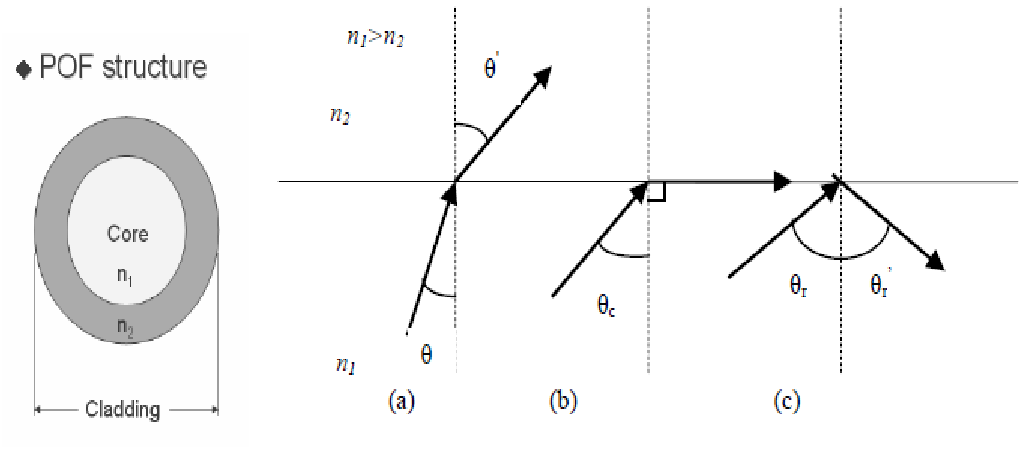



**Figure 4 POF structure,refraction and total internal reflection[8]**

### 1.2 Problem Statement

High energy consumption for lighting through electricity has prompted an extensive research on utilizing solar radiation for indoor lighting. The usage of solar radiation is more practical in country with a tropical climate. Malaysia,in this case , will be an optimal choice . The utilization of the solar radiation is to be done through the design of an optical fibre based indoor lighting system. The optical fibre based indoor lighting system will be an ideal solution for lighting in places that do not have the access to direct sunlight. This system will mainly consist of a parabolic dish collector for sun radiation collection and optical fibres to transmit light to the interior area of buildings.The luminance of light will also be measured and monitored using a lux meter. For demonstration purposes, an alternative approach has been carried out. This applies the application of light refraction instead of light reflection. Another issue that is hoped to be curbed with the development of this optical fibre daylighting system is the defiency of Vitamin D of office workers. Besides that, this day lighting system is hoped to reduce in the additional internal heat gain.

## 1.3 Objectives & Scope of Study

### 1.3.1 Objectives

- To design and develop an optical fibre based indoor lighting by the utilization of solar radiation
- To fabricate the optical fibre based indoor lighting system
- To perform testing on the optical fibre based indoor lighting system
- To measure illuminance of light emitted by the optical fibre based indoor lighting system

### 1.3.2 Scope of Study

This study aims at designing a optical fibre based indoor lighting system where solar radiation is directed to a collector which then transmits the light photons to the optical fibres. The optical fibres acts a transportation system of the light. It receives the sun rays at one end and emits them at the other end. The study will comprise of understanding the working principle of the system before the fabrication and testing process. The study will include a comprehensive study on natural lighting and its benefits besides a detailed analysis on the system itself. The main scope will be to understand solar energy and its optimization.

### 1.3.3 Relevancy of the Project

The project is relevant in a way that it deals mainly with the knowledge of the mechanical engineering course. Other than that , it also relevant in a way that it requires analytical thinking and designing skills. Other than that, during the fabrication process, the manufacturing understanding is needed, which is part of the mechanical engineering course structure. All in all, the project comprises mainly of knowledge and understanding of a mechanical engineer.

### 1.4 Project Feasibility

Regarding the project feasibility, the project is feasible as it deals partly with the knowledge I have acquired from the mechanical engineering course. Other than that, the project is feasible as the Final Year Project comprises of period for a total of 2 semesters, which provides adequate time for research and completion of project. This project is also feasible because it can be completed with the provided laboratory facilities at the place of study which is Universiti Teknologi PETRONAS itself.

# CHAPTER 2 LITERATURE REVIEW

| Reference Number | Author | Title | Year | Main Discussion Points | Remarks |
|---|---|---|---|---|---|
| **[6] (Ullah & Shin, 2012)** | Irfan Ullah and Seoyong Shin | Development of Optical Fiber-based Daylighting System with Uniform Illumination | September 2012 | • The uniform distribution of light through fibre bundle to the interior of the building<br>• Discusses two approach of optical fibre system which are parabolic mirror and Fresnel Lens<br>• Hybrid system of combining sunlight and LED | • This paper provides a good overall understanding of the optical fibre lighting system<br>• Combination of hybrid and uniform distribution of optical fibre under one paper creates a space of mix up between facts. |

| | | | | | |
|---|---|---|---|---|---|
| **[7] (Li & C, 1999)** | Danny H.W. Li, Joseph C. Lam | Measurements of Solar Radiation and Illuminance on Vertical Surface (Li & C, 1999)s and Daylighting Implications | 1999 | • This paper focuses on the measurement of solar radiation on vertical surfaces<br>• Calculation and Data representation on daylight illuminance is shown | • Only solar radiation measurement on vertical surface is highlighted<br>• Good representation of data showing indoor and outdoor illuminance |
| **[8] (Munisami & D.Kalymnios, 2008)** | J. Munisami , D.Kalymnios | Novel Technique for Solar Power Illumination using Plastic Optical Fibres | 2008 | • This paper presents a novel solar illumination technique using POF as both the light collecting/concentrating mechanism and the transmission medium<br>• This paper also discusses on the present daylighting systems | • A good introduction on daylighting is provided<br>• The working principle of POF(Plastic Optical Fibre) is clearly shown |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **[9] (Sapia, 2013)** | C. Sapia | Daylighting in buildings: Developments of sunlight addressing by optical fiber | March 2013 | • This paper proposes the method of sizing the collectors and reflectors of the optical fibre daylighting system through a MATLAB procedure<br><br>• This paper also includes economic comparison between the proposed system for daylighting of commercial buildings and the traditional lighting system made by a series of fluorescent lamps | • Economic analysis done in this paper is an extra added feature that sometimes lacks in other papers. Economic comparison has provided required details in the cost aspect of the daylighting system<br>• The sizing done in this paper gives an insight on the procedure and methods used |
| **[10]** (Abdul-Rahman & Wang, 2010) | Hamzah Abdul-Rahman and Chen Wang | Limitations in current day lighting related solar concentration devices: A critical review | September 2010 | • This study introduces the day lighting related solar concentration devices | • The limitation concept could have been highlighted more thoroughly through the use of a diagram as an aid |

| | | | | | |
|---|---|---|---|---|---|
| | | | | • It also highlights the pointlite feauture of the optical fibre<br>• The paper futher discusses on the mechanical properties,thermal properties and chemical properties of a platic optical fibre<br>• This paper explains the principles of study, advantages and disadvantages for application of these daylighting related devices | • Detailed explanation on the properties of the Plastic Optical Fibre |
| **[11] (Hana & Kimb, 2010)** | Hyunjoo Hana, Jeong Tai Kimb, | Application of high-density daylight for indoor illumination | June 2010 | • This paper focuses on the design and fabrication of fiber optic solar concentrator system with a simple parabolic profile for the delivery of a high- | • Provides a concept on the designation of solar ray concentrators, optical fibres and diffusers |

| | | | | | |
|---|---|---|---|---|---|
| | | | | density solar flux into the interior of a building for indoor illumination | • This paper includes three dimensional design drawings which aids understanding of concept |
| **[12] (Grise & Patrick, 2002)** | Dr. William Grisé & Dr. Charles Patrick | Passive Solar Lighting Using Fiber Optics | 2002 | • This research paper higlights the utilization of optical fibre for distribution and conveyance purpose of solar light<br>• This paper also focuses on a light transmission effectiveness of the proposed system | • An in depth analysis on optical fibre light transmission effectiveness was done<br>• Also focuses on loss In light intensity of the optical fibres |
| **[13] (Muzathik, Wan Niki, Samo, & Ibrahim, 2010)** | Abdul Majeed Muzathik,Wan Mohd Norsani Wan Nik,<br>Khalid Samo and Mohd. Zamri Ibrahim | Hourly Global Solar Radiation Estimates on a Horizontal Plane | 2010 | • This research paper presents a data analysis data of the solar radiation in Malaysia<br>• This paper higlights the usage of models to obtain measurements of solar radiation | • The solar radiation measurement is required for solar energy studies |

| | | | | | |
|---|---|---|---|---|---|
| **[14] (Andre & Jutta, 2002)** | Erik Andre and Jutta Schade | Daylighting by optical fibres | 2002 | • An introduction on the three current fibre optic lighting system which are the Japanese Himawari, German SOLUX and American Hybrid Lighting<br>• Discusses some key concepts on fiber optic daylighting system | • A thorough and detailed explanation on the existing fibre optic daylighting system<br>• Presents crucial concepts of fibre optics such as light loss. |
| **[15] (Ghisi, 2002)** | Enedir Ghisi | The Use of Fibre Optics on Energy Efficient Lighting in Buildings | | • Highlights the energy saving element of a fibre optic lighting system.<br>• Presents an environmental assessment impact considering the reduction in greenhouse gasses due to the enrgy savings by fibre optic incorporation Hybrid Lighting | • Displays a clear view of the energy saving concept.<br>• Comparison of energy saving between artificial lighting and fibre optic lighting were highlighted. |

| | | | | | |
|---|---|---|---|---|---|
| **[19] (Joshua, 2009)** | Joshua Folaranmi | Design, Construction and Testing of a Parabolic Solar Steam Generator | June 2009 | • This paper highlights design, construction and testing of a parabolic dish solar steam generator<br>• It discusses on the working principle of a parabolic dish | • Adequate information on parabolic dish working principle<br>• Design Analysis and certain specifications of the sun is also provided |
| **[20] (Smith, 1988)** | Nancy Ruck & S. C.J. Smith | The Passive Daylighting of Building Interiors | 1988 | • In this research paper, the collection,concentration and transmission of lights are highlighted<br>• Different types of transmission system are highlighted including optical fibre<br>• Transmission depends only on the length of the optical fibre and not the diameter of the optical fibre | • The paper is comprehensive in terms of explanation of the overall working of a daylighting system<br>• It also highlights disadvantages and advantages of the optical fibre |

# CHAPTER 3 METHODOLOGY

## 3.0 Introduction

A proper planning and schedule is crucial in the completion of a particular project. With time factor , adequate and structured planning will ease the progress in undertaking a certain project. Thus, it is crucial to establish a plan Achieving the objectives of this project within allocated time is crucial. Therefore a proper planning and scheduling is needed to complete the tasks within the timeframe. A good planning and scheduling will greatly influence the outcome of the project. In this chapter the research methodology will be discussed. The process flow and the tools required will also be discussed.

## 3.1 Research Methodology

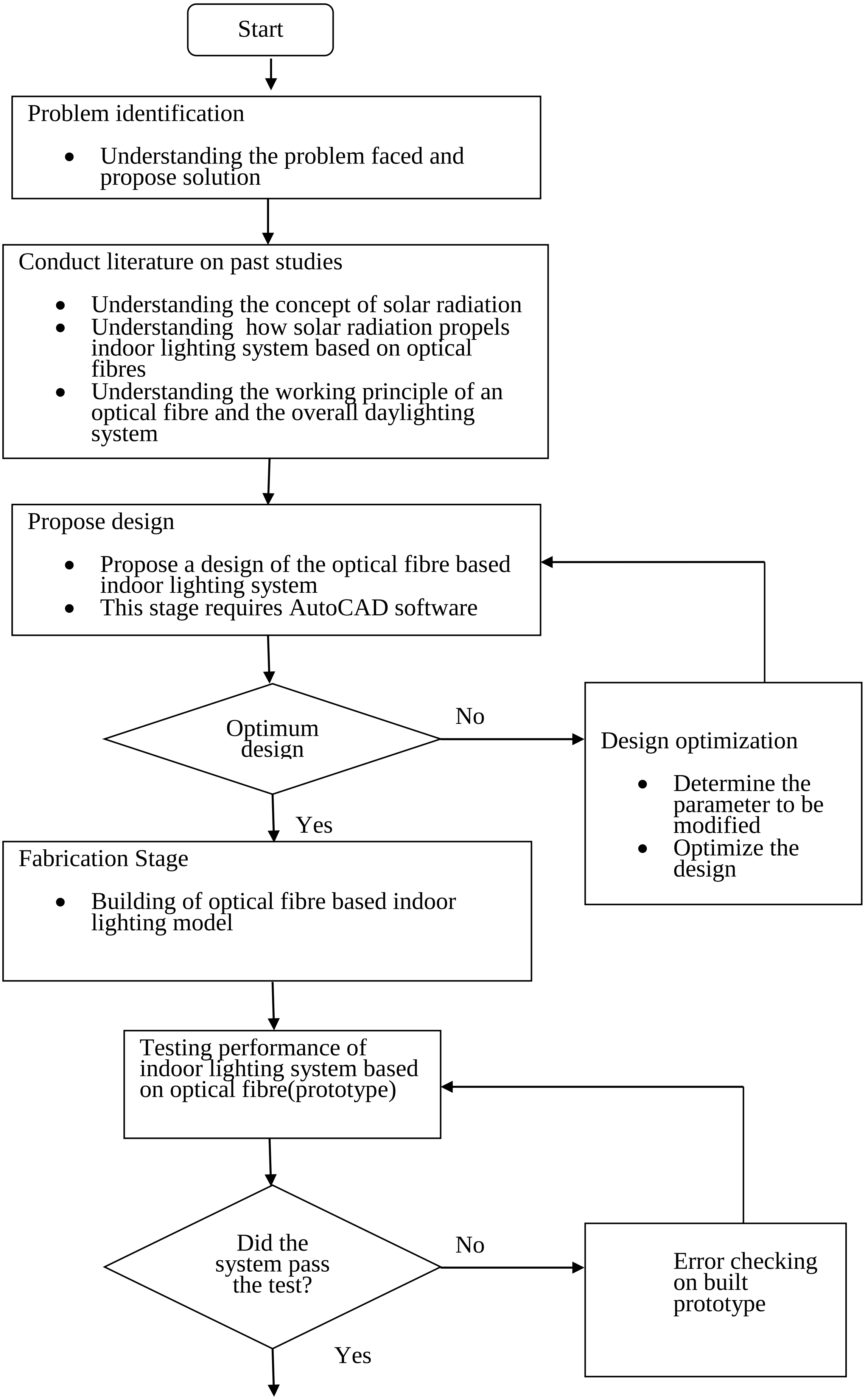
In order to achieve the main of this project as stated earlier, the other five sub-objectives need to be accomplished and analyzed well .For the first sub-objective which is to conduct a literature review on linear generator , a well-structured literature review on selected suitable papers is done.

Next, using a designing software,in this case, AutoCAD software is proposed, a design of the daylighting optical fibre system is to be designed. The design is an essential initiation step before the fabrication process is done. The designing process is expected to consume about 2 to 3 weeks. The design is an important feature as it will ensure marketability and mass production of the system.

Once the designing process is completed and justified, the fabrication process can occur. To fabricate the prototype of the day lighting system, a list of tools and equipment required is to be made. Other than that, the availability of the tools are also to be taken into consideration. Another important aspect that can be utilised here is the DIY(Do-It-Yourself) element. If the tools needed can be made by oneself instead of purchase, then this will reduce the cost of building the prototype. As an example, a DIY optical fibre can be taken into consideration. The DIY approach will lower production cost, resulting in a cost-effective project.

In any production of a system, model or any sort of innovation, testing the efficiency or the performance is crucial. This is to ensure that the fabricated model meets its workability function. A good model will be of high efficiency and meets the set objectives.

### 3.2 Process Flow



Cont'd

Finding

- Results and discussion
- Writing thesis

End

## 3.3 Gantt Chart (Refer Appendices)

## 3.4 Project Activities and Milestones

| Activities | Details |
|---|---|
| **1. Research and Review Literatures** | - Building the research base.<br>- Extract relevant procedures and information |
| **2. Design of Daylighting System** | Design the daylighting system using AutoCAD software |
| **3. Fabrication of Day lighting system** | Fabricate the optimized design of the daylighting system |
| **4.Daylighting System Test** | Test on the workability of the day lighting system |
| **5. Illumincance Measurement** | Measuring the illuminance of light exterior and interior part of the day lighting system |
| **6. Study of the affect of parameters of Optical Fibre on the Illuminance** | Study the affect of different parameters of optical fibers such as length, bending affect, and batch effect on the illuminance of light. Also includes study of light distribution in the system. |
| **6. Analyze the Results** | Discuss the findings from the results obtained and make a conclusion out of the study |
| **7. Report Writing** | Compilation of all works into a final report |

### 3.4 Tools

**Table 1 Software Tools Required**

| No | Software | Function |
|---|---|---|
| **1.** | AutoCAD | To design optical fibre daylighting model |
| **3.** | Microsoft Excel | To tabulate result and findings |
| **4.** | Microsoft Word | To write the report |

**Table 2 Hardware Tools Required**

| No | Hardware | Function |
|---|---|---|
| **1.** | Casing | For casing building of prototype<br>Acts a building |
| **2.** | Optical Fibres | To transfer light into interior of casing |
| **3.** | Light Collectors | To collect light |
| **4.** | Lux Meter | To measure illuminance of light |

# CHAPTER 4 DESIGN OF DAYLIGHTING SYSTEM

## 4.1 Introduction

The optical fibre based daylighting system comprises of two main components. The components are the solar collectors and optical fibre bundles. The primary function of the solar collector is to collect sunlight and direct it to the optical fibre bundles. It aims to focus sunlight to the optical fibre bundle. The most commonly used method of the solar collector is the parabolic dish. The next important component is optical fibre. The optical fibre acts as the main medium of transportation of light. It trasnports the collected sunlight for interior lighting purpose. The variants of the optical fibre that will be studies includes the length of the cable, batch effect ,bending test and light distribution effect. The effect of these variances on the illuminance of light are to be studied.

### 4.1.1 Light Collectors

In a daylighting system, the light collectors play an essential role in garnering an adequate amount of sunlight. There are two main principles these solar collectors work on. The first working principle is the reflection of light and the other is the refraction of light. The type of solar collectors that work on the principle of light reflection is the parabolic solar collector. On the other hand, the type of solar collector that works on refraction of light is the Fresnel lens.

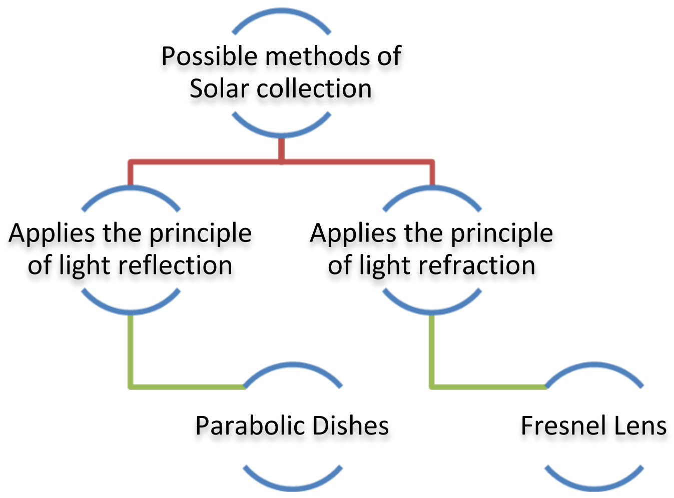



**Figure 5 Possible Methods of Solar Collection**

### 4.1.2 Optical Fibres

Once light is collected through the light collector, it is directed to the optical fibres. Optical fibres are wirelike tubes that are very flexible. This flexibility is a key feature in the daylighting system design, as it allows the transmission of light to areas that are not accessible to direct sunlight. The optical fibres work on the principle of total internal reflection. The principle of total internal reflection causes 100% reflection making the optical fibre an optimal option for solar light transmission. An optical fibre comprises of two main components which are the core and cladding. The core is the middle section of the optical fibre whereas the cladding is the covering of the core. The two main conditions for total internal reflection to occur is the refractive index of the first medium is greater than the refractive index of the second medium (n1>n2) and the angle of incidence must be greater than the critical angle (i>c).

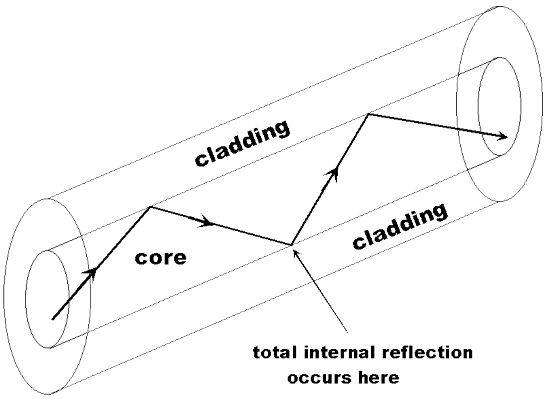



**Figure 6 Concept of Total Internal Reflection in an Optical Fibre[16]**

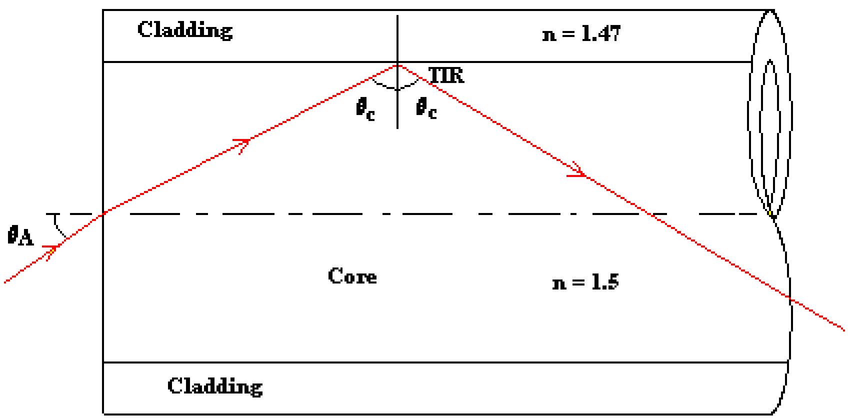



**Figure 7 Total Internal Reflection in an Optical Fibre[17]**

The core has a larger refractive index than the cladding, causing light to be totally reflected back into the cladding. Optical fibres are usually made out of plastic or glass, with plastic being relatively cheaper than glass. Optical fibres are also available in two modes. These modes are single mode optical fibre and multimode optical fibre(see Figure 8.). Single mode optical fibre usually have a small core of 9µ whereas a multimode fibre has a larger core,which is approximately about 50 µ or 62 µ. Single mode of optical fibre is usually used for long distance whereas multimode fibre is used for shorter distance. This is because the attenuation or transmission loss is higher in a multimode fibre compared to single mode fibre.

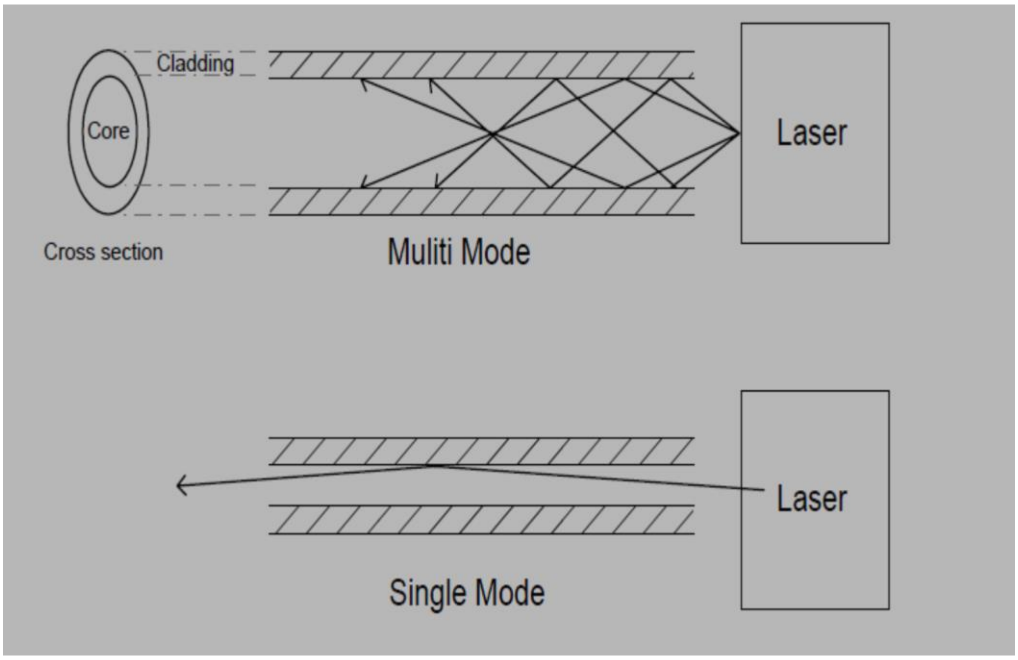



**Figure 8 Single Mode and Multimode Optical Fibre[18]**

## 4.2 Design of Optical Fibre Based Daylighting System

The design of the optical fibre based daylighting system is executed using the AutoCAD software. The design comprises of three main units which are the building, the optical fibre and the parabolic solar collector. The design is represented in two dimensional view(see figure 9. ) . The building is the base with the parabolic dish seated at the roof of it. The optical fibres then is attached to the parabolic dish and runs throughout the building.

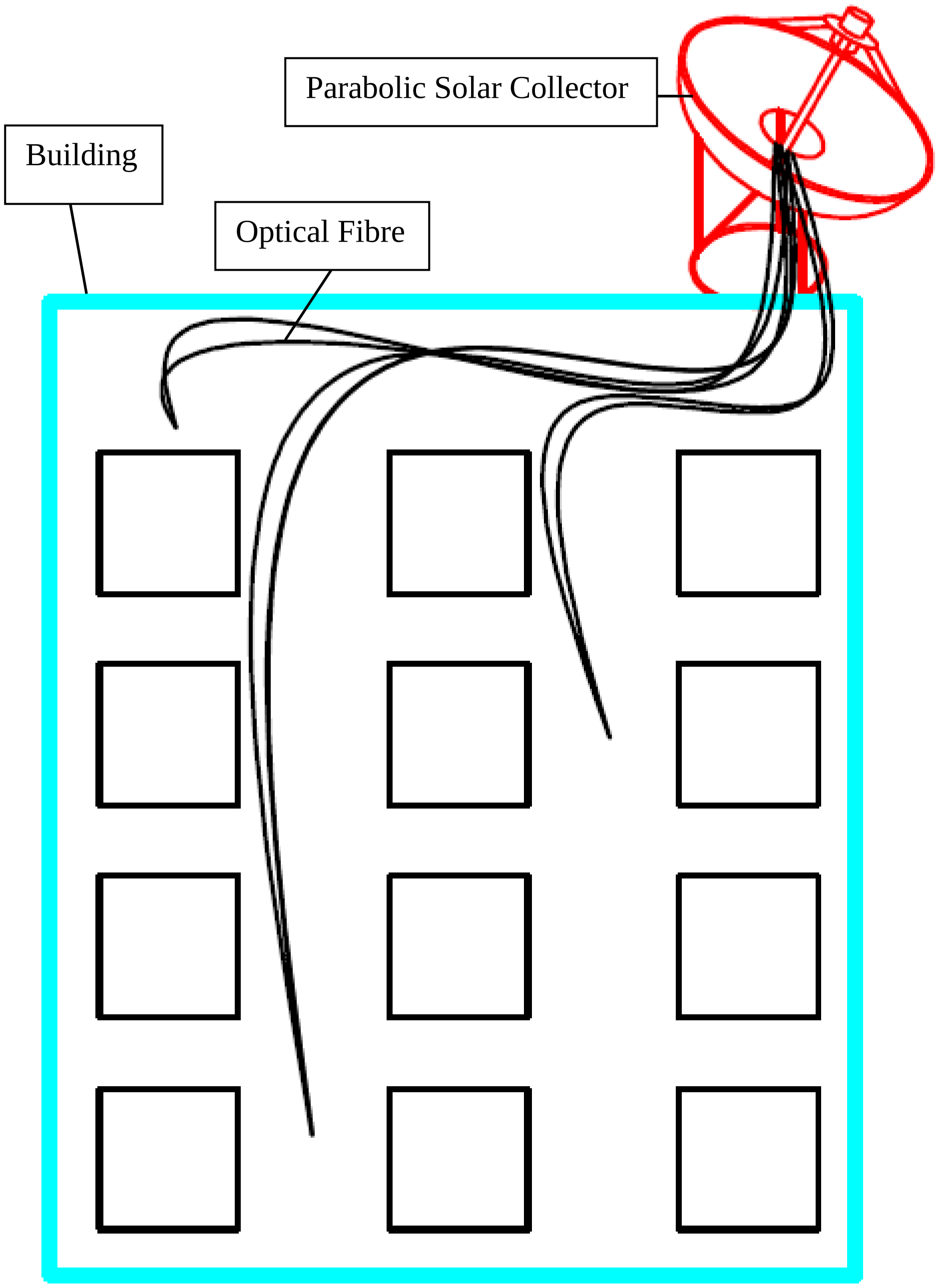



**Figure 9 Optical Fibre Daylighting System**

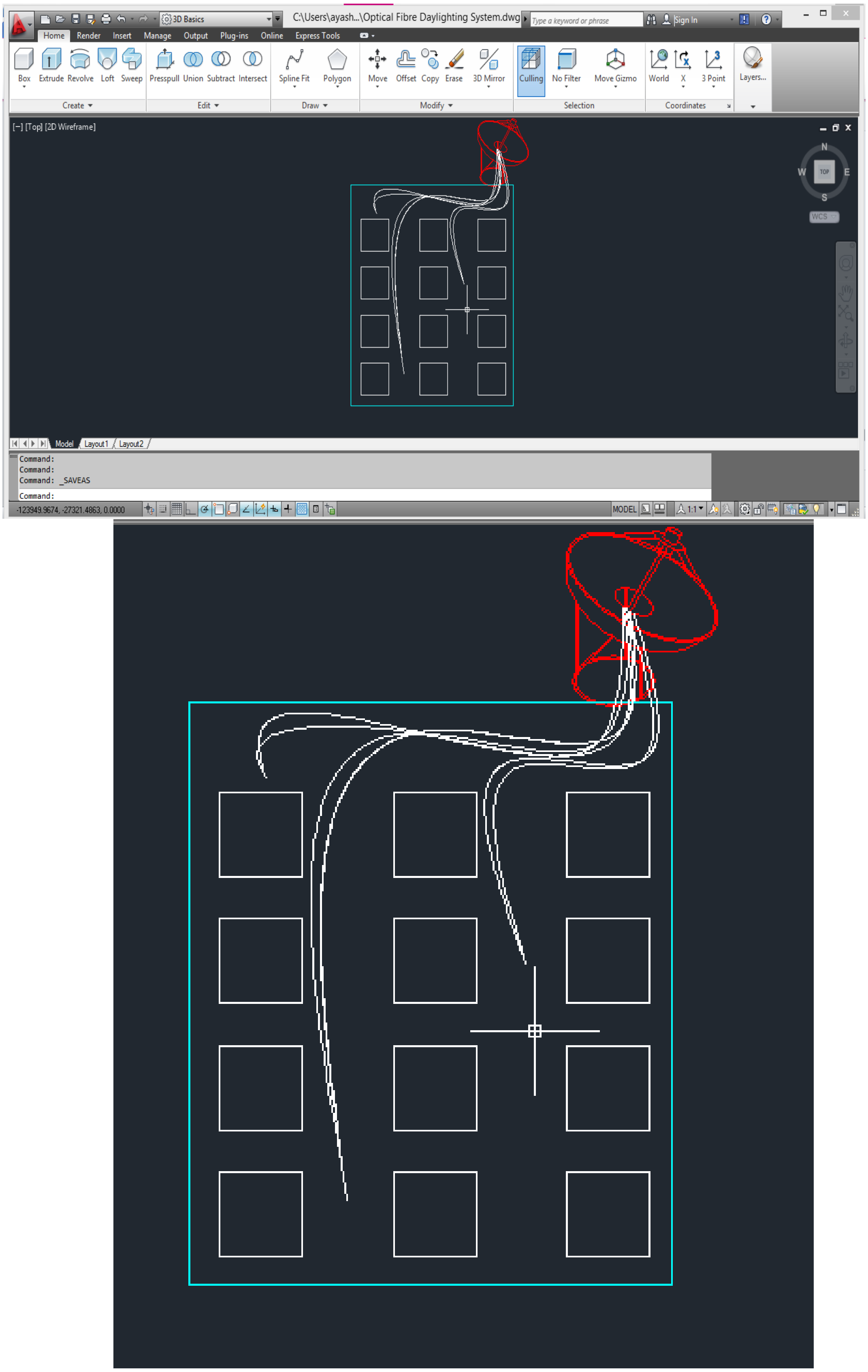



**Figure 10 AutoCAD Design of the Optical Fibre Daylighting System**

### 4.3.3 Parabolic Solar Collector

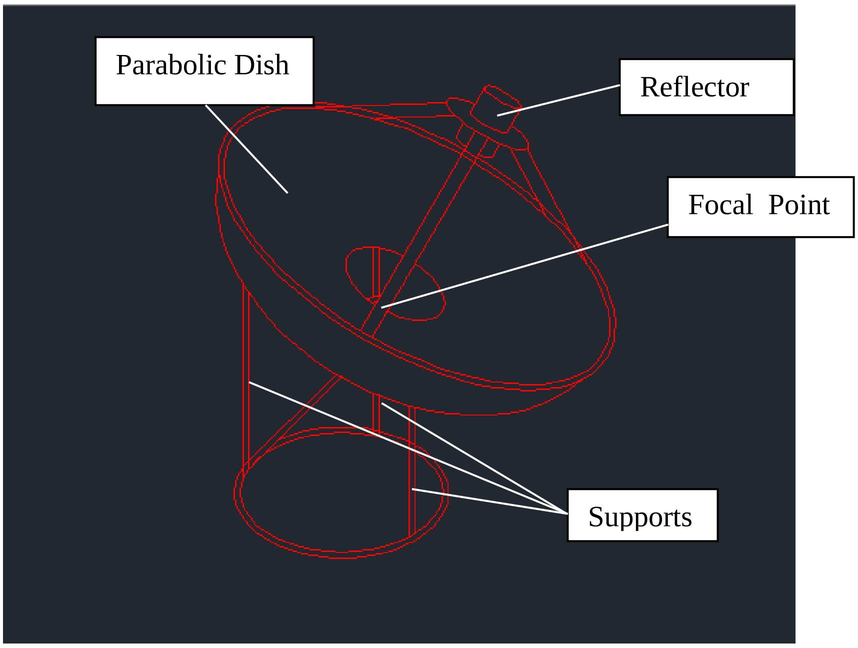



**Figure 11 Parabolic Solar Collector**

The parabolic solar collector comprises of four main parts. The main feature incorporated in this type of solar collector is the stationary or passive type. In this case, the parabolic dish is a stationary solar collecting device with respect to sun movement[19]. The main parts are the parabolic dish,reflector, focal point and the supports. The parabolic dish functions as a primary concave mirror where parallel and incident light rays reflect off. These light rays are then reflected of the reflector and converge or come together on a principal focus or focal point [20]. This focal point will be the placement of the optical fibre bundle for the transmission of light to the interior. The supports assist in supporting and stabilizing the solar collector. The parabolic dish is usually made up of a reflective material such as aluminium. Other than that, another option is to place an array of mirrors on the parabolic dish for reflection purpose.

### 4.3.4 Parabolic Dish Parameters

The main parameters that need to be determined for the sizing of the parabolic dish is the diameter of the dish and the depth of the dish. The diameter and the depth of the dish will provide focal point length. The focal point length is obtained throught the parabola calculator 2.0 developed by Edisher Giorgadze.

Assuming approximation of a parabolic dish with given data as below :

| |
|---|
| Diameter of Dish = 24 cm |
| Depth of Dish = 7 cm |

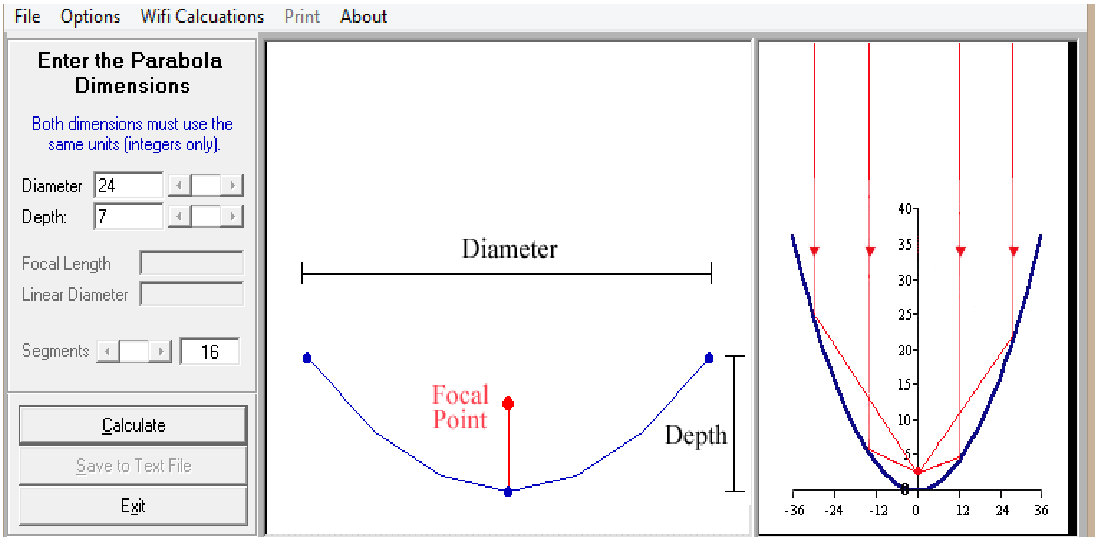



**Figure 12 Focal Point,Depth and Diameter of Parabola**

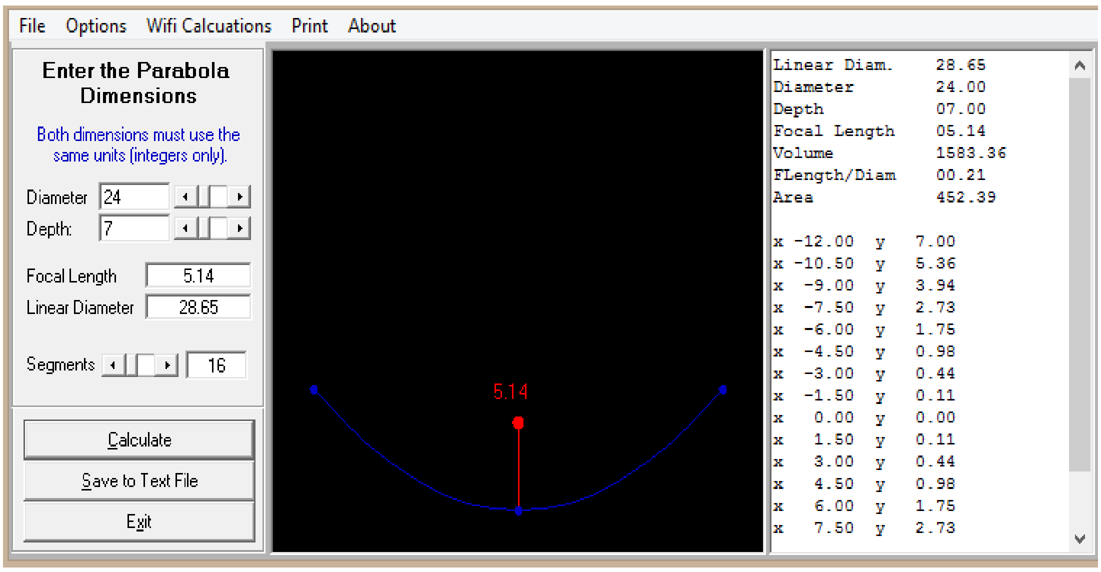



**Figure 13 Focal Length of Parabola**

With a dish diameter of 0.024 m and a dish depth of 0.07 m, the obtained focal point length is 5.14 cm or 0.0514 m. The equation of the parabola is as follows :

$$y = a(x^2) + bx + c$$

Where for this parabola ;

a = $4.861^{-2}$ b = 0 c = $-1.110^{-16}$

thus,

$$y = 4.861^{-2}(x^2) + (0)x + (-1.110^{-16})$$

$$y = 4.861^{-2}(x^2) - 1.110^{-16}$$

### 4.3.5 Building Sizing

For the building sizing, the volume has to be considered. The building which will be built using wood, will contain a volume of 0.061 $m^3$ , with a length of 0.48 m, width of 0.325, and a height of 0.39 m(see figure 14.)

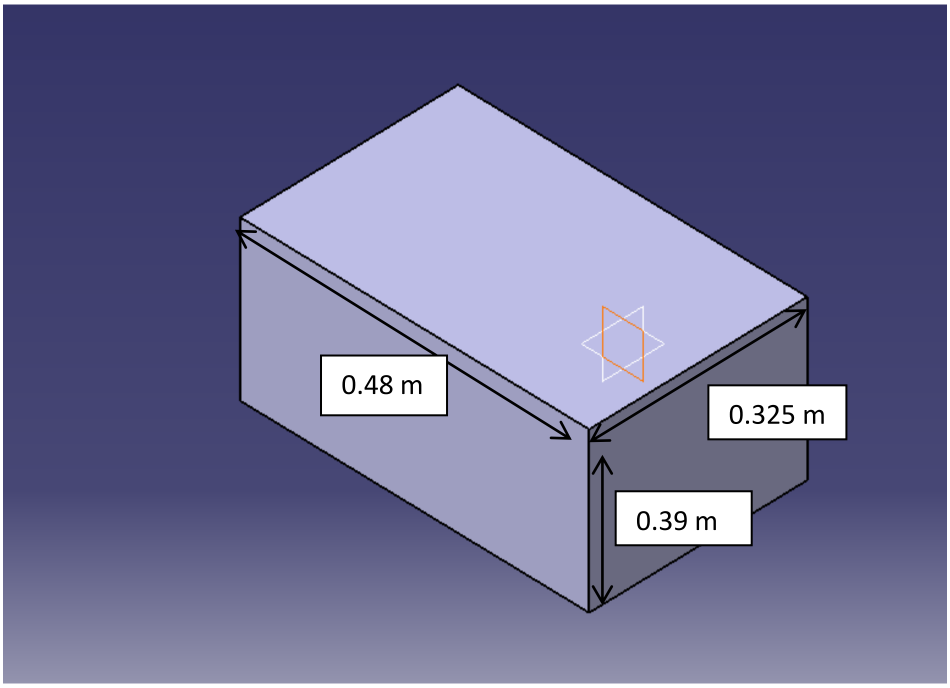



**Figure 14 Building Sizing**

# CHAPTER 5 RESULTS AND DISCUSSION

## 5.1 Alternative Approach of the Day lighting System

The previous section discussed on the usage of light reflection principle on optical fibre based day lighting system. The light reflection principle utilizes the use of parabolic solar collectors as the main part of the light collecting medium. Light is reflected off the parabolic solar collector into the secondary mirror which acts as a reflector. This reflector then reflects the collected light into the optical fibre bundle. As a purpose for demonstration however, the alternative approach of the day lighting system has been considered. This alternative approach focuses on the principle of light refraction.

### 5.1.1 Light Refraction Method

The light refraction method utilizes the principle of light refraction in the optical fibre based day lighting system. This method involves two main steps. The first or initial step is to focus the on the refracting medium or the refractor. Then,the refractor continues to provide a better and sharper focus of light on one side of the optical fibre bundle. The final outcome will be the illuminance at the other end of the optical fibre bundle. This method can be achieved or executed by two main refracting mediums, which are Fresnel Lens or the magnifying glass. In this experiment or study, the magnifying glass is used as the main refracting medium.

### 5.1.2 Principle Operation of the Magnifying Glass

The two main lens that are considered for the light refraction method of an optical fibre daylighting system are the Fresnel lens and the convex lens. Convex lens are used to develop a magnifying glass. The main function of a magnifying glass is to enlarge an object. The convex lens of the magnifying glass is usually mounted in a frame and a handle attached to it. In the optical fibre based day lighting system, the main function of the magnifying glass is to refract and focus the light on the optical fibre bundle. Light is refracted when it goes through mediums of different densities. For example, in a magnifying glass,light from air enters glass. Glass has a higher density than air which causes it to bend towards the normal line.
A magnifying glass has a smooth surface on both sides. However,the surfaces are not flat but curved outward. but it is not flat. The surface of the glass is curved outward.

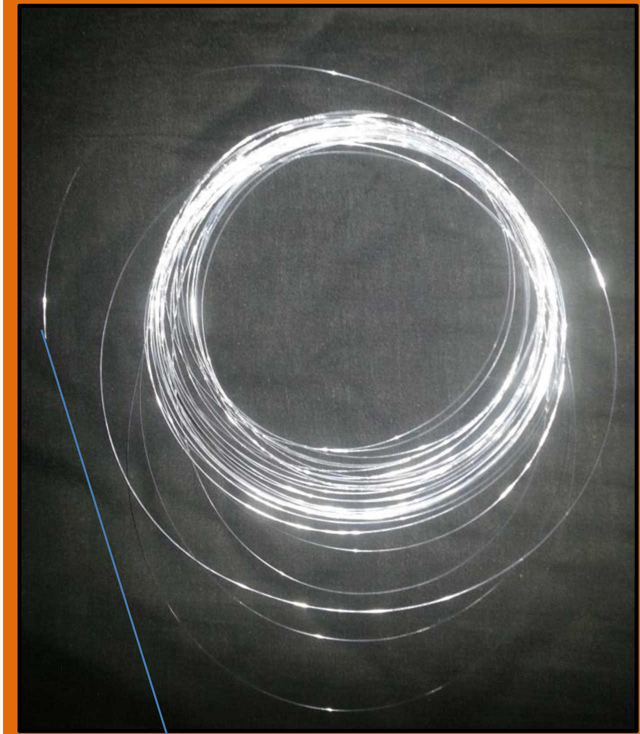
This kind of curve causes the light that enters it from a long distance it will curve in a path that

takes it inward, towards the center of the lens. Both sides of a magnifying glass are convex lenses. As the light rays pass through 2 convex lenses, the rays are refracted toward the principal axis of the convex lens. The energy of the all the light rays is focused at one point. There is the same amount of light on both sides of the lens but on the side opposite the light source that same light is confined to a smaller space, the space represented by the volume of that cone. The same number of photons in less space means that the light will be brighter. When the light ray passes through the glass it gets refracted to the centre or also known as the focal point. Since all the light rays or photons combine at the centre, the intensity of the light increases.

### 5.1.1 Parts Analysis for Optical Fibre Day lighting System Setup

The main tools needed for the setup of the optical fibre day lighting system is the stand, a magnifying glass, source of light, optical fibre bundle, sleeve and the housing. For indoor demonstration purpose , the direct solar radiation or sunlight is replaced with a torchlight. The sleeve is used to contain and keep the bundle of optical fibres in place. The housing acts as the building interior in which the optical fibres are attached to. The bundle is attached at the roof of the housing. The stand functions to hold the magnifying glass and and the torch for the transfer of light.

## 5.2 Tools of the Optical Fibre Daylighting System

| Tools | Function/Characteristics |
|---|---|
| Optical Fibre<br><br><br>**Figure 15 Optical Fibre** | Function<br>- Acts as the main mode of transport for light (termed as light guide)<br><br>Characteristics<br>- Transparent<br>- Made of Polymethyl methacrylate (PMMA)<br>- Single mode type<br>- 2E-3 m outer diameter<br>- Total length is 20 meters |
| Magnifying glass 2<br><br>**Figure 16 Magnifying Glass 2** | Function<br>- Refracts and focuses the light on its focal point through the usage of convex lens<br><br>Characteristics<br>- Magnification : 3x<br>- Lens Diameter : 0.087 meters/87mm |

| Tools | Function/Characteristics |
|---|---|
| Sleeve<br><br>**Figure 17 Sleeve** | Function<br>- Houses and contains the optical fiber bundle.<br>Characteristics<br>- Material type : synthetic<br>- Tubelike<br>- Outer Diameter: 0.04 meters<br>- Can function in temperature up to 125 °C |
| Torchlight<br><br>**Figure 18 Torchlight** | Function<br>- Main source of light. Replaces sunlight for indoor demonstration purposes.<br>Characteristics<br>- Gives out white light<br>- Has zooming capabilities to focus light.<br>- Has flickering capabilities |

### 5.2.1 Optical Fiber Day lighting System Setup

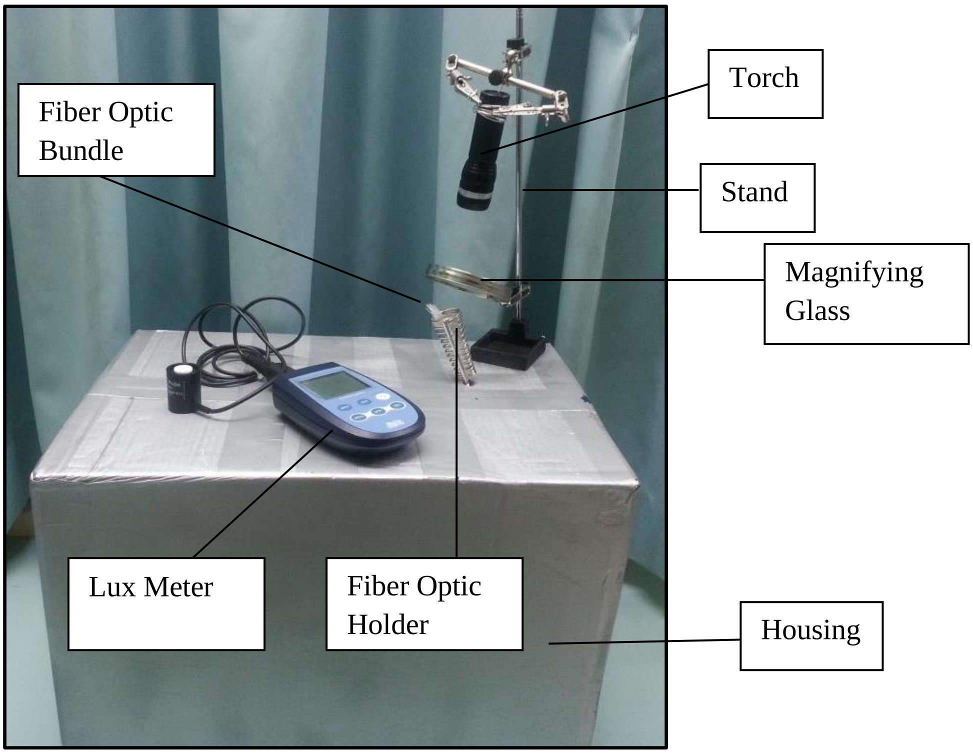



**Figure 19 Optical Fibre Day lighting System Setup**

The setup shows the assembly of the optical fiber day lighting system. The system consists of the housing ,sleeve,optical fiber bundle , magnifying glass, torch light, and the stand. The optical fiber holder is used to keep the optical fiber in place. The housing is used to act as a building in which the daylighting system is worked and functioned upon. The reason of choosing silver as the interior and exterior colour is because lighter colour reflects more light than darker shade colours. The torch is the main primary source of light to replace the sunlight for indoor demonstration purposes. The magnifying glass is placed below the the torch to be the main refracting tool. . The housing is also attached with a flap at the side in order to get a clearer view of the illuminance of light in the interior part of the housing itself.The schematic drawing of the day lighting system is attached as per below.

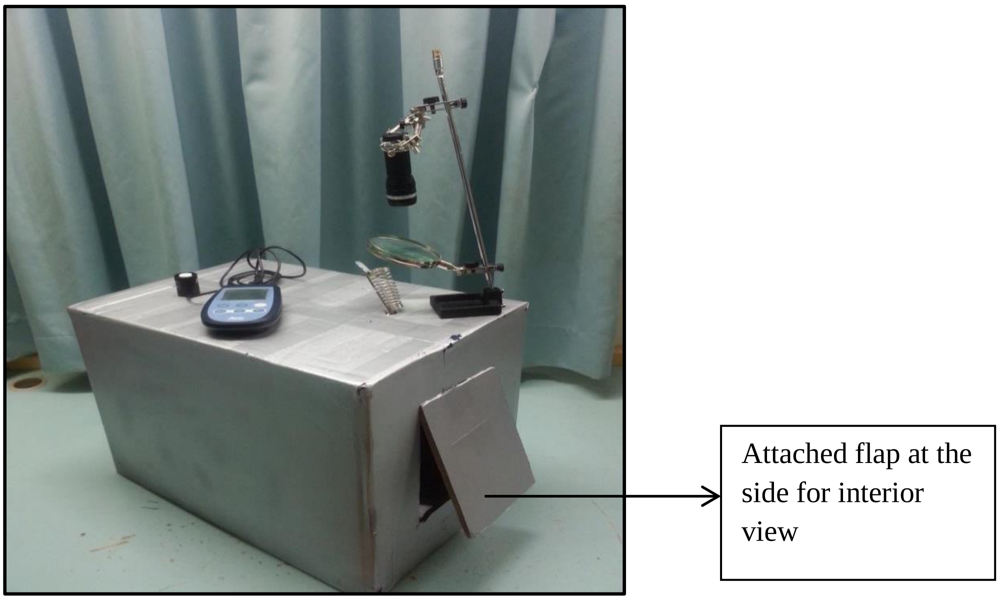



**Figure 20 Attached Flap on Day lighting System**

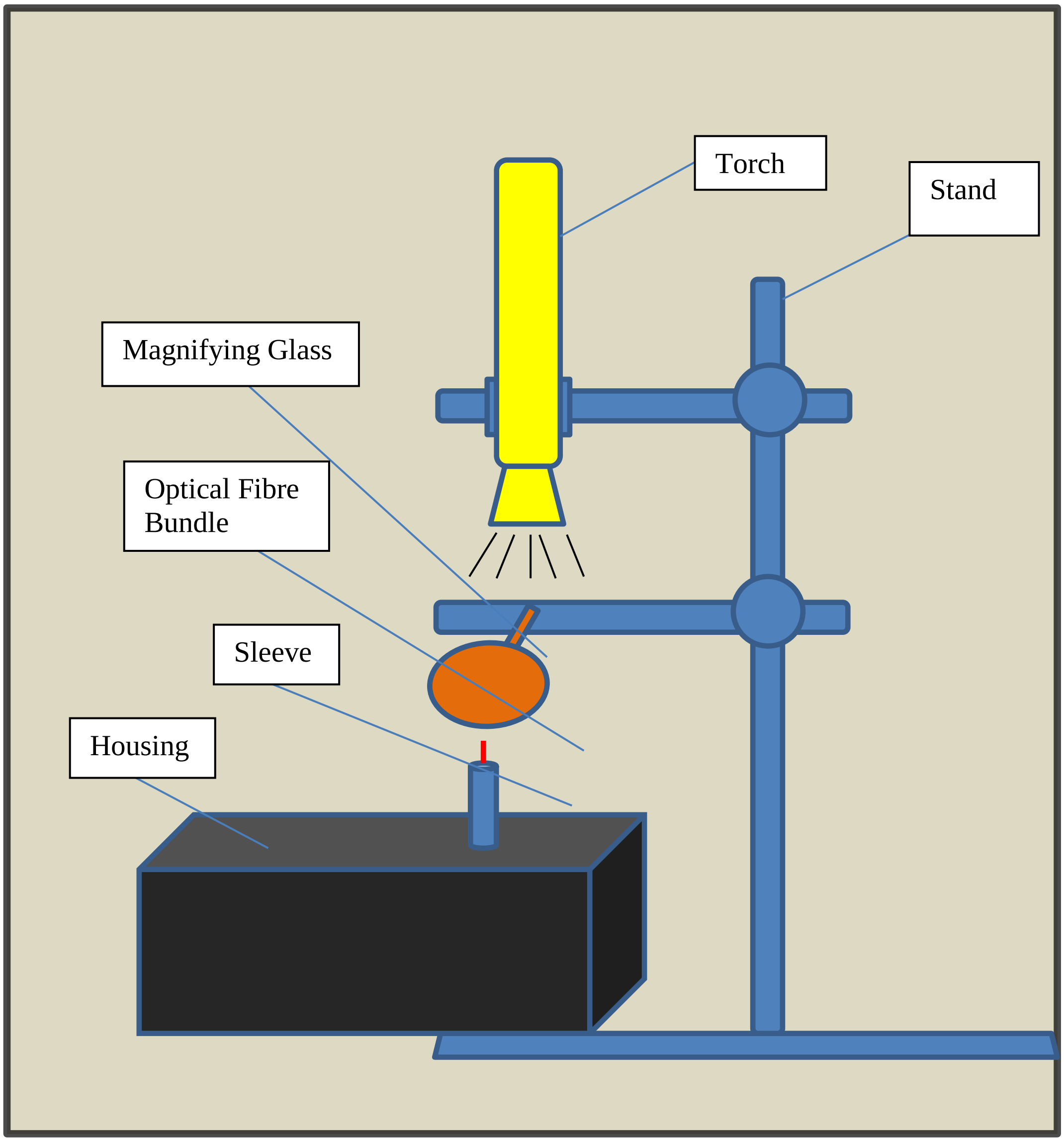



**Figure 21 Schematic Diagram of the Optical Fibre Day lighting System Setup**

## 5.2 Results and Analysis

### 5.2.1 Measurement of Illuminance

The main objective of this study is to develop an efficient optical fiber day lighting system. Efficiency in this case means the ability and capability of the optical fiber to transport light from one end to the other. The outcome of the system is to be able to deliver sufficient amount of light for interior lighting. The main parameter that is focused here is the illuminance measurement of the day lighting system. Illuminance is a measure of the intensity or the brightness of light on a surface. The device used to measure illuminance is the lux meter. The lux is the unit measurement of brightness which is also known as illuminance. The total amount of visible light emitted by a source is measured in lumens. One lux is equivalent to one lumen of light spread across a surface one square meter. A candela indicates the brightness level of one candle.

One lux = One lumen (lm) / $m^2$

### 5.2.2 Working Principle of a Lux Meter

A lux meter works by using a photo cell to capture light. The conversion of light to electric current then takes place through this meter. This current measurement is needed in order to allow the device to calculate the lux value of the light it captured. The meter takes into account the size of the room in a way that simply measuring the intensity of the light source in lumens would not. A typical lux meter can measure a lux range of 0 to 50 000 lux.


**Figure 22 A Digital Lux Meter**

*Retrieved from http://farmtech-mart.com/measurement_tool*

### 5.2.3 Working Principle of Lux Meter used in the Experiment

The type of lux meter used in this experiment is HD 2302.0 Lightmeter. The main function of this equipment is to measure the illuminance of light in the day lighting system. This lux meter can measure a lux range of 0.01 lux to $200x10^3$ lux.

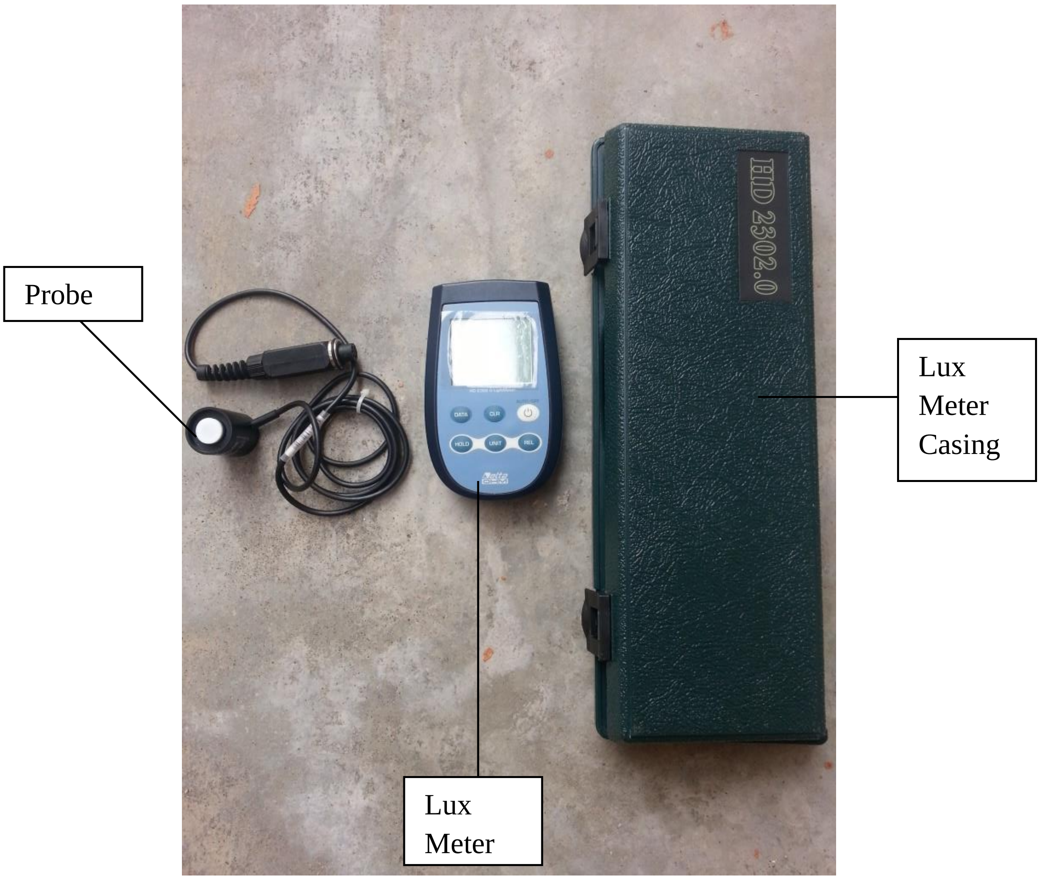



**Figure 23 Lux Meter Components**

The three main components of the lux meter is the meter itself, the casing to contain the meter and the probe. The main measuring element of the lux is the probe that measures the illuminance of light in the fabricated day lighting system. The probe is a sensor that detects the light and measures the illuminance.

**The method of operation of a lux meter is as per below :**

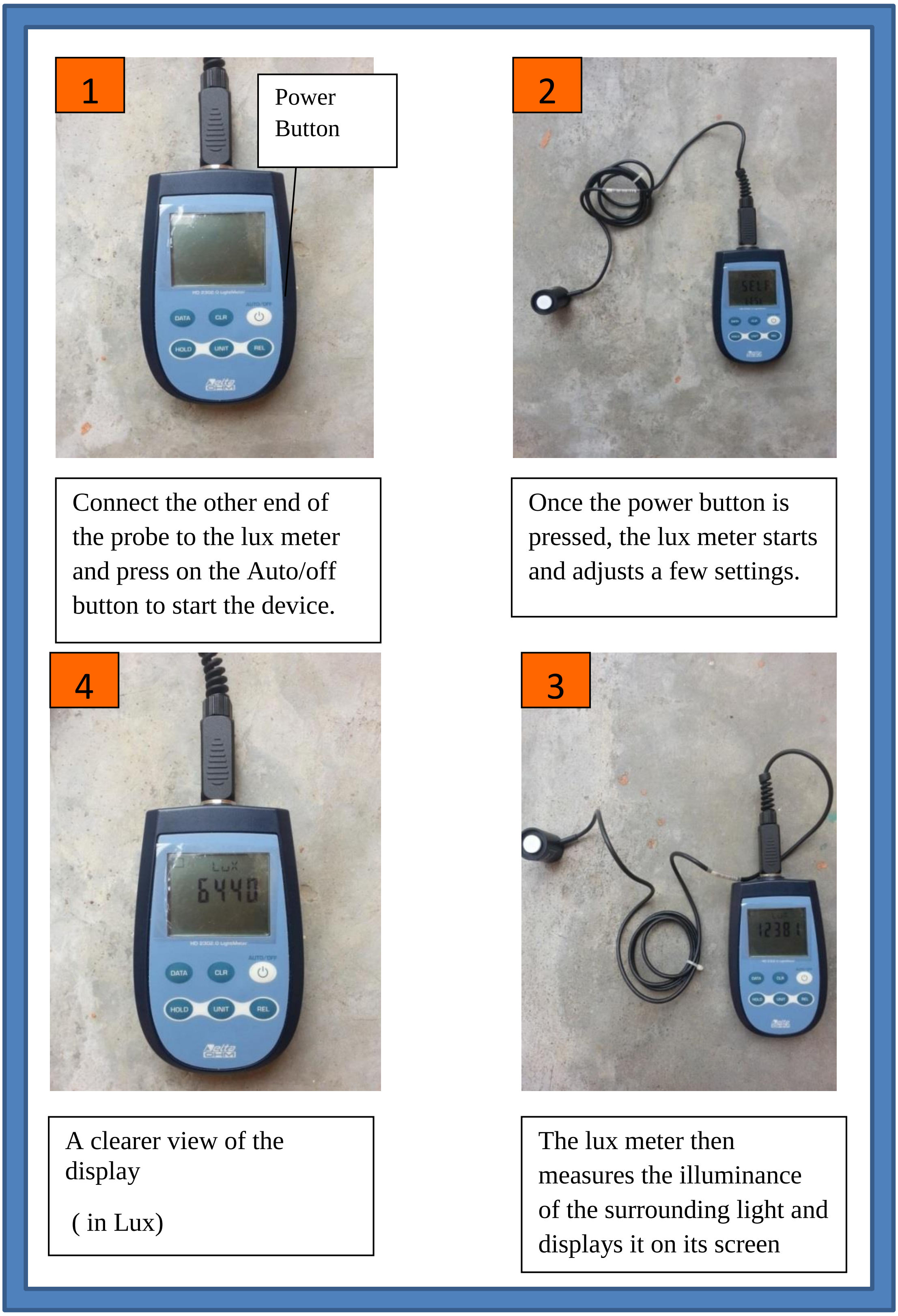



**Figure 24 Operating Method of the  Lux Meter**

### 5.2.4 Illuminance Measurement Results

**Experiment 1**

An illuminance measurement using the lux meter was conducted outdoor to obtain the actual illuminance of sunlight. The experiment was conducted on two type of region. The regions are the unshaded area and shaded area. The unshaded area directly receives sunlight whereas the shaded area does not receive sunlight. The following is the obtained illuminance measurement of both the areas tested on.

**Table 3 Shaded and Unshaded Area Illuminance**

| Illuminance (lux) / Area | Reading 1 | Reading 2 | Reading 3 | Average |
|---|---|---|---|---|
| **Shaded Region** | 13806 | 12799 | 13143 | 13249 |
| **Unshaded Region** | $22.73x10^3$ | $27.18x10^3$ | $29.25x10^3$ | $26.39\ x10^3$ |

From the tabulated results, it can be concluded that the unshaded region obtains more illuminance from the sunlight which 26.39 $x10^3$ lux in average compared to an shaded region which receives an average illuminance of about 26.39 $x10^3$ lux.

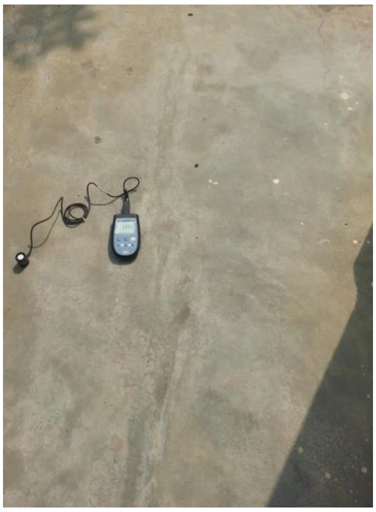


**Figure 25 Illuminance Measurement in Unshaded Area**

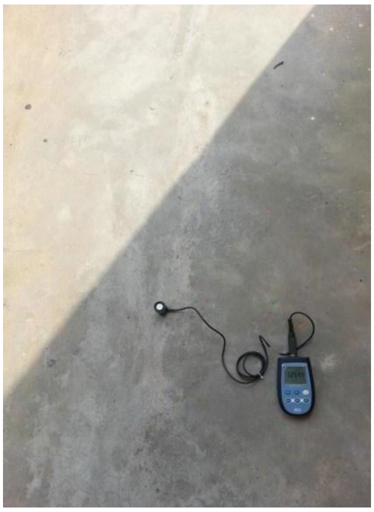


**Figure 26 Illuminance Measurement in Shaded Area**

**Experiment 2**

After executing experiment 1 which focuses on the outdoor actually sunlight luminance , the illuminance measurement experiment was conducted on the developed optical fiber day lighting system. The optical fiber day lighting system operates in a way that the torch will replace sunlight to function as a primary source. This is done to ease in experimentation and for indoor demonstration purposes. The light emitted by the torch will then be refracted by the magnifying glass to produce a focused point of light on the optical fiber bundle. The optical fiber bundle then transfers the light into the interior part of the housing. A bundle of optical fiber in this manner is termed light guide, as they are the main transport medium of light to the whole interior of the building. The experiment was conducted to test three different parameters that affect illuminance of light in the interior part of the housing . These parameters are the batch effect of the optical fibere, the length of the optical fiber and also the bending test conducted on the optical fiber. Other than that, light distribution throughout the interior of the housing was also studied. As an initial step, the illuminance of the torch was measured. Other than that , the distance between the torch and magnifying was also fixed in order to get the optimized amount of refracted light. All the experiments were conducted in a total dark space in order to retrieve the results without the interference of external light source. This is to avoid the error or inaccuracy in the results. Below are the data collected on this experimentation details before proceeding further into the consequent experiments.

**Figure 27 Illuminance Measurement of Primary Light Source**

- Illuminance of Primary Light Source (Torch)
  : 196.76 lux
- Illuminance of Refracted Light by Magnifying Glass
  : 147.27 lux
- Distance between torch and magnifying glass for optimized amount of light refracted
  : 0.25 metres

**Experiment 2.1 Batch effect of the Optical Fiber Bundle on the Illuminance Measurement of the Building Interior**

Batch effect parameter deals with the amount or number of optical fiber contained in one bundle. The batch effect experiment is conducted to investigate the relationship between the batch effect and the illuminance measurement. In this experiment bathches of 10,20,30 and 40 units of optical fiber were tested for its' illuminance. Test is done for each batch sample for various length on distinct experiments. The lengths that were tested are 0.1 m, 0.2m ,0.3 m, 0.4 m, and 0.5 m. Below are the tabulated data.

- Fixed Variable : Primary Light Source
- Manipulated Variable : Number of optical fiber in a bundle
- Responding Variable : Illuminance of light ((lm) / $m^2$)

**Figure 28 Illuminance Test on Batch Effect**

This test was conducted in a dark room in order to obtain the most accurate results. The optical fiber bundle is inserted to the holder and then inserted into the interior of the building through a hole. The probe is inserted and the illuminance is measured.

**Table 4 Batch Effect on Illuminance Measurement Results**

| Illuminance (lux) / Fiber Length (m) | 10 units | 20 units | 30 units | 40 units |
|---|---|---|---|---|
| **0.1** | 35.78 | 56.32 | 75.75 | 80.81 |
| **0.2** | 35.31 | 53.23 | 70.61 | 75.63 |
| **0.3** | 33.68 | 48.91 | 60.35 | 69.51 |
| **0.4** | 25.19 | 33.75 | 51.62 | 64.82 |
| **0.5** | 23.53 | 28.75 | 40.3 | 53.65 |

From the table, it can be concluded that as number of optical fibres in a single bundle increases, the higher the illuminance of light measured. For 10 units of optical fibre, the illuminance was at the lowest level whereas the illuminance was measured the highest at the maximum units of 40 optical fibre in a single bundle.  The change in illuminance is significant.

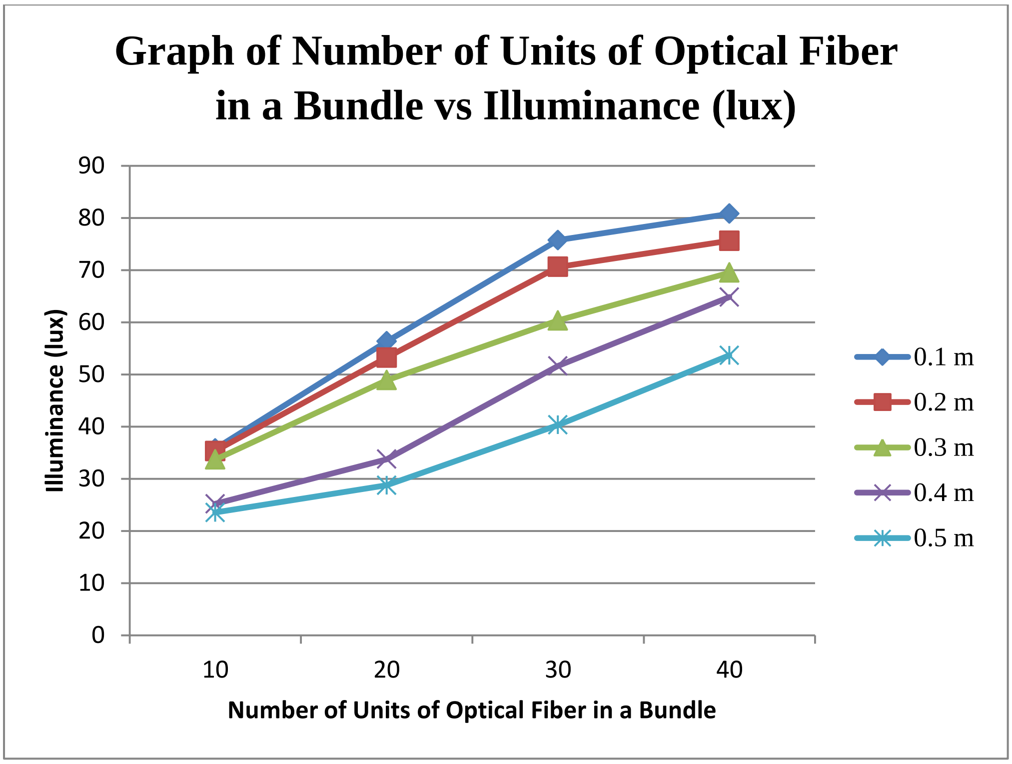



**Figure 29 Graph of Number of Units of Optical Fiber in a Bundle vs Illuminance(lux)**

According to the graph of number of units of optical fiber in a bundle vs illuminance(lux) ( see figure 30.) , it can be justified that increment in the number of units of optical fiber in a bundle increases the illuminance of the light emitted as well. Thus, the number of units of optical fiber in a bundle is directly proportional to the illuminance of light.

**Experiment 2.1 Effect of length of the Optical Fiber Bundle on the Illuminance Measurement of the Building Interior**

The following experiment tests on the effect of length of the optical fiber itself on the illuminance measurement of the building interior. The setting for the distance between torch and magnifying glass is the same as the previous experiment. The length of the optical fiber used in this experiment is 0.1 m, 0.2 m ,0.3 m ,0.4 m, and 0.5 m. The details of the experiment is setup (see Figure 31.) is as per below :

- Fixed Variable : Primary Light Source
- Manipulated Variable : Length of the optical fiber
- Responding Variable : Illuminance of light ((lm) / $m^2$)

**Figure 30 Test of length of optical fiber on the illuminance of light**

The data for illuminance of light for each length of optical fibre are recoreded and tabulated.

**Table 5 Effect of Optical Fiber Length on Illuminance of Light**

| Illuminance (lux) / Fiber Length (m) | 10 units | 20 units | 30 units | 40 units |
|---|---|---|---|---|
| **0.1** | 35.78 | 56.32 | 75.75 | 80.81 |
| **0.2** | 35.31 | 53.23 | 70.61 | 75.63 |
| **0.3** | 33.68 | 48.91 | 60.35 | 69.51 |
| **0.4** | 25.19 | 33.75 | 51.62 | 64.82 |
| **0.5** | 23.53 | 28.75 | 40.3 | 53.65 |

From the table, it can be validated that as the length of the optical fiber increases, the illuminance of light in the interior of the housing decreases. Thus, the length of the optical fiber is inversely proportional to the illuminance of light. From the range of optical fiber length of 0.1 meters to 0.5 meters, the latter has the lowest illuminance of light. However, there is not a significant change in illuminance of light. For example , for 40 units of optical fiber in a bundle, the optical fibre at the length of 0.1 meters emitted a light illuminance of 80.81 lux compared to an optical fiber of length 0.5 meters which emitted a light illuminance of 53.65 lux.

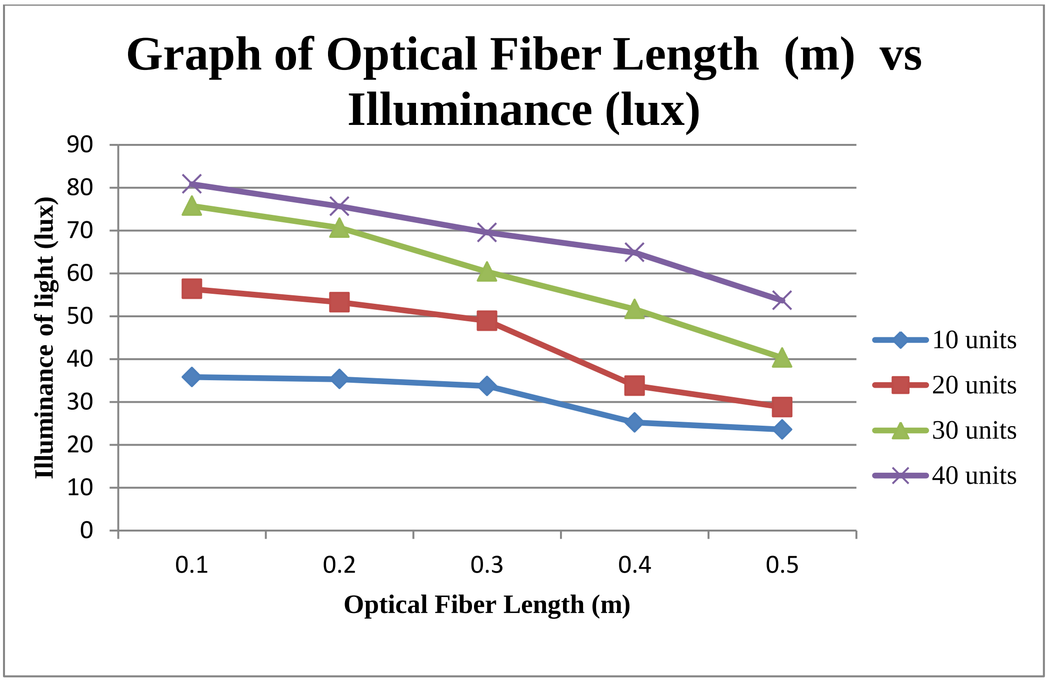



**Figure 31Graph of Optical Fiber Length vs Illuminance**

The graph plotting to observe the relationship between the length of the optical fibre and the illuminance of light emitted by the optical fibers. It can be seen that illuminance decreases as length of the optical fiber increases. For example,taking into account 20 units of optical fibers in a bundle,the highest illuminance is recorded by the shortest length of the optical fiber which is 0.1 meters, with a illuminance of about 56.32 lux and the lowest illuminance of 28.75 lux which is emitted by the longest length of optical fiber which is about 0.5 m.

### Experiment 2.3 Light Distribution of Optical Fibre on Building Interior

The third experiment focuses on the study of light distribution of the optical fiber on the building interior. In order to achieve this , the probe of the lux meter was placed in different distance from the light emtting end of the optical fiber. The setting for the distance between torch and magnifying glass is the same as the previous experiment. The range of the test covered from one end of the box to the other end. This meaning illuminance measurement were taken for every 0.08 metres of the 0.48 meters length housing. The experiment is setup(see figure 32.) and the measurements were recorded.

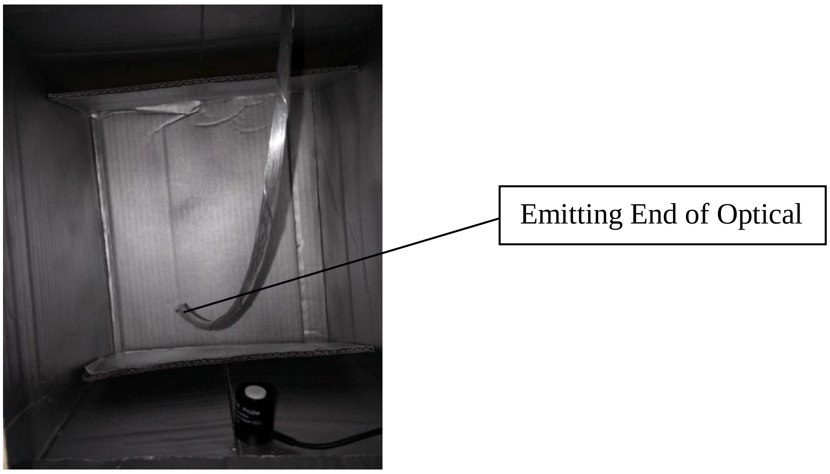



**Figure 32 Light Distribution Test**

**Table 6 Distance from Emitting End of Optical Fibre against Illuminance of Light (lux)**

| Distance from Emitting End of Optical Fibre (m) | Illuminance ( lux) |
|---|---|
| **0.00** | 0.38 |
| **0.08** | 0.36 |
| **0.16** | 0.24 |
| **0.24** | 0.26 |
| **0.32** | 0.12 |
| **0.40** | 0.00 |

The highest illuminance was recorded at 0.38 lux when the probe is placed directly under the emitting end of the optical fiber, at 0.00 meters. As the probe is placed further away, the illuminance decreases. The inference for this is light is not highly intense in distribution as it moves away from the light emitting end of the optical fiber. The lowest illuminance of light is recorded at 0.00 lux , when the probe is placed at 0.40 metres away from the light emitting end of the light guide ( optical fiber ).

**Experiment 2.4 Bend Effect of Optical Fibre on the Illuminance Ability**

The final experiment is done to study the effect of bending the optical fiber and its effect on the illuminance ability of the optical fiber. The study focuses on four bending angles. The angles tested are 0°, 45°,90°,135° and 180°**.** Below are the tabulated results.

**Table 7 Bending Angle and Its' Effect on Illuminance Capability of the Optical Fiber**

| **Bending Angle ( ° )** | **Illuminance Capability** |
|---|---|
| **0** | Capable |
| **45** | Capable |
| **90** | Capable |
| **135** | Capable |
| **180** | Capable |

Based on the test, the optical fiber is capable to emit light at all the bending angles tested. This proves that bending does not affect the capability of the optical fiber to emit light.

### 5.2.5 Percentage Losses

Based on the recorded illuminance measurement, the percentage losses are calculated to observe the degradation or increment in the light illuminance. The formula used to calculate the percentage loss is as per below :

$$\frac{Illuminance\ of\ Primary\ Source\ of\ Light - Measured\ Illuminance\ of\ Current\ Factor}{Illuminance\ of\ Primary\ Source\ of\ Light}\ x\ 100\ \%$$

Measured illuminance of primary source(torch) = 196.76 lux

Measured illuminance of refracted light by magnifying glass = 147.27 lux

Highest measured illuminance of light emitted by the optical fiber at its end = 80.81 lux

Lowest measured illuminance of light emitted by the optical fiber at its end = 23.53 lux

**Table 8 Percentage Loss of Illuminance**

| Factors | Percentage Loss |
|---|---|
| **Measured illuminance of refracted light using magnifying glass** | $\frac{\mathbf{196.76\ lux - 147.27\ lux}}{\mathbf{196.76\ lux}}$ x 100 % = 25.15 % |
| **Highest measured illuminance of light emitted by the optical fiber at its end** | $\frac{\mathbf{147.27\ lux - 80.81\ lux}}{\mathbf{147.27\ lux}}$ x 100 % = 45.12 % |
| **Lowest measured illuminance of light emitted by the optical fiber at its end** | $\frac{\mathbf{147.27\ lux - 23.53\ lux}}{\mathbf{147.27\ lux}}$ x 100 % = 84.40 % |

From the above tabulations , it can be concluded that the percentage loss of light illuminance is highest with the longest and least amount of optical fibers contained in a single bundle. The reasoning to this is due to the fact that internal losses increases as length increases.For this experiment, a 0.5 metre optical fiber containing 10 units of optical fiber in a bundle records the highest loss. On the other hand, the least loss of illuminance is when the optical fiber bundle is at its lowest length and most number of units of optical fibers in a batch or bundle. In this experiment, the optical fiber of length 0.10 metres records the lowest loss of illuminance with the highest number of optical fiber strand in a single bundle which is 40 units.

### 5.2.6 Optimization of Solar Radiation for Indoor Lighting in Universiti Teknologi PETRONAS

Universiti Teknologi PETRONAS homes staffs and students and is a potential candidate where the optical fiber based day lighting system can be optimized. This study focuses on the lecturers' office building where solar radiation can be fully utilized for day lighting purposes. This can be done through the usage of either the parabolic dish or Fresnel lens based optical fiber daylighting system. The parabolic dish is based on the principle of reflection whereas the Fresnel lens is based on the principle of light refraction. The optical fiber based day lighting system will replace the current electricity – consuming lighting system. Other than that, the staffs will also be exposed to more vitamin D since the direct sunlight is used. This will curb the issue of deficiency of vitamin D due to long working hours indoors. Besides that, the optical fiber daylighting system will help reduce the additional internal heat gain by the reduction in window usage. This reduction in internal heat gain will also directly help reduce the consumption of power due to air conditioning. Below are the three main rooms in the staff academic blocks taken into consideration and their respective dimensions.

**Table 9 Building Unit and Its Dimensions**

| Building Unit | Dimensions ( Width x length x height) (m) | Surface Area ($\mathbf{m^2}$) |
|---|---|---|
| Lecturer Office ( small) | 3 x 3.3 x 2.62 | 9.9 |
| Lecturer Office ( big ) | 3 x 5.1 x 2.62 | 15.3 |
| Meeting Room | 7.43 x 7.43 x 2.62 | 55.2 |

Based on the dimensions above, the volume of the small lecturer's office is calculated as 25.94 $m^3$, the big lecturer office has a volume of 40.09 $m^3$ whereas the meeting room has a volume of about 144 $m^3$. Based on the table of effect of length against the illuminance produced at the end of the optical fiber, the highest loss of illuminance between 0.1 difference in length of the optical fiber is 10.26 lux. This means that for every 1 meter, there will be a drop of 102.6 lux of illuminance.

It is estimated that for the building units, an average of about 300 to 400 lux is needed to illuminate the whole area. The primary source of light is the sunlight. Thus, direct solar radiation is used to illuminate the interior of the building. The direct solar radiation illuminance is considered as 26 390 from the measurement of previous experiment. Below are the calculations obtained for number of units of optical fiber needed, final illuminance obtained from the end of the optical fiber and also the percentage losses.

**Table 10 Illuminance Loss Calculation**

| Factors | Calculations |
|---|---|
| Measured loss illuminance of refracted light assuming a percentage loss of 25.15 % | $\frac{25.15}{100}$ x 26390 lux = 6597.5 lux |
| Refracted light on optical fiber bundle | 26390 – 6597.5 = 19 792.5 lux |
| Percentage loss per metre of optical fiber bundle | **102.6 lux** |
| Total losses for 10 meters of optical fiber | 102.6 lux x 10 meters = 1026 lux |
| Illuminance loss measurement with the highest percentage loss of the optical fiber (84.4 %) | $\frac{84.4}{100}$x 19792.5 lux = 16704.87 |
| Final measured illuminance obtained at the end of the optical fiber | 19 792.5 lux - 16704.87 lux = 3087.63 |

40 units of optical fiber lights up 0.2 $m^2$ from the previous conducted experiment. This means that a total of 200 units of optical fiber is needed to light up one meter square. Thus, for the small lecturer office with a total area of 9.9 $m^2$, a total of 1980 units of optical fibre is needed to light up the whole area. Other than that, for

the big lecturer office with an area measured of 15.3 $m^2$, a total of 3060 units of optical fiber are needed. Last but not least, the amount of optical fibers needed for the meeting room is 11 040 units.

**Table 11 Building Unit and Illuminance Required**

| Building Unit | Illuminance Required (lux) | Illuminance Provided by Sunlight (lux) | Optical Fiber Length (m) | Number of units of optical fiber needed | Final Illuminance Obtained (lux) |
|---|---|---|---|---|---|
| Lecturer Office (Small) | 350 | 26390 | 10 | 1980 | 3087.63 |
| Lecturer Office (Big) | 350 | 26390 | 10 | 3060 | 3087.63 |
| Meeting Room | 800 | 26390 | 10 | 11 040 | 3087.63 |

Based on the tabulated data, it shows that the total final illuminance obtained at the end of the optical fiber bundle is about 3087.63 lux which is adequately more than the required illuminance of about 350 to 800 lux. Other than these factors, the economical consideration is also noted. For every 1 meter, the cost of the optical fiber is RM 0.40.

**Table 12 Economic Analysis**

| Building Unit | Cost (RM) |
|---|---|
| Lecturer Office (Small) | 1980 x RM 0.40 x 10 meters = RM 7920 |
| Lecturer Office (Big) | 3060x RM 0.40x 10 metres = RM 12240 |
| Meeting Room | 11 040 x RM 0.40 x 10metres = RM 44160 |

The tabulated cost calculations suggest that it is viable for Universiti Teknologi PETRONAS to consider developing the optical fiber day lighting system. Although it is a costly investment, it will save a suffice amount of electricity consumptions that will lead to unnecessary energy usage and cost consumption.

# CHAPTER 6 CONCLUSION AND FUTURE WORK

## 6.1 Conclusion

In a conclusion, the basic design of the optical fibre based day lighting system has been highlighted. The design was executed using AutoCAD software . The AutoCAD design drawing comprises of three main units. These units are the solar collector, the optical fibre and also the building. Certain parameters of the solar collector such as diameter of dish,depth of dish and also focal length has been calculated . A parabolic equation has also been defined through the usage of Parabola Calculator 2.0.Besides that, the basic sizing for the building has been determined. This building will house the solar collector and the optical fibres. It is to be built using wood and will resemble the actual building. The overall volume of the building is about 0.21 $m^3$. For indoor demonstration purposes, this study was focused on the principle of light refraction for the development of the optical fiber day lighting system. The assembled day lighting system is test efficiency wise where the system’s illuminance measured. The role of factors such as length of the optical fiber, batch effect of the optical fiber,bending affect test, and light distribution test on the light illuminance measurement was studied. Based on these factors, it is concluded that the increment of the optical fiber length and decrement of number of units per batch decreases the overall measured illuminance. The light distribution was also studied and it is validated that illuminance is measured decreased as its further away from the source of the illuminance which is the end of the optical fiber itself. Bending test was conducted and it is reasoned that bending doesn’t affect the illuminance of optical fiber in any way. The analysis done for optical fiber daylighting system in UTP suggests that it will be a possible alternative to the current electricity consuming indoor lighting system.

## 6.2 Future Work

Basic design of the optical fibre daylighting system has been laid out with certain criterias identified. Further optimization of the daylighting system design will be carried out. Optimization of design will include a sun tracking device if possible. This is to ensure adequate amount of sunlight is transferred to the optical fiber bundle. Besides that, the optical fiber system should be developed based on the standards and comfort of lighting set for a typical room and people.

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# APPENDICES

Appendix : Gantt Chart

| Project Title: UTILIZATION OF DIRECT SOLAR RADIATION FOR INDOOR LIGHTING | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov |
| **Project Title Selection** | ★ | | | | | | | | | | |
| **<u>Planning & research phase</u>** | | | | | | | | | | | |
| **Literature review** | | ★ | | | | | | | | | |
| **<u>Design, testing and analysis phase</u>** | | | | | | | | | | | |
| **Design of optical fibre daylighting system** | | | | ★ | | | | | | | |
| **Fabrication of optical fibre daylighting system** | | | | | | ★ | | | | | |
| **Testing and analysis** | | | | | | | ★ | | | | |
| **<u>Presentation phase</u>** | | | | | | | | | | | |
| **Submission of Progress Report** | | | | | | | | | | | |
| **Pre-EDX** | | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Submission of Draft Report** | | | | | | | | | | | |
| **Submission of Dissertation** | | | | | | | | | | | |
| **Submission of Technical Paper** | | | | | | | | | | | |
| **Oral Presentation** | | | | | | | | | | | |
| **Submission of Project Dissertation** | | | | | | | | | | | |

Legend

Process

★ Key Milestones