Luminous Measurement of LED Lights in Cost Effective Way

A Thesis submitted to the

Dept. of Electrical & Electronic Engineering, BRAC University in partial fulfilment of the requirements for the Bachelor of Science degree in Electrical & Electronic Engineering

By

Abdul Halim	10221042
Abdul Shakib Billah	10321004
Ishrat Jahan	10321044

Supervised by

Dr. A. K. M. Abdul Malek Azad

Department of Electrical and Electronic Engineering

August 2014

BRAC University, Dhaka

DECLARATION

We hereby declare that this thesis paper is a result of our own work and effort and all the other information's from other sources have been acknowledged in the reference section. We haven't submitted this to anywhere else for any sort of award or publication.

Date:

Supervisor

Dr. A.K.M. Abdul Malek Azad

Abdul Halim

Student ID: 10221042

Abdul Sakib Billah

Student ID: 10321004

Ishrat Jahan

Student ID: 10321044

ACKNOWLEDGEMENT

We have incurred many debts of gratitude over the last few days while preparing for this report. First and foremost, we would like to pay our gratitude to the Almighty Allah for giving us the ability to work hard. This is our humble attempt to present gratitude in writing this report**.** Secondly, we would like to express our gratitude to our Supervisor Dr. A.K.M Abdul Malek Azad for his valuable guidance and support. We really appreciate what he has taught us for this thesis; we express our heart-felt gratefulness for that. We would also like to express our gratitude to the research assistants Sabbir Ahmed Khan and Rafiur Rahman for their continuous effort and support.

Hence, we have taken help from different sources for preparing the report. Without the help, completing the report perfectly would not have been possible. Now here is a petite effort to show our deep gratitude to those helpful persons who have put it up on the texts and websites.

Last but not the least, we would like to thank all our fellow students and others whose names are not mentioned here, but directly or indirectly offered suggestions and guidelines to the completion of our work. We warmly thank them for their kind contribution.

Abstract

This paper targets economic and sustainable methods of lumen testing of LED lights. Its resurgence being in a developing nation, like Bangladesh, it is necessary that such an expensive method, around the world, be brought down to reasonable circumstance. We initially acknowledge and elaborate the varying methods that are already present. Furthermore, we discuss the methods of our experiments and their results using varying techniques to strengthen our initial hypothesis, which focuses on lumen testing affordability.

Table of Content

Table of Figures

List of Tables

1. INTRODUCTION

1.1Background and Motivation

Low cost method for luminous flux measurement in a developing country like ours is a must. Not only for industrial lighting purpose but also for accurate commercial usage as well. Compared to other remaining methods for example in case of box photometer method, the use of integrating sphere method is highly precise in terms of accuracy and cost.

The box photometer method is easier to build and quicker than the integrating sphere method. Box photometer method is prone to error due to the change in light source location and orientation. Our thesis compares the measurement accuracy low cost measuring of light to a spectroradiometer integrating sphere system and other systems.

Measurement of illuminance done with box photometer and integrating sphere method are compared to our cylindrical cost effective method. Calibration during the procedure of testing was made to make sure how closely our low cost method can replace other remaining competitive method. We used graphical analysis to find out the characteristics of different method under different conditions.

We varied the height, distance, light levels and spatial distribution of light. The ultimate objective of this thesis is to provide and come up with an affordable solution for the off grid light industry for improving the uncertainly of various other methods. We used a general setting and principles, apparatuses to carry out the study.

The overall sole purpose of this thesis is that lighting is a very basic human need of this modern century, since the human development the necessity of artificial lighting is undeniable. Use of modern incandescent, fluorescent, LED luminaires the general well-being, productivity of society is impossible. The necessity of low cost solution may be small but has a significance importance to the lighting industry.

To understand the assurance of quality we had to revise the available methods of international standards. Lighting in South East Asian developing countries like Bangladesh has gone through tremendous growth level since its independence as a sovereign nation. With electricity reaching to almost every corner of the remotest union to the unreachable hill tracts of southern Bangladesh, use of efficient lighting has become a major issue.

Low cost luminous testing of lights not only saves wastage of power but also maintenance sustainability. Due to huge load densities and over population in most of the cities of Bangladesh the grid electricity seems to be slow. The growing demand of electricity is putting everlasting pressure and curable demand for efficient lighting among many of us. Many are unable to cope with high cost, relying on solar home systems (SHS) for remedy.

Lighting with solar home system is not the ultimate solution while the cost is very high and people have to rely on backup power from national grid. However the market is already loaded with low quality lighting products providing risk factors for users. For better illumination reducing operating cost cylindrical method of testing can be reliable. Understanding current lighting products with their rating was also a concern regarding choosing the ultimate cylindrical procedure for a small, medium and large cylinder.

Market spoilage with low quality lamps, LEDs is a concern to battle insufficient usage and power wastage demanding high quality performance. Failure of modern lighting products can increase the cost of illumination. The rising popularity of LEDs in developing country like ours the urgency of quality testing for better performance has already begun.

Integration of cylindrical method that is useful, highly accurate, durable required a certain designing and measuring of the sphere. In our study we carry out three different cylinder of different size and several lamps with rated lumen on to compare with other available methods. The price of high quality lamps for low income users of our country can be made into a reality using this.

1.1.1 Optical measurement for high power LEDs and solid state lighting products

With the rapid growth of economy in Bangladesh the LED industry and solid state lighting products is also growing at a demanding rate. Hence the need for optical measurements of these products is a must.

Basics of optical measurement: How much radiometric power should be emitted by the source per unit wavelength is described by the spectral radiant flux. It also allows user to be familiar with other properties of light source that includes color rendering index, purity, dominant wavelength etc.

To measure spectral radiant flux there are two methods: The lights from a light source inside a sphere is collected by integrating sphere method. While goniophotometer measures the radiant flux around the source bat different angle and integrates the result. Integrating sphere is more preferred for goniophotometer method.

1.2 LED Lamps as SHS System

Solar Home System (SHS) has offered a tremendous contribution in last 15 years in our country.[1] In Bangladesh there is a numerous solar supply due to its geographical location. A financial institution established by government of Bangladesh; Infrastructure Development Company Limited (IDCOL) manage the SHS project in Bangladesh.[1] LED bulbs have progressed the most among all the SHS products such as batteries, charge controllers etc. There are a couple of companies manufacturing LED bulbs today in our country. These bulbs are not only used in under developed areas but also in urban areas as well because of its low power consumption and brighter light producing ability. Also Led bulbs are better in terms of longevity. In a developing country like Bangladesh such products are much appreciated that consume less power and last longer than the available products of same category.

2. OVERVIEW

We are aiming to use a cost effective method for luminous flux measurement. There are several methods for measuring luminous flux available now-a-days, including the common method used in industrial laboratories with access to a goniophotometer for measuring luminous intensity distribution.

2.1 Objective and Field of Application

The derivation of the luminous flux from a measurement of the luminance distribution of a lamp is the method used in many international standards laboratories to set up the basic standards of luminous flux. The unit of luminous flux, the lumen, is established in terms of the SI base unit of luminous intensity, the candela.[2] The accurate measurement of the spatial variation of the colorimetric properties of light sources and their spectral power distribution can also be done by using this method:

Standard photometer:Secondary standard for illuminance measurements. [2]
Sphere photometer: Measures illuminance levels relative to the luminous flux. [2]
Spectroradiometer*:* Used for measuring the spectrum of the luminous flux sources. [2]
Integrating sphere: Collects the total luminous flux of the lamp inside the sphere. [2]

2.2 Methods of Measurement

-From the luminous intensity distribution it can be calculated [2]
-Also from the illuminance distribution can be calculated [2]
-Measurements can be made with a sphere photometer by photometric or spectral measurements; [2]
-Using a box photometer [2]
-Relative measurements via illuminance, luminous intensity or luminance.[2]

2.3 Photometric Quantities

Luminous flux: By evaluating the radiation according to its action quantity derived from radiant flux. [3]

Luminous intensity: The degree or amount of a specified quality or characteristic of the luminous flux that leaves the source and propagated in the element of solid angle contains the given direction. [3]

Illuminance: The degree or amount of a specified quality or characteristicof the luminous flux incident on an element of the surface that contains the point, by that particular area of that element.[3]

2.4 Calculation of Luminous Flux from Luminous Intensity Distribution

This method uses goniophotometers for the measurement of luminous intensity. To evaluate the luminous flux, the luminous intensity should be integrated over the full angle. In practical purpose the integrals are replaced by sums. The smaller the angular steps that are chosen, the more accurate would be the resulting luminous flux. The light sourced should be placed closest to the centre and it is not at all necessary to keep it exactly in the centre of the Imaginary hemisphere. [4]

2.5 Calculation of Luminous Flux from theIlluminance Distribution

From the distribution of illuminance against a closed surface relationship can be used to derive the luminous flux. In order to measure the illuminance distribution over the spherical surface around the light goniophotometer is used. [4]

2.6 Measurement of Illuminance Distribution

1) A successive measurement along a line on the sphere periphery is done to measure the illuminance. This line basically surrounds the light source. The angular step size is less for such movement of photometer.[5]

2) On a surface which is conical in shape is where the illuminance distribution is measured.
3) The Successive measurement on a vertical plane is done to obtain the illuminance distribution. [5]

Spectral resolution: There are band pass for spectrometer. Smaller the band pass, higher the resolution. A larger band pass can cause widening of the spectral radiant flux. [6]

Stray light: The incoming light is spitted into its spectral components. Stray light within the spectrometer should be minimized. National Institute of Standards and Technology, USA (NIST) has discovered an algorithm to reduce stray light in spectrometers [6]

Spectroradiometer vs. Photometer: Output current of a photometer is proportional to the luminous flux while a spectroradiometer measures the total spectral radiant flux.[6]

Total Luminous Flux: Narrowband of LED makes the measurement uncertain as we already know total luminous flux of LED can be measured either by integrating sphere or goniophotometer method where both of them give visible uncertainty. [7]

Total Spectral Radiant Flux: Are increasingly used these days for LED measurement, a suitable method for measuring color quantities and photometric quantities. If we use an array spectroradiometer we can get faster results as sphere photometer system. [7]

Color quantities: What do we mean by color quantities? The color characteristics of LED can be specified by chromaticity coordinates, correlated color temperature and color rendering index for white LEDs. [7]

2.7 Usefulness of Using LED in Flux Measurement

- Virtually ideal
- Almost monochromatic in most cases
- Measurements are easily carried out

2.8 Integrating Sphere versus Goniophotometer

- Integrating sphere is fast and relatively low cost compared to goniophotometer method.
- Integrating sphere method does not require dark room while goniophotometer method may require. [7]

2.9 Safety and Handling Precautions

- The lamps should be turned on and off slowly (30–60 seconds). The lamps shouldnot be moved while operated.[8]
- Should not touch the envelope of the external source. After operating, allow the lamp cool down for 2 hours before removing it from the setup.[8]
- Should not touch the bulb of the internal source with bare hands. Use cotton gloveswhen mounting the lamps into the socket.[8]
- Should be careful when changing the internal source between calibrations. The bulb is probably still warm.[8]
- Should be very careful when handling customer lamps.[8]

2.10 International Comparisons

The latest international comparisons of the unit of luminous flux:

- 2000: Comparison of luminous flux units with NIST (USA) [9]
  Level of agreement 0.06 % with an expanded uncertainty (k = 2) of 1.01 %.

- 2003: Comparison of luminous flux units with SP (BIPM calibration in 2001) [9]
  Level of agreement 0.16 % with an expanded uncertainty (k = 2) of 1.10 %.

2.11What is Lumen?

It is the unit of luminous flux. It is different from radiant flux. In fact lumen can be considered as the measure of total amount of visible light. Usually lights are labelled in lumen internationally.

Relationship between luminous intensity and other measures: In most of the cases luminous flux and luminous intensity are confused. The unit of luminous intensity is candela. The magnitude of electromagnetic field is the candela. That has a power level equivalent to a visible-light field of 1/683 watt (1.46 x 10^{-3} W) per steradian at 540 THz. [10]

Lumen maintenance: Light produced from a light source or luminaire is compared by lumen maintenance.

Luminous efficacy: The higher the visibility of light the better is the chance of luminous efficacy. The source that provides luminous efficacy determines how well a given quantity can produce strong visible light. Due to spectral sensitivity not all wavelengths are visible.[9]

Incandescent light bulb: Manufactured at a wide range of sizes with light output and voltage ranges Capable of working on both AC and DC current. Compared to other lights incandescent lights are less expensive, can convert less than 5% of energy. When fluorescent bulbs are not used they can be replaced by incandescent light.[9]

Fluorescent lamps: Use of fluorescence at low pressure while producing visible light is the principle of fluorescent lights. Though costly due to the requirement of ballast but the lower energy cost attracts [9]

Customers to fluorescent lamps: Another huge benefit of fluorescent light is that they are environment friendly and easily disposable.

Cold cathode fluorescent lamp: Commonly used in discharge lamps and neon lamps. Low temperature is not suitable to operate cold cathode lamps. Cold cathode lamps are usually used in LCDs, computer monitor and TV screen. [10]

2.12 *What Do We Understand by Luminous Flux and Why Is It Used For Lighting?*

In simple words the luminous flux is energy per unit time, over a visible wavelength radiated from a source. It is energy of wavelength sensitive to human eye. The daylight sensitivity of human eye has a peak at almost 555nm often known as photopic vision. While night sensitivity is known as scotopic vision has a peak at 507 nm. The weighting factor or luminous efficacy converts radiant flux to luminous flux.

When the source radiates over a spectrum determining luminous flux is complex. The standard incandescent lamp generates continuous spectrum while mercury vapour lamp emits light in a line spectrum. Normally the luminous flux for incandescent lamp is given while manufactured by the laboratory for example a 100 Watt incandescent lamp has a lumen rating of 1700. [11].

2.13 Facts on Luminous Flux

- It is an electromagnetic energy [12]
- Wavelength ranges from 390 nm to 770 nm [12]
- Flux is measured from power emitted per solid angle[12]
- Radiation can work in a three dimensional space. [12]

2.14 Radiant Intensity

- Quantitative expression reflection of a source electromagnetic energy. [12]
- Power emitted from a isotopic radiator. [12]
- Radiation in all direction including three dimensional spaces. [12]
- Standard unit is watt per steradian.[12]
- Equivalent of a kilogram meter squared per second. [12]

- Steridian defines radiant intensity at any wavelength.

2.15 Photometer Head

A photometer head is a device that has a light sensitive detector. To measure spectral weighting or for the spectral distribution of the light this device is used. It is perceived with the properties for directive assessment of the light. [12]

2.16 Applications

Universal and competitively priced laboratory instrument	Photometer heads for different applications; optional thermostatic stabilization and cosine correction; classification in conformity with DIN 5032-7 and CIE 69
Illuminance meter	Ultra-fast Goniophotometric measurements
Tristimulus colorimeter	Goniophotometriccolour measurement
Luminance meter	Laboratory measurements of automotive license plates

Table 1: Applications

2.17 Acceptance Area

The area of the photometer head that receives and evaluate the incident light directionally. [2]

3. GONIOPHOTOMETER

Goniophotometer and photometer together forms the goniophotometer**,** whichdisplays photometric properties of visible light to human eye. The actual uses of goniophotometers are in automotive and general lighting industry.Photometer for measuring the directional light distribution properties of sources, luminaries, media and surfaces. Used for light emitted from an object at different angles.[14]

3.1 Types of Goniophotometer

Distinction between different types of goniophotometer used for the measurement of illuminance distribution is possible.

1) **Test object in fixed position:**In this type of goniophotometers the light source is kept stationary at the burning position.[14] The photometer head revolve around the stationary light source about two axis and they cut each other at 90°around the test object. [14]
2) **Test object rotated about a spatially fixed centre:**Unlike the previous method the test object is revolved vertically at different points on the plane. The photometer is rotated perpendicularly around the test object. Likewise the two axis cuts each other at 90°.[14]
3) **Test object rotated about a vertical axis with a moving Light centre**: In this case both the test object and the photometer head are placed at the end of the revolving shaft. Around the burning position of the test object it is rotated. Such type of goniophotometer is more mechanical and automated fashioned. [14]

3.2 Maintenance

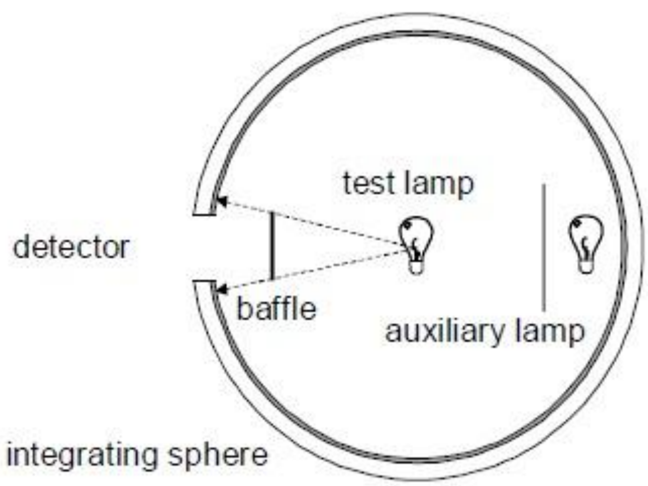
The standardization must be regulated in order to ensure accurate dimension and traceability. There are mirror goniophotometers as well to do the experiment more accurately.

3.3 Traceability Chain of Luminous Flux

The unit of luminous flux is linked to the units of illuminance and luminous intensity viathe standard photometer. Therefore luminous flux is traceable to the primary standards ofoptical power, spectral transmittance and length.

3.4 Radiant Power and Luminous Flux Measurement

Radiation is emitted from different light sources such as lamps, lasers, LEDs and optical fibers in all directions.[15] The luminous flux of parallel beam is directly measured by flat detectors in a very efficient way. At the entrance of the integrating sphere sources can be attached.[15] Radiation reflected internally inside the sphere often causes error. However the measurement uncertainly can be reduced.[15] The hollow sphere should me ten times larger than the lamps dimension. Smaller sized sphere provide a larger diameter port to position the lamp inside the sphere. [15]



.

Figure 1: Setup for radiant power and luminous flux measurements of a lamp [15]

3.5 Lumen Comparison and Conversion

As already discussed, the luminous efficacy defines the merit of a light. Power is usually the radiant flux of the sources output or the total power that the source consumes. Two terms are used to describe the efficacy one is the luminous efficacy of radiation (LER) and the other is luminous efficacy of source (LES). When a certain amount of electricity is given LES describes how well the source can produce light. On the other hand LER describes how well it can respond to the mixed wavelengths. [15]

3.6Luminous Efficacy of Radiation

Wavelength outside visible spectrum is not useful as they are not seen by human eye. The fraction of electromagnetic power is measured by luminous efficacy of radiation.[15] Wavelengths outside the visible spectrum are responsible for reduction of LER. The luminous efficacy has a SI unit of lumen/watt. [15]

Lighting efficiency: The overall luminous efficacy of artificial sources is evaluated by the luminous efficacy of the sources.[16] The difference between luminous efficacy of source and luminous efficacy of radiation describes that LES is for the input energy that is lost as heat while LER is the property of radiation reflected by a source. [16]

Energy efficient lighting: Modern day consumer ratio of power finds lighting consumes 11% use of energy in residents and 18% of commercial usage. Adopting efficient technology in lighting can save energy and contribute towards reliability.[16] To contribute to reduce energy usage in lighting purpose may reduce light pollution as well.[16] New technologies used in incandescent bulbs may result in substantial net energy use reduction.[16] The higher the efficiency of lighting occurs the more chances are visible for efficient lighting technology development. [16]

Technologies that reduce lighting use: Present day availability of timers and sensors can reduce lighting use. With the presence of infrared and ultrasonic sensors [16], light fixing can be more accurate. The use of photo sensors in lighting these days are also promising. [16]

Improving building design to maximize the use of light: Building designed in a substantial way to incorporate efficient amount of natural daylight entry can reduce the necessity of huge amount of lighting, therefore contributing to a large scale energy savings. [16] Artificial lighting may be a supplement during night. [16] Builders can use light painted colors on building walls to ensure maximum reflectance of lighting used. [16]

Reducing GHG emission: Taking holistic approach that not only considers how designing may affect natural lighting but also makes sure enough room for heating and cooling system, so that the building can receive maximum amount of sunlight. [16] In order to reduce the electricity use and GHG emissions there are not many new technologies available these days. But considering the quality of lighting, frequency and the environment for light use GHG reduction can be made. [16]

3.7Most Common Lighting System Necessary for Buildings [17]

Incandescent bulbs:

- Current passes through tungsten filaments and bulb emits light. [17]
- Energy used in bulb is emitted 90% as heat.[17]
- Using lumen for evaluating them and output to energy from the input. [17]
- Efficiency of standard incandescent bulb is less than the halogen incandescent bulb.[17]

Compact fluorescent bulb:

- Internal gas filled chamber connects with UV light while current passes through emitting light. [17]
- Fluorescent tubes has special coating, all fluorescent lamp requires high cost ballast. [17]
- The main purpose of ballast inside is to regulate current.[17]
- Two types of ballasts are found, namely magnetic and electric.[17]

- In CFL lights ballasts are integrated or non-integrated.[17]

High intensity discharge (HID) lamps:

- Same principle works for this type too, again light is emitted when current passes through the ballasts.[17]
- Gas filled tube has two electrodes on either side.[17]
- Has long start-up period and not usable everywhere.[17]
- Best used in sports field and street lights [17]

Low pressure sodium lamps:

- Most usable in outdoors. [17]
- Long start up and cool down time.[17]
- Used specially in highway, garage and security lighting.[17]

Light emitting diode (LED):

- Electron hole pair combination releases energy in the form of light. [17]
- LED uses 75 to 80 % less electricity compared to incandescent bulb.
- The usual lumen rating of LED is 27-150 lumens per watt.[17]
- Have small yet very bright bulbs, more durable than other lights.
- Solid state lighting by use of solid objects is being developed by researchers that could save energy.[17]

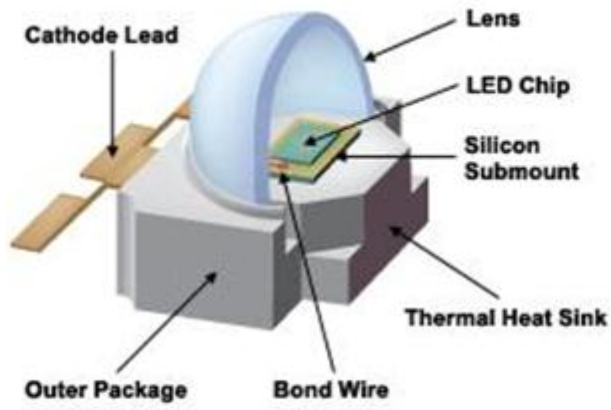


Figure 2: Light emitting diode

Hybrid solar lighting:

- Relatively new technology, light conducting optical fibre is used to send visible amount of solar energy. [17]
- This technology has a promising future, solar collector separates visible light from infrared radiation.[17]
- Not most competitive with other lighting options.[17]

Emission reduction potential:

- By using efficiency measures, GHG emission associated with lighting can be reduced.
- Efficiency measure may lead to low utility bills using less artificial light. For example 75% less energy is used by CFLs.[17]

Cost:

- Switching of light where unnecessary to produce low utility bills.
- Installing timers and sensors while overall savings depend on the electricity consumption rate.

3.8Equipment Needed for Calibrating Luminous Flux Standard Lamps

A. Light measurement

1. PRC-photometer
2. Integrating sphere
3. Spectroradiometer
4. Precision aperture
5. Current-to-voltage converter (CVC)
6. Digital voltmeter

B. Light source

1. Lamp power supply
2. Standard resistor
3. Digital voltmeter
4. Alignment laser

C. Control and data acquisition

1. Computer
2. Software

Obstacle to further development:

- Cutting edge technologies can contribute to consumers and municipalities.
- Slightly longer payback period.

3.9Determination of Luminous Flux from a Light Source Using Hemisphere Method

- The total luminous flux from a light source can be done by placing the source in the centre.[19]
- Then an imaginary hemisphere and measuring the illuminate from the source at different meridian angles, and parallel angles are taken with in the hemisphere. [19]

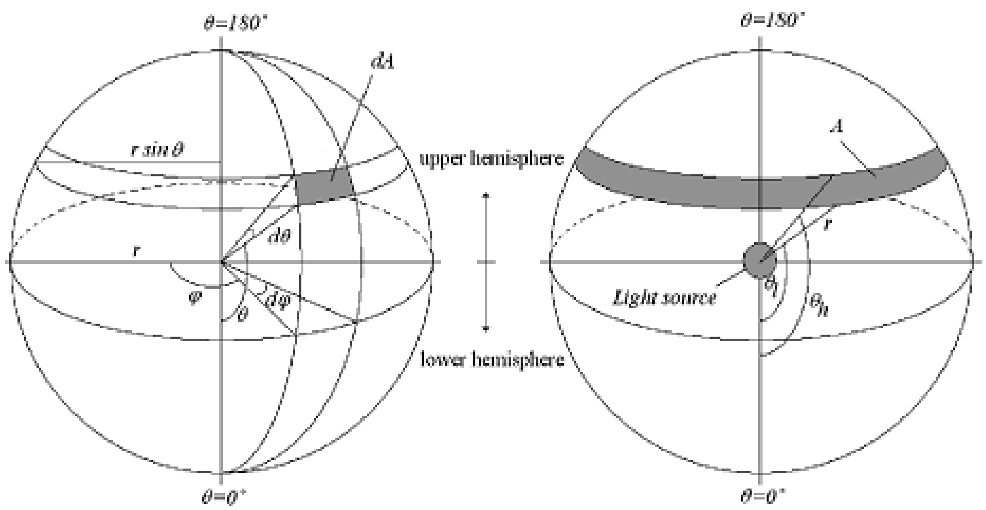


Figure 3: Spherical surface scanned by Goniophometer (Sametoglu, 2010)

- By taking the measurement at different places illuminance is measured for small zone on the surface of the hemisphere and enables determination of the luminous flux in the area.[19]
- Hence the total luminous flux emitted from the source is determined by summing up the luminous flux of individual zones at the surface of the sphere.[19]

Θ(Meridian angle) is the angle between the plane on which the LED is mounted and the photometer head. [19]

φ (Parallel angle) is the angle between the reference axis of the plane and the line along which the photometer head is rotated. [19]

3.10Calculating the Total Luminous Flux of LED Lamp Incident over the Surface of a Hemisphere

An average illuminance E0 (θ, φ) is calculated for each meridian angle.

- E0 (θ, φ) is then integrated over the respective meridian interval to give to illuminance E (θ, φ) over a small meridian line dl at φ°

  EI (θ, φ) = $\int$ E0 (θ, φ) Sinθdθ lumen/m2 [19]

- EI (θ, φ) for the different meridian intervals is then summed to give the illuminance E (φ) over the meridian line.

  E (φ) = $\sum$ EI (θ, φ) [19]

- E (φ) is integrated over 2π to find the total luminous flux, ΦV incident on the surface of the hemisphere.

  ΦV = $\int$ E (φ) dφ lumen [19]

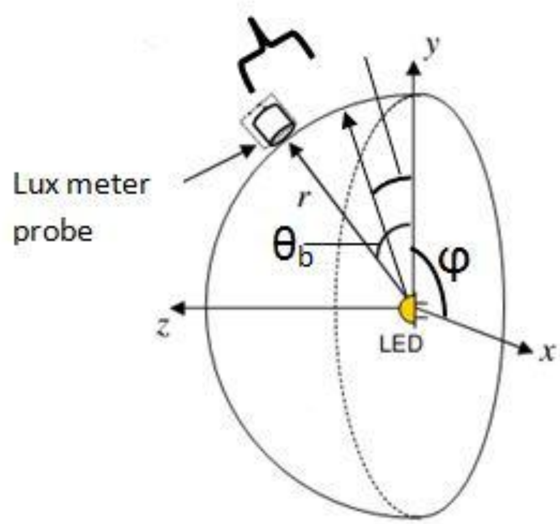


Figure 4: Parallel Meridian Angle Distribution

3.11Luminous Flux Calibration using Absolute Integrating Sphere

- Developed by NIST to realize the luminous flux unit using the ultimate integrating sphere instead of goniophotometer
- The spatial nonuniformity of the integrating sphere is corrected.
- A new luminous-flux calibration facility with a 2.5 m integrating sphere has been recently completed at the NIST.
- Total luminous flux inside the sphere can be compared with a given flux entering the sphere.
- For scanning beam source when the scanner rotates inside the sphere, the optical source power should be independent of the alignment.
- The illuminance is measured on the entrance aperture, using a reference photometer.

3.12TheNew Integrating Sphere Method for Spectral Radiant Flux Determination of Light Emitting Diodes

- Alternative to traditional light sources.
- Hemispherical radiation of high-power LEDs used to increase the accuracy of the flux determination using a custom-made integrating sphere.

3.13Spatial Integration Method for Luminous Flux Determination of LED

- Without any backward emission this method is used for measuring total luminous flux of light emitting diodes.
- Parabolic concentrator is used to collect light from LED.

3.14 Luminous Flux Measurement by Goniophotometer

- Measures angular dependence of photometric quantity.
- Photometer head is rotated around the centre and photometric centre of the light source is considered as the centre.
- Luminous intensity is found by measurement of illuminance.

4. METHODOLOGY

4.1 The Cylindrical Procedure

Existing procedures for lumen test is quite costly in our country's perspective, sowe have used our handmade cylindrical black box of different dimensions and sizes. From this cylindrical black box we have measured all the necessary data and established some relevant equations from what we have measured the total lumen of the light. The result is satisfactory (±5%) of the rated value.

4.1.1 Calibration

To obtain accurate measurement data from LEDs certain calibration procedures are followed, the following flow chart describes how we can go for the calibration.[2]

Correction of absorption of light source: Spectral reflectivity changes whenever an object is inserted in the integrating sphere, affecting the overall accuracy of the measurement. Absorption can be corrected by an auxiliary lamp placed inside the integrating sphere. The procedure can be repeated. The absorption correction factor should be measured on a regular basis.[2]

4.2 The Construction of Cylindrical Black Box

In order to test the total luminous flux emission of a LED light, three different black boxes have been used of different sizes. The small cylinder is 50 cm in diameter, the medium one is 65 cm and the big one is 125 cm in diameter.

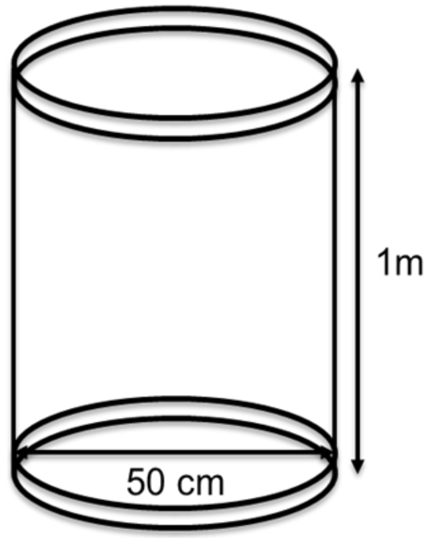


Figure 5: Small Cylinder

.

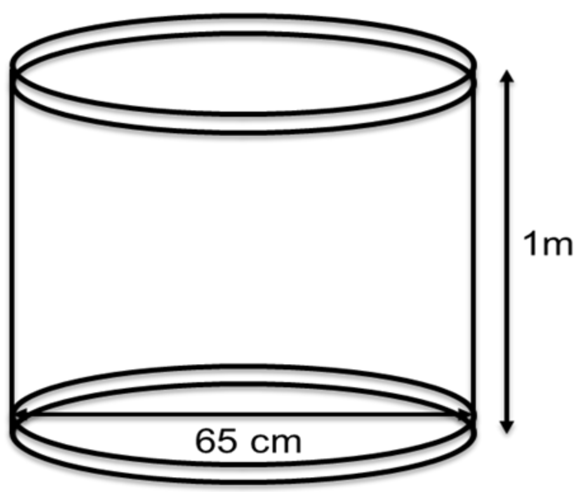


Figure 6: Medium cylinder

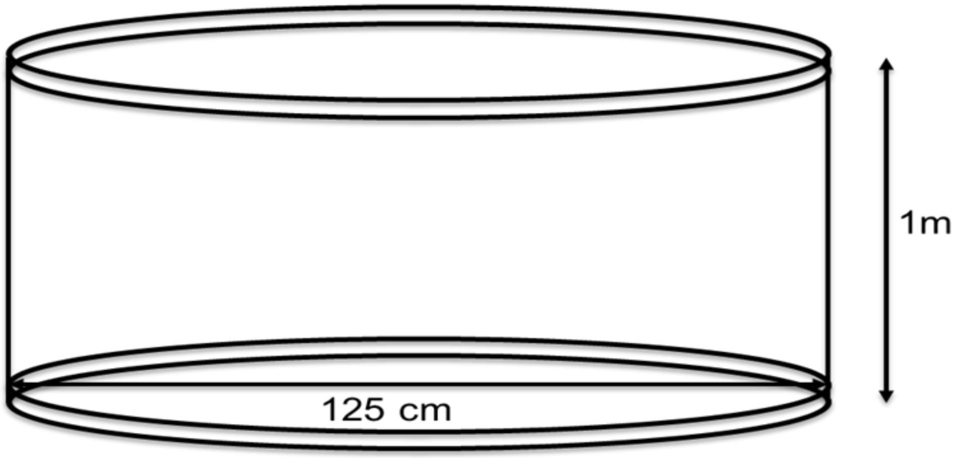


Figure 7: Large cylinder

For the reflective part we have used P.V.C (Polyvinyl Chloride) board which is white in color and can be bended in circular manner. The structural frame consists of three circular rings of desired radius and is connected with steel bar to hold the rings.

The P.V.C board then inserted in the rings by bending it. In order to make the outer surface absorbing charcoal black colored black model paper is glued inside the cylinder. The slit cover of the cylinder was also made in the same manner and is coated with absorbing surface on the outer side.

4.3 Measurement Criteria

This cylindrical black box used in our lab has a reflecting coating in the inner surface and absorbing black on the outer surface. The length of the cylinder is 1 meter. The lamp is placed at the center of the base of the black box. The reflective surface is to reflect the light emitting from the lamp to the top of the cylinder and it is concentrated on one plane. The illuminance measurement is done inside the cylinder closing the lids at the centre of the top lid and an has been designed, rather than a single constant, to calculate the total luminous flux from a single measured illumination value**.**[1]

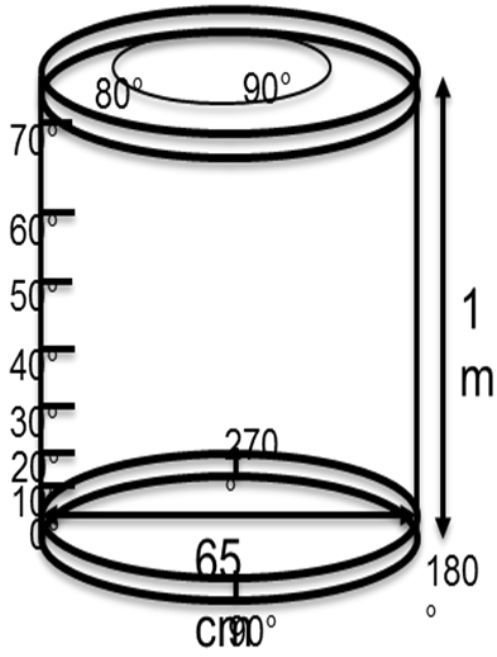


Figure 8: Meridian Angle Distribution (Small & medium cylinder)

The illuminance readings are measured using lux meter for meridian angle at different parallel from 0-360° at an interval of 45° angle; that is in a fixed position of 1 meter from the lamp. Hence, this is repeated for 0-90° meridian angles at 10° interval. This 10° is for tanθ. Starting from tan10° in each parallel it increases by 10°. Some of the points were taken on the slit opposite to the light Using Pythagoras theorem.

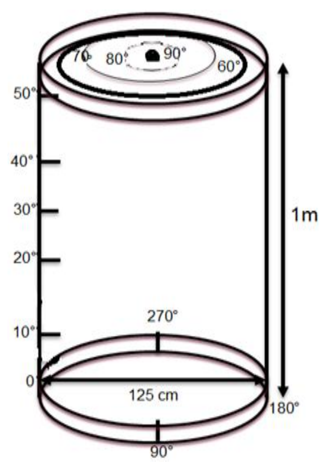


Figure 9: Meridian Angle Distribution (Big Cylinder)

For the small and the medium cylinder only 80° and 90° points are taken on the slit but for the big cylinder 60-90° angles are on the slit. This is simply because it depends on the radius. The more the radius the more distant the points would be from the light source.

4.4 Measurement of Lux and Lumen

To measure lux at each points of the cylinder we had to use the lux meter. The lux is a unit of measurement of brightness; more accurately for measuring illuminance. It is derived from candela which is the unit of measurement for the power of light.

Figure 10: Lux meter

Figure 11: Placement of Led Lights in the Cylinders

At each point the lux meter head was placed exactly the way light falls at the point. The lux meter takes some time to be stable and give the correct lux value. It was well taken care of that the experiment place was dark and Zero obsolete value in the lux meter.

5. RESULTS

5.1 Small Cylinder

Figure 12: The Small Cylinder (Final Product)

5.1.1 JSF 3W

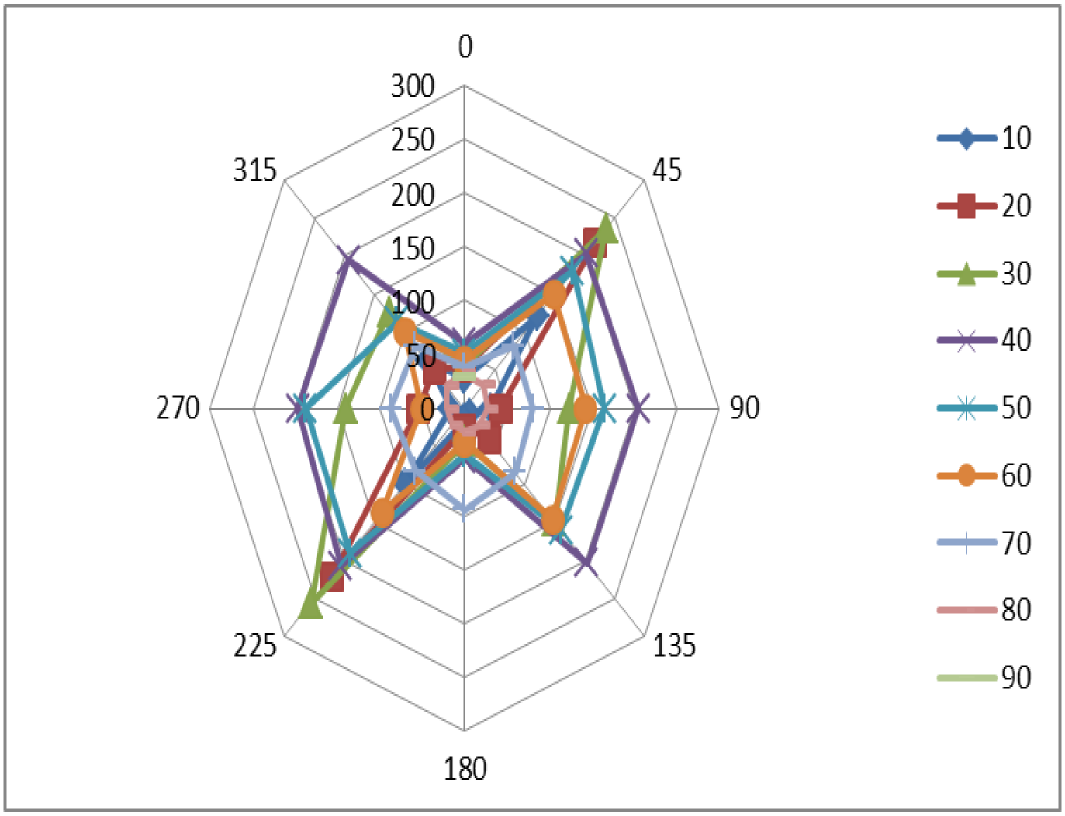


Figure 13: Polar view of JSF 3W Lux readings in small cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

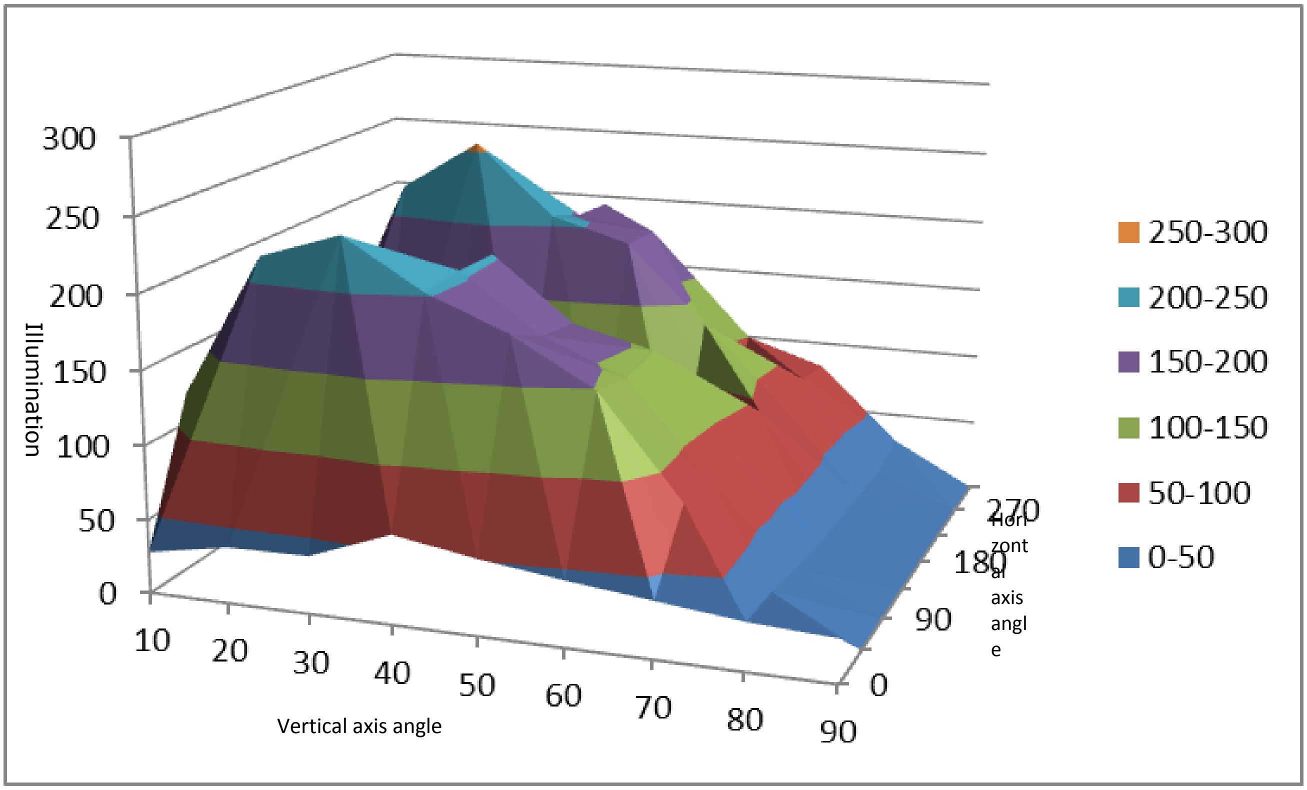


Figure 14: 3D view of JSF 3W Lux readings in small cylinder

The illumination is at it's highest peak at 25°vertical axis angle

5.1.2 G power 6W

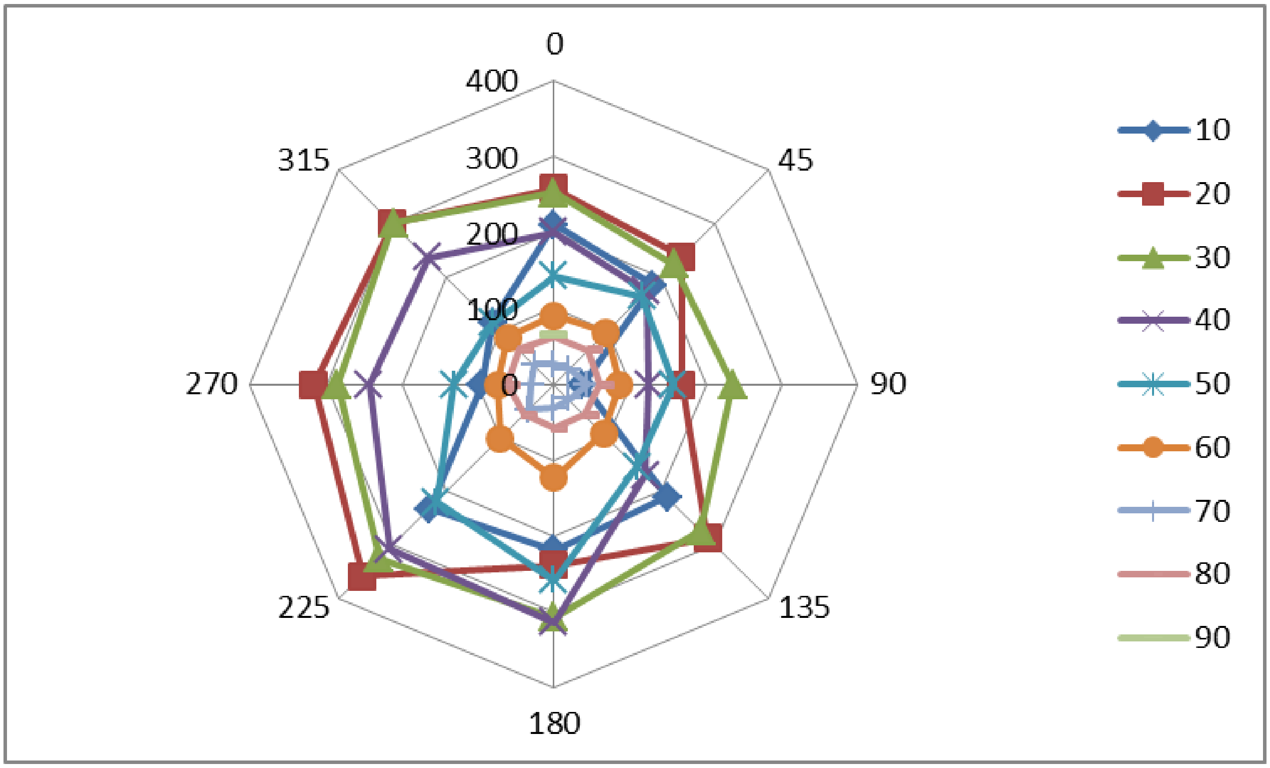


Figure 15: Polar view of G Power 6W Lux readings in small cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

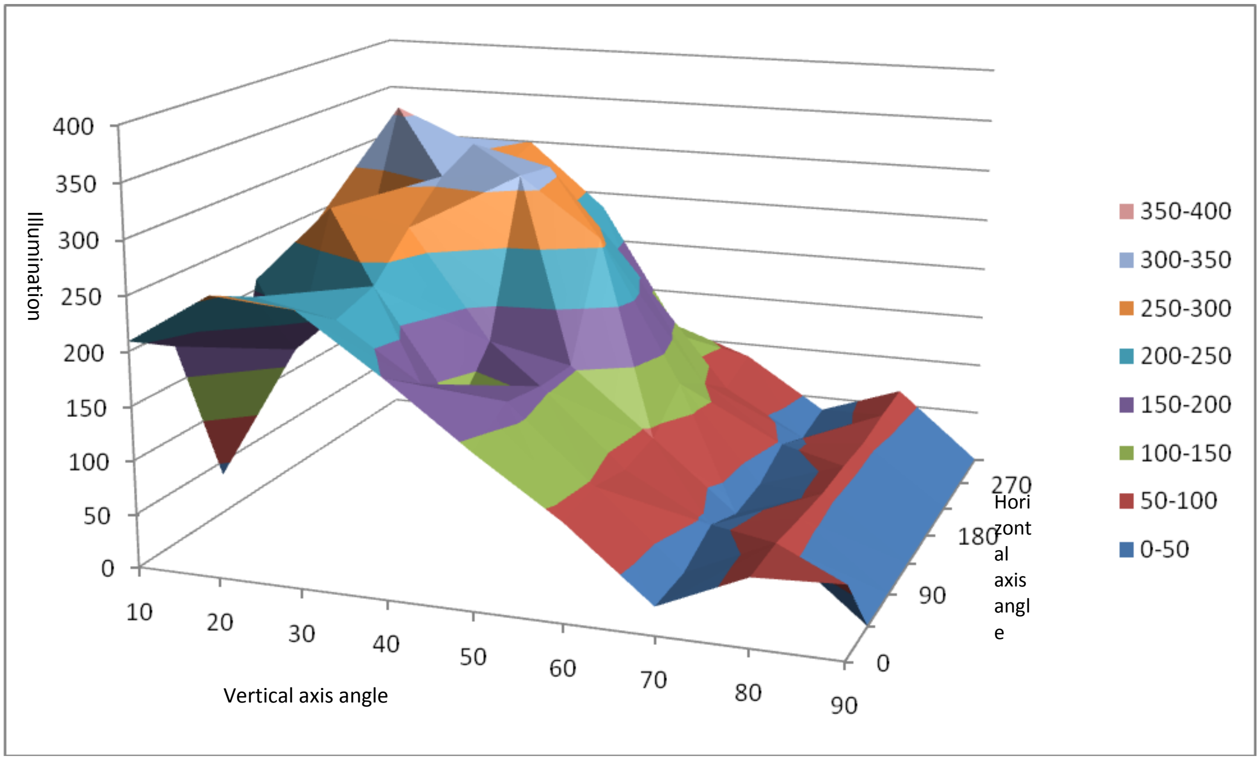


Figure 16: 3D view of G Power 6W Lux readings in small cylinder

The illumination is at it's highest peak at 25° vertical axis angle

5.1.3 Solar IC 5W

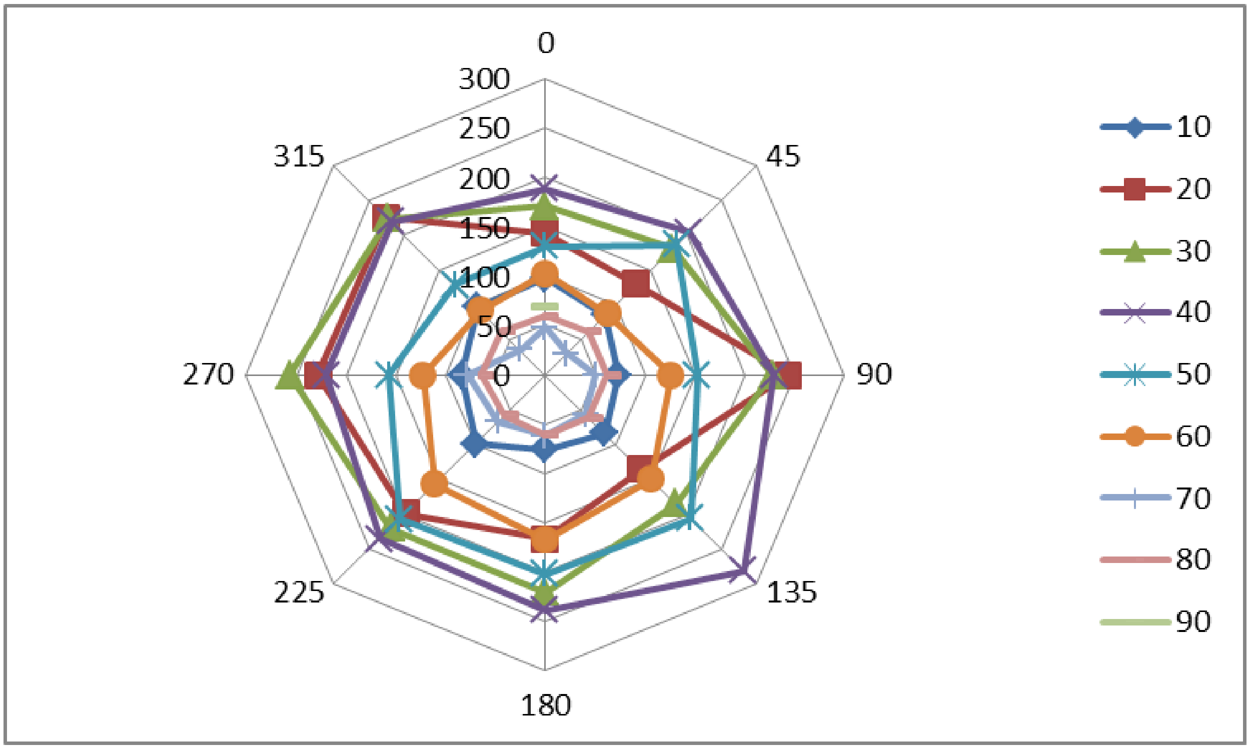


Figure 17: Polar view of Solar IC 5W readings in small cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

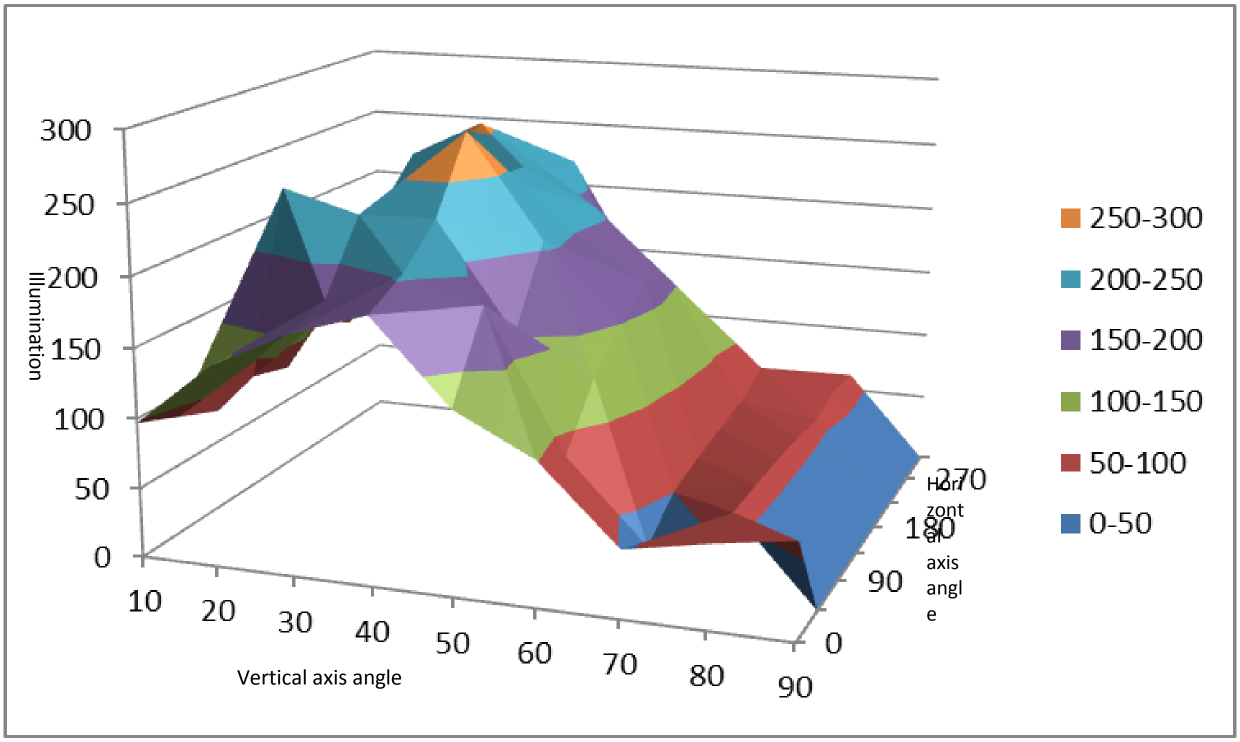


Figure 18: 3D view of Solar IC 5W readings in small cylinder

The illumination is at it's highest peak at 30° vertical axis angle

5.1.4 Method Validity

To find out the Lumen we had put the Lux reading at 90° angle of the cylinder in X axis and the rated lumen in Y axis for each of the light. Plotting it in Matlab we got a linear curve that shows the relationship between Luminous flux and illumination.

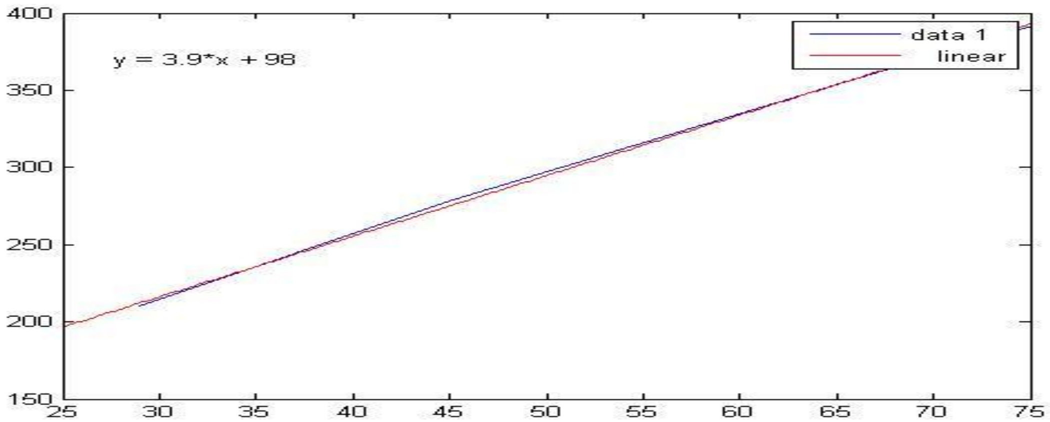


Figure 19: Relationship between Lux (x-axis) and Rated Lumen (y-axis) for small cylinder

The result shows a deviation within ±5% of the rated value for the cylindrical method

Equation found from our cylinder, total luminous flux = 3.9*illuminance + 98

The **K factor** for Small cylinder is **3.9**and the offset is **98**

Putting the lux values in the equation we get the total luminous flux for each light, and then the percentage deviation is compared with the rated lumen for each light. The same procedure was repeated for the medium and large cylinder.

	Measured lux	Rated lumen:	Calculated Lumen:	Deviation from goniophotometer method
Lamp 1	29 lux	210 lumen	211.1 lumen	0.523%
Lamp 2	45lux	278.25 lumen	273.5 lumen	1.7 %
Lamp 3	64lux	350 lumen	347.6 lumen	.68%
Lamp 4	75lux	391.5 lumen	390.5 lumen	.255%

Table 2: Calculated Lumen and the Percentage Deviation with the Rated Lumen for Small Cylinder

5.2 Medium Cylinder

Figure 20: The Medium Cylinder (Final Product)

5.2.1 3W Lamp

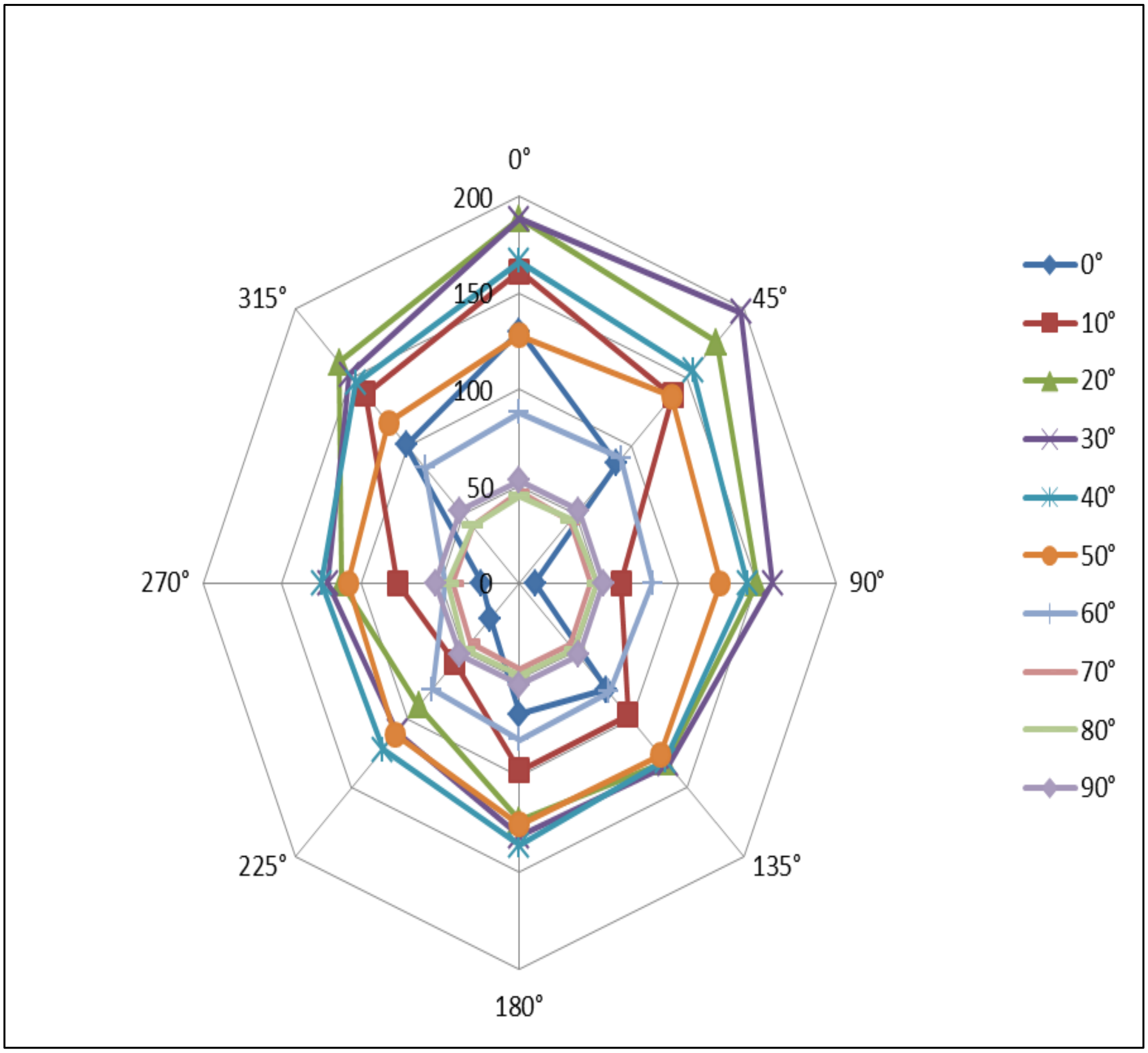


Figure 21: Polar view of 3W Lamp readings in medium cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

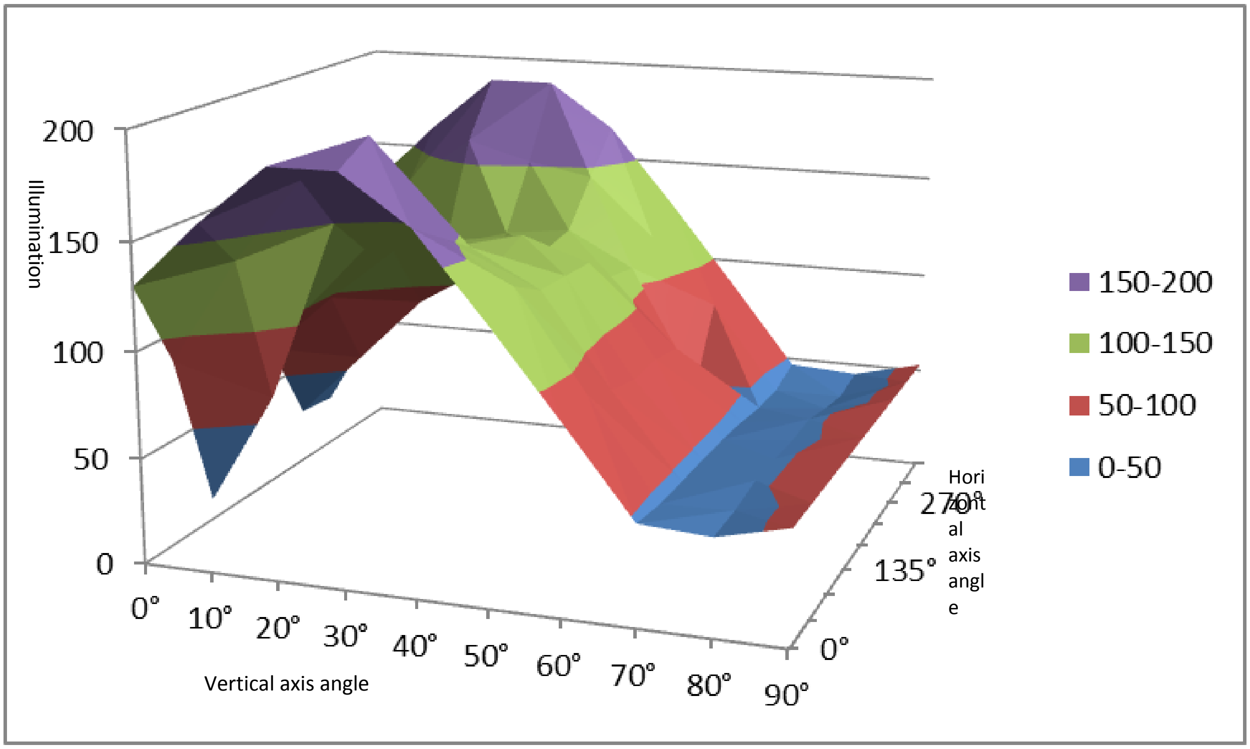


Figure 22: 3D view of 3W Lamp readings in medium cylinder

The illumination is at it's highest peak at 30° vertical axis angle

5.2.2 Solar 6W

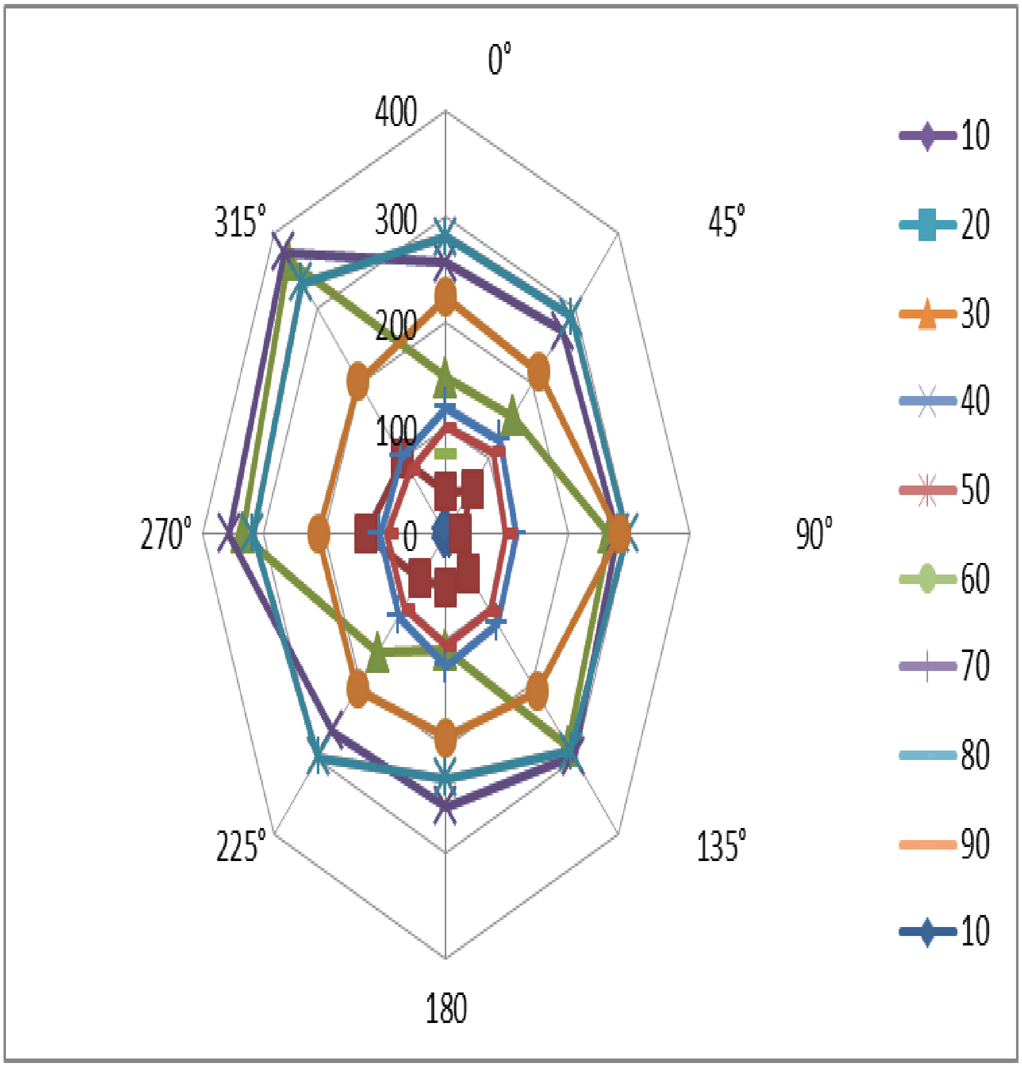


Figure 23: Polar view of Solar 6W readings in medium cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

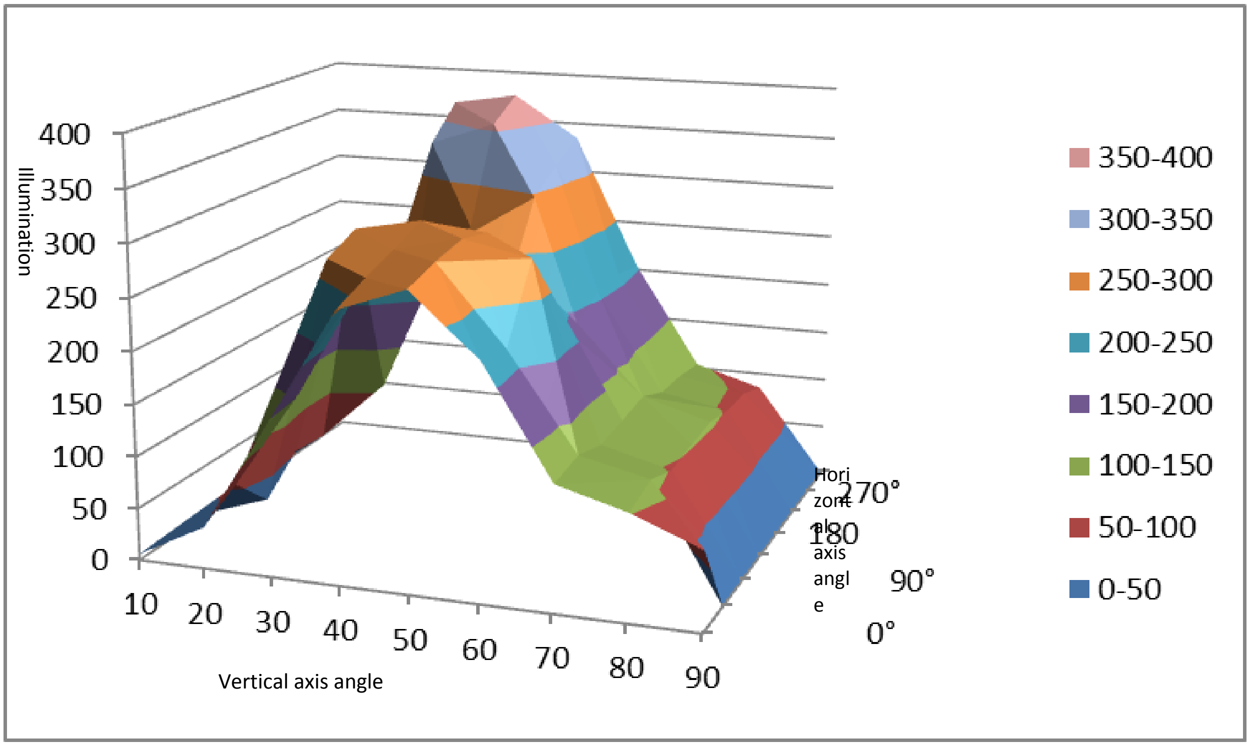


Figure 24: 3D view of Solar 6W readings in medium cylinder

The illumination is at it's highest peat at 45° vertical axis angle

5.2.3 Solar IC 6W Low P3201206

*Low indicates the bulb has been optimized to a low current.

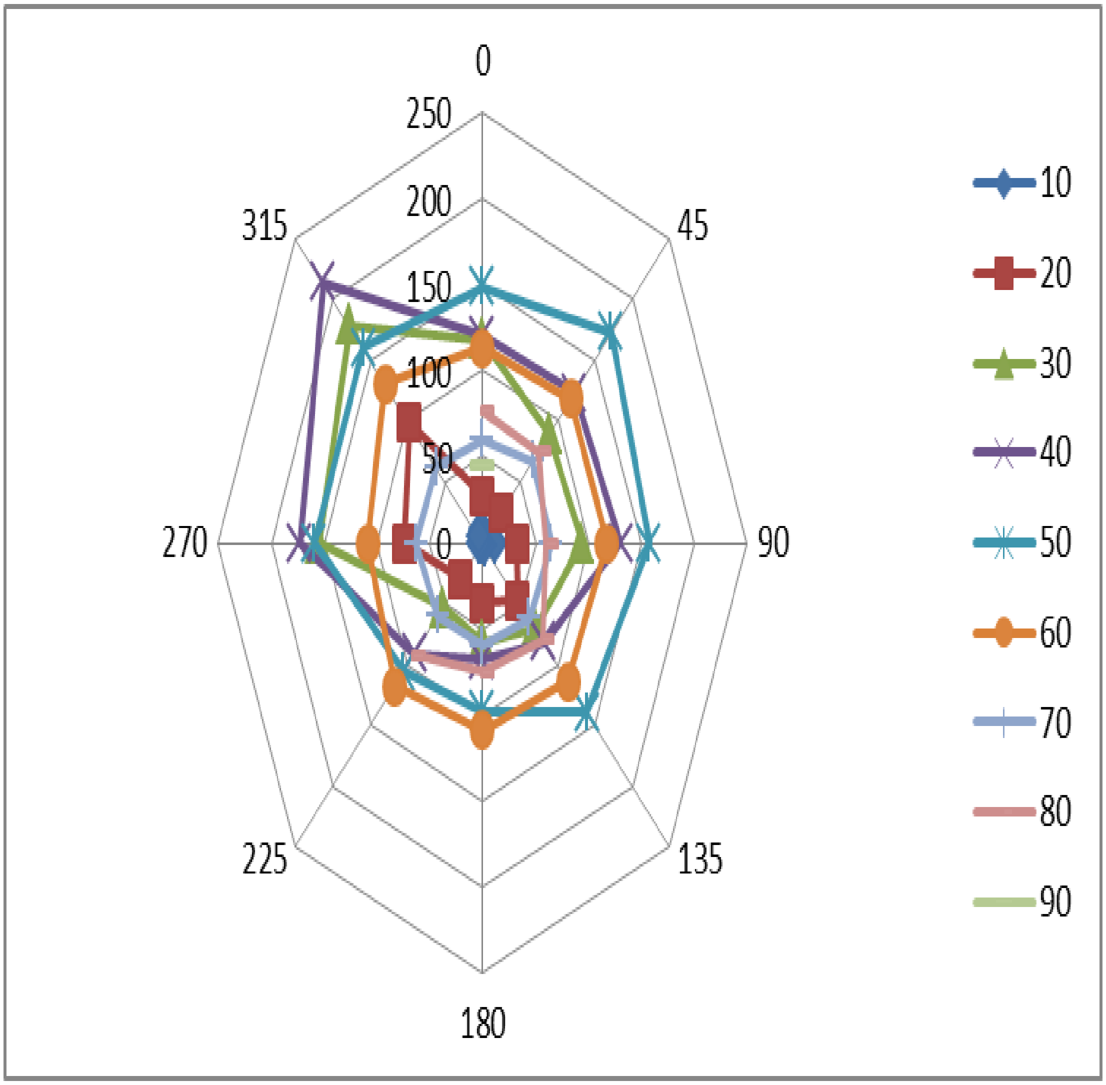


Figure 25: Polar view of Solar IC 6W Low P3201206 readings in medium cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

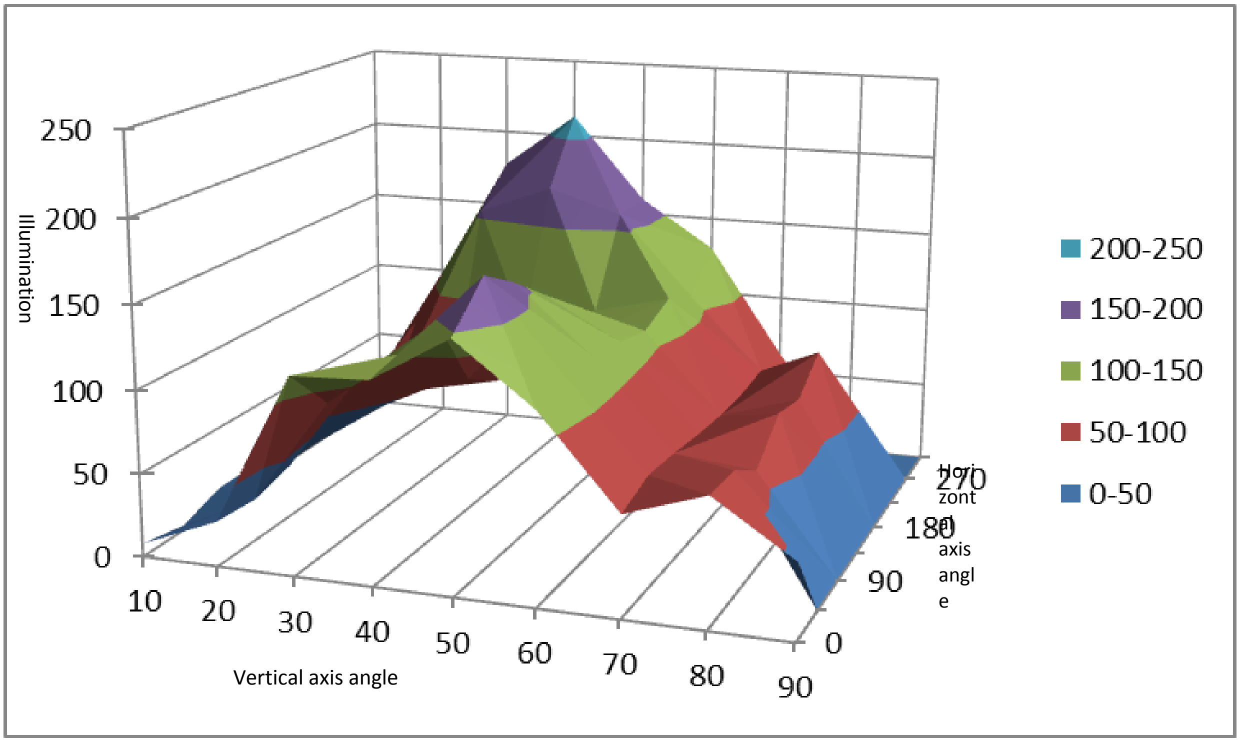


Figure 26: 3D view of Solar IC 6W Low P3201206 readings in medium cylinder

The illumination is at it's highest peak at 40° vertical axis angle

5.2.4 Solar IC 6W High

*High indicates the bulb has been optimized rated current

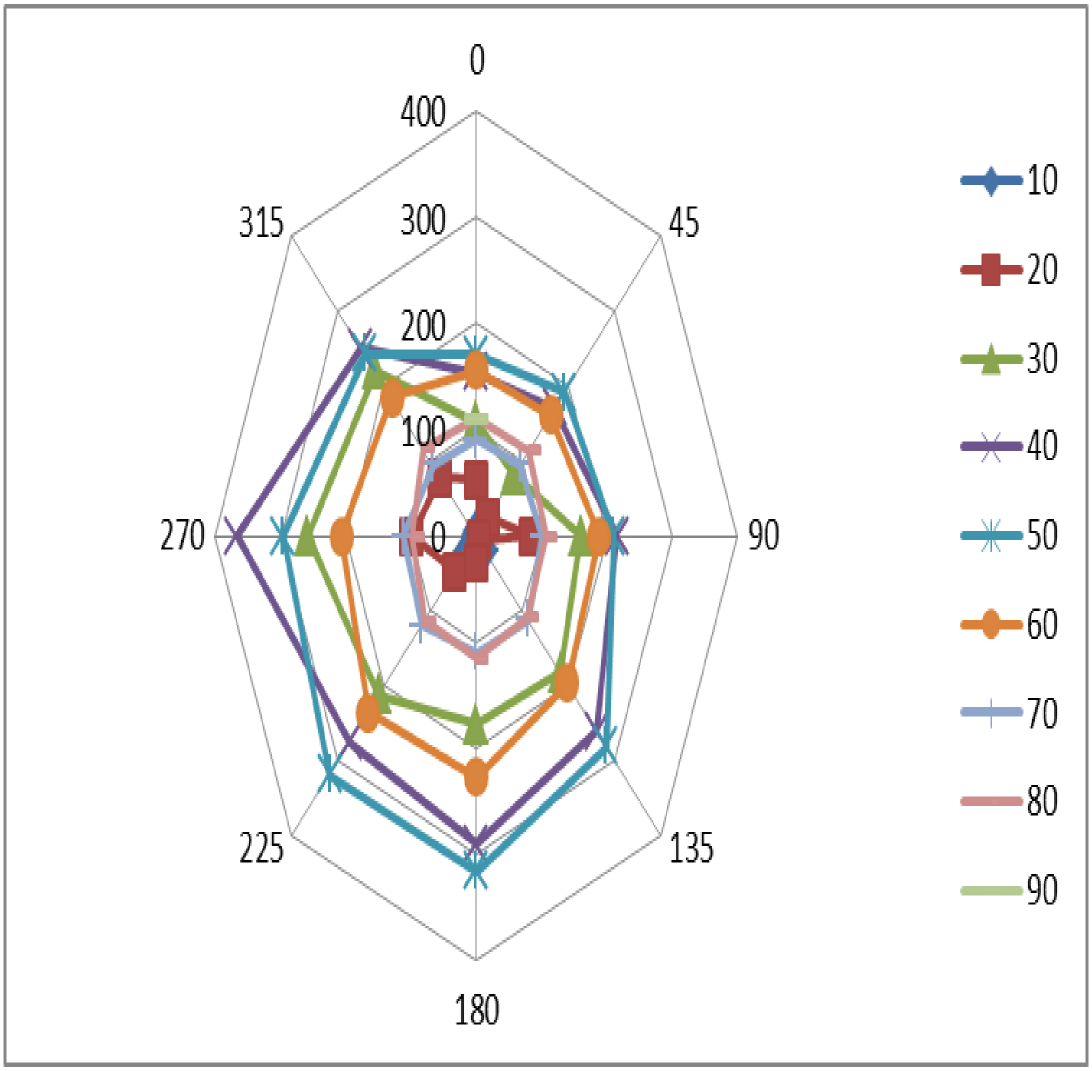


Figure 27: Polar view of Solar IC 6W High readings in medium cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

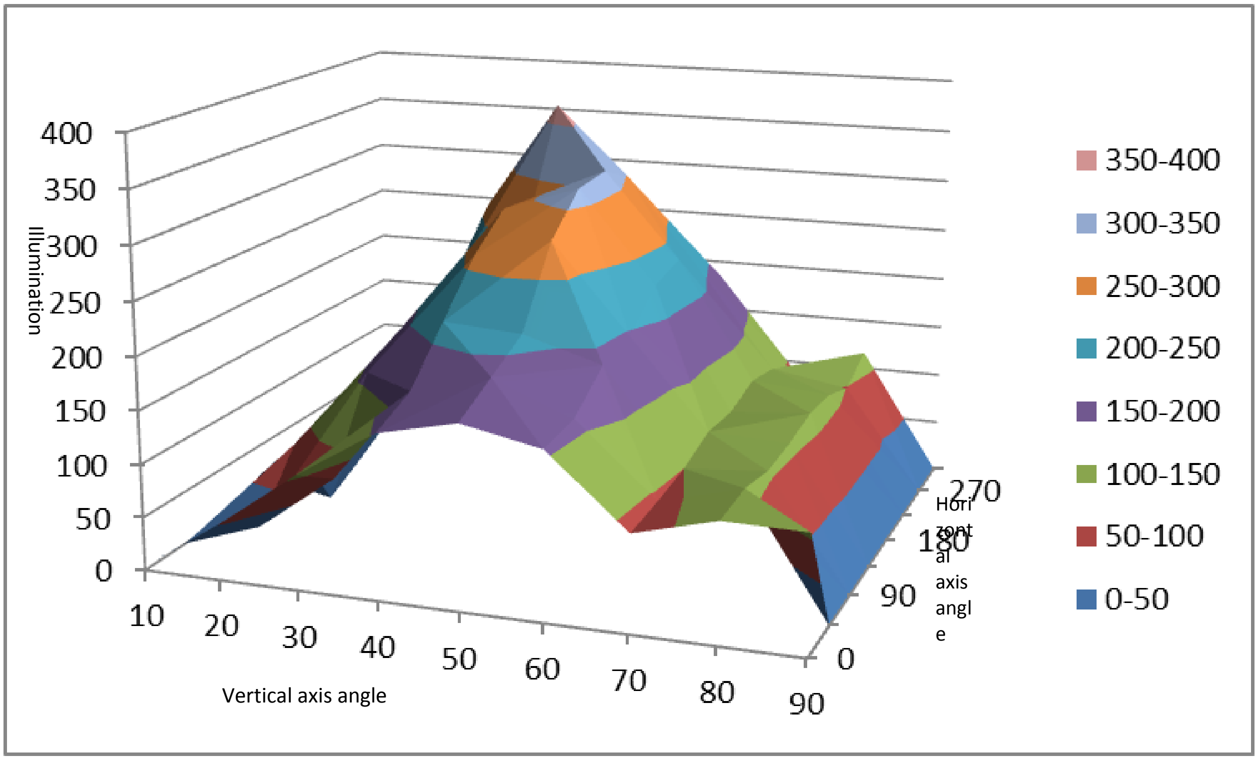


Figure 28: 3D view of Solar IC 6W High readings in medium cylinder

The illumination is at it's highest peat at 45° vertical axis angle

5.2.5 Method Validity

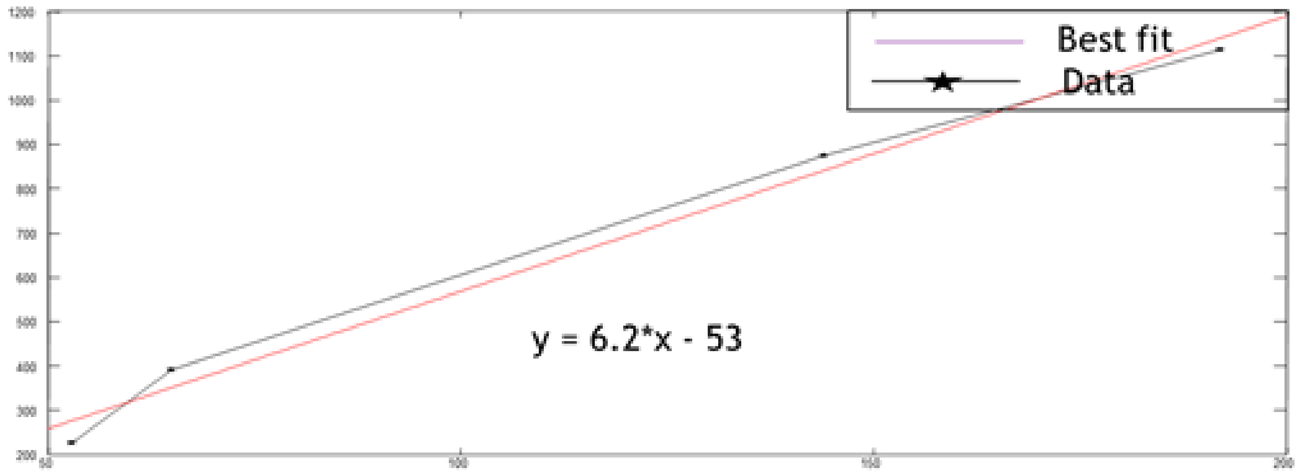


Figure 29: Relationship between Lux (x-axis) and Rated Lumen (y-axis) for medium cylinder

A curve for luminous flux against illumination is drawn and the equation derived.

Equation found from our cylinder, Total luminous flux = 6.2*illuminance – 53

The **K factor** for Medium cylinder is **6.2**and the offset is **-53**

	Measured lux	Rated lumen:	Calculated Lumen:	Deviation from goniophotometer method
Lamp 1	53 lux	278.25 lumen	275.6lumen	0.95%
Lamp 2	144lux	873.308lumen	839.8lumen	3.99%
Lamp 3	192lux	1113.06lumen	1137.4lumen	2.14%
Lamp 4	151lux	874.74lumen	883.13lumen	0.95%
Lamp 5	125lux	732.95lumen	728lumen	0.68%
Lamp 6	112lux	628.76lumen	641.4lumen	1.97%

Table 3: Calculated Lumen and the Percentage Deviation with the Rated Lumen for Medium Cylinder

5.3 Large Cylinder

Figure 30: The Large Cylinder (Final Product)

5.3.1 Solar IC9W (757.63 lm)

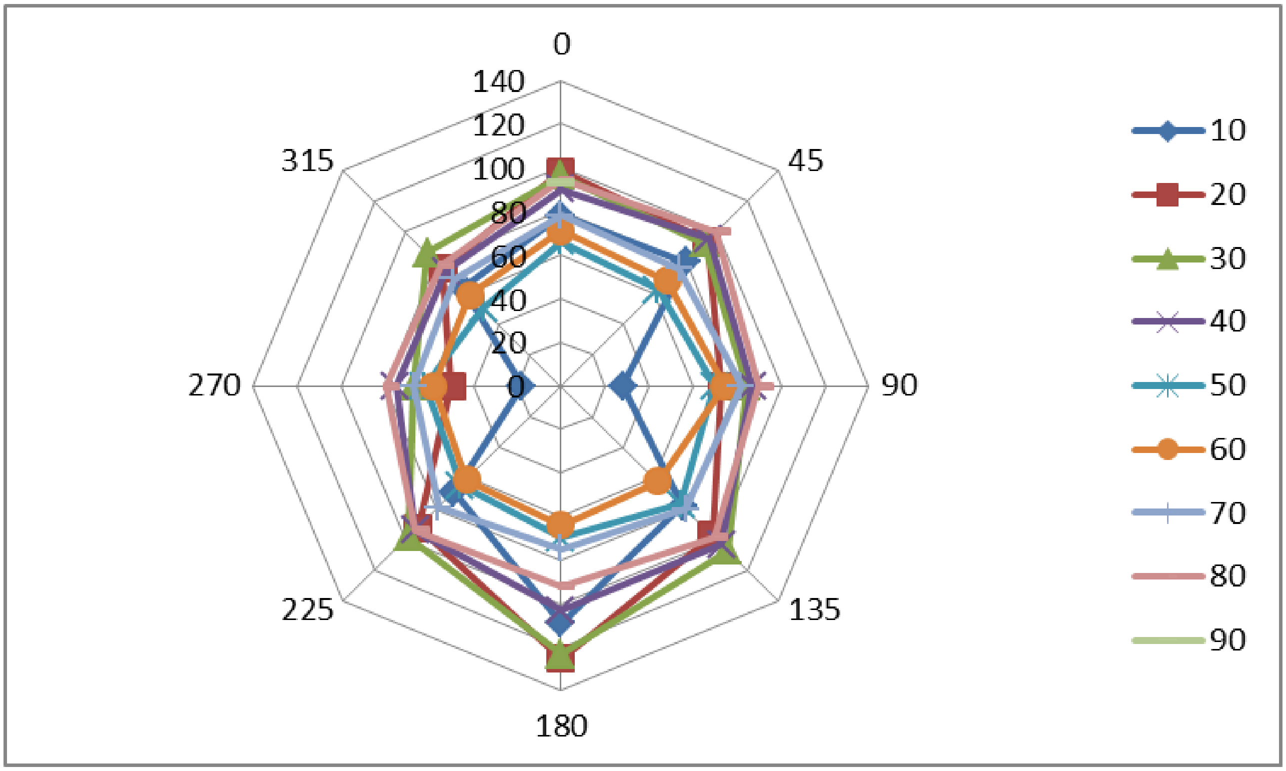


Figure 31: Polar view of Solar IC 9W (757.63 lm) readings in large cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

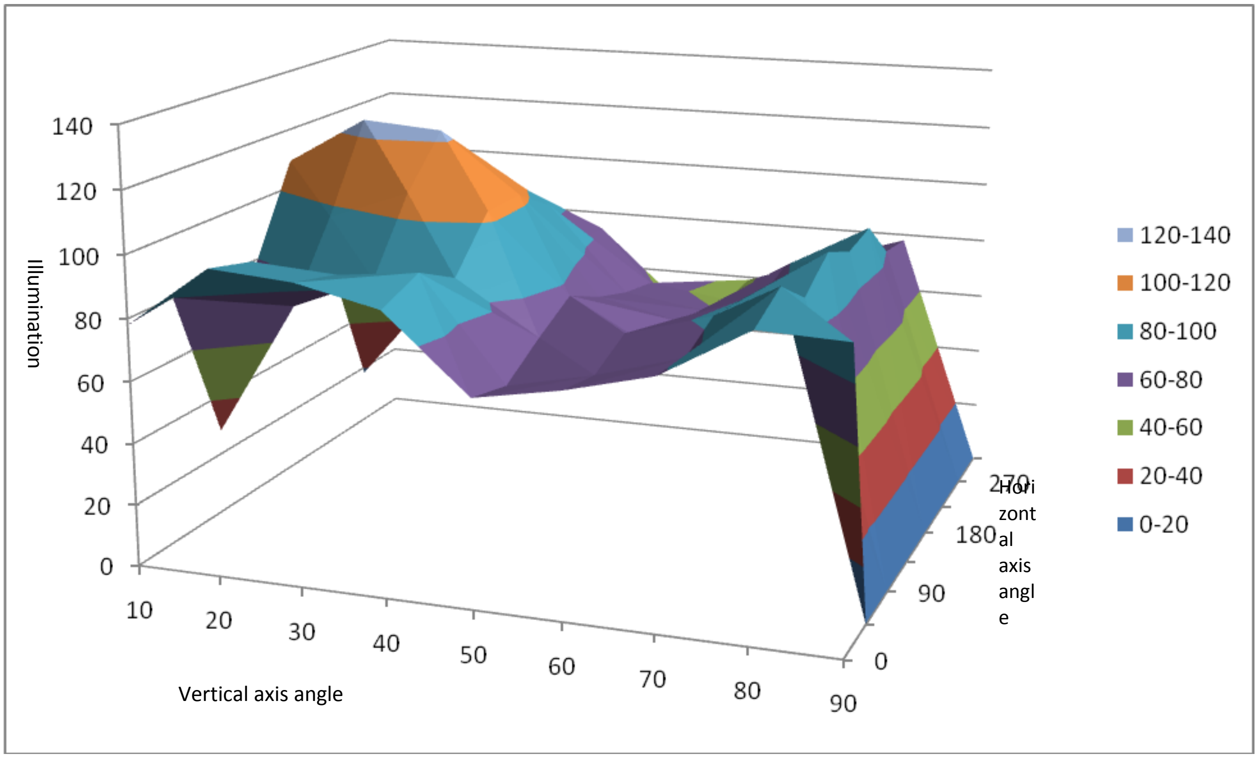


Figure 32: 3D view of Solar IC 9W (757.63 lm) readings in large cylinder

The illumination is at it's highest peat at 30° vertical axis angle

5.3.2 Solar IC 9W (931.35 lm)

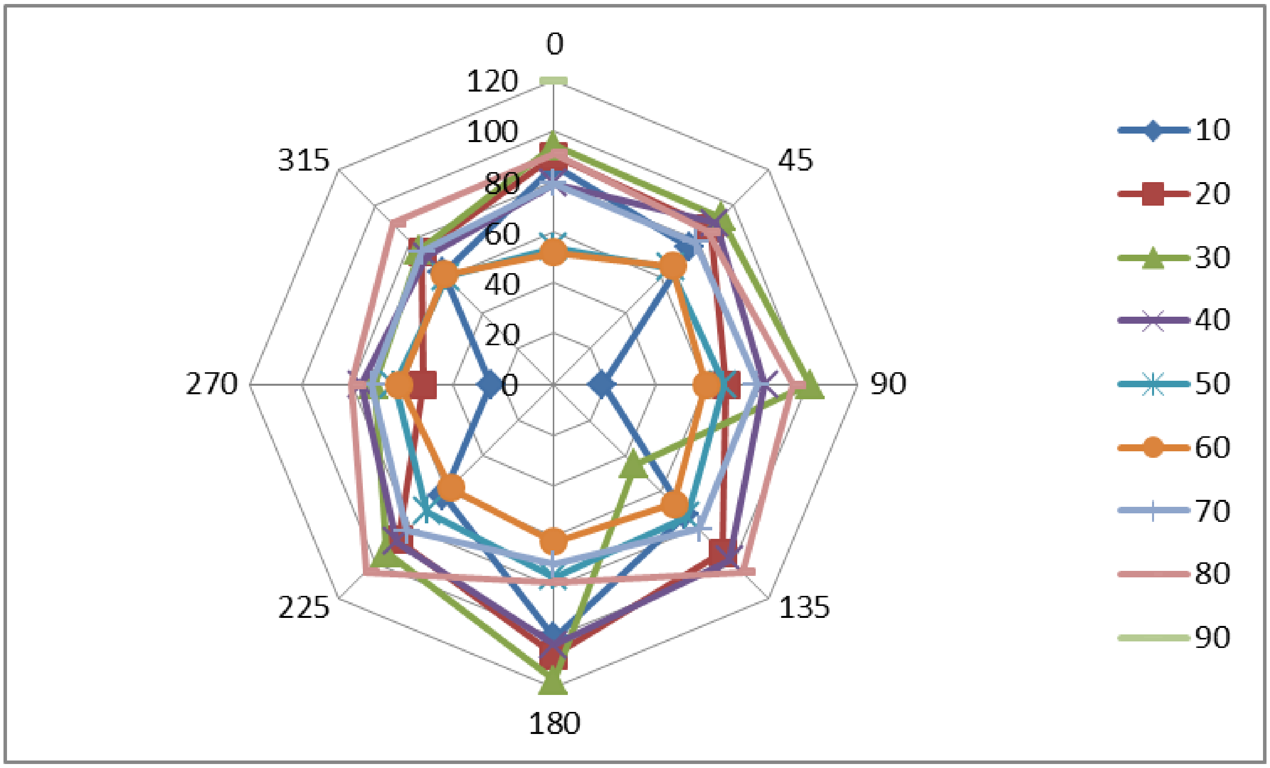


Figure 33: Polar view Solar IC 9W (931.35 lm) readings in large cylinder

As the light was placed horizontal so the illumination was not fairly distributed entirely so we can see at the opposite angles illumination was quite similar.

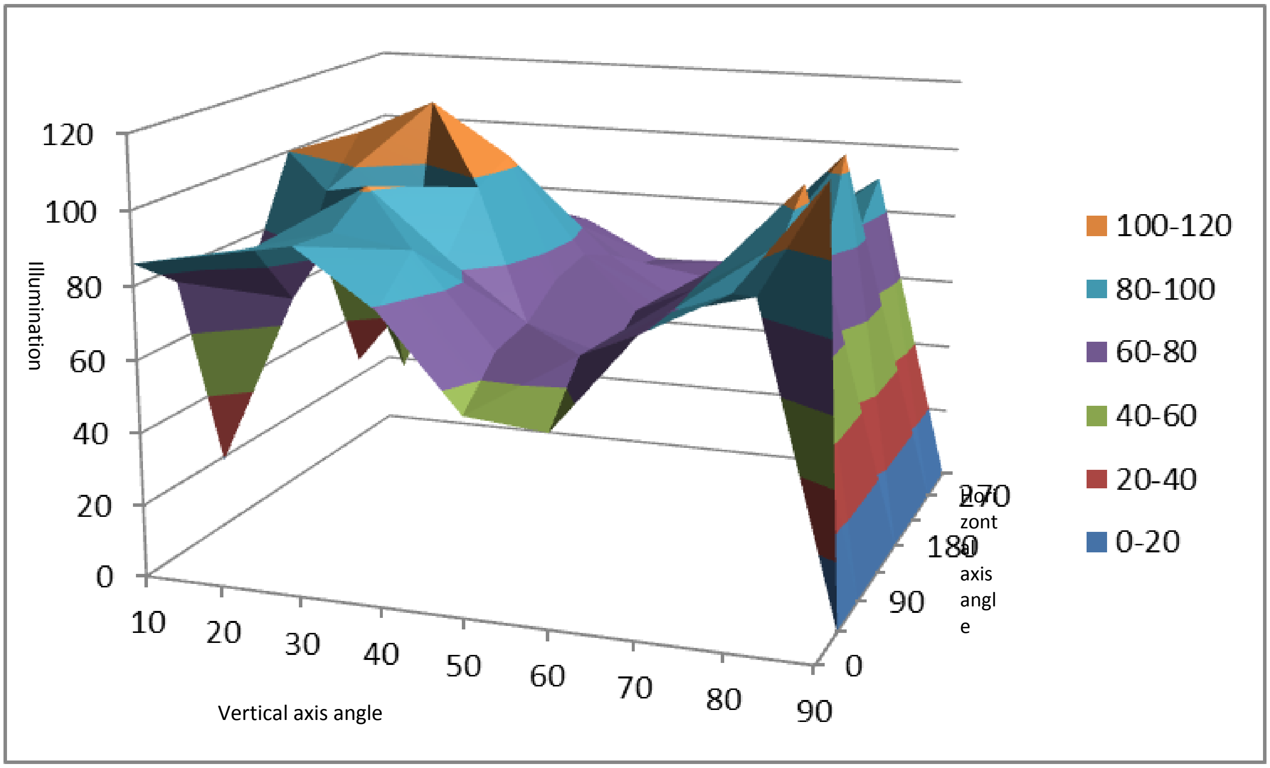


Figure 34: 3D view Solar IC 9W (931.35 lm) readings in large cylinder

The illumination is at it's highest peat at 30° vertical axis angle

5.3.3 Method Validity

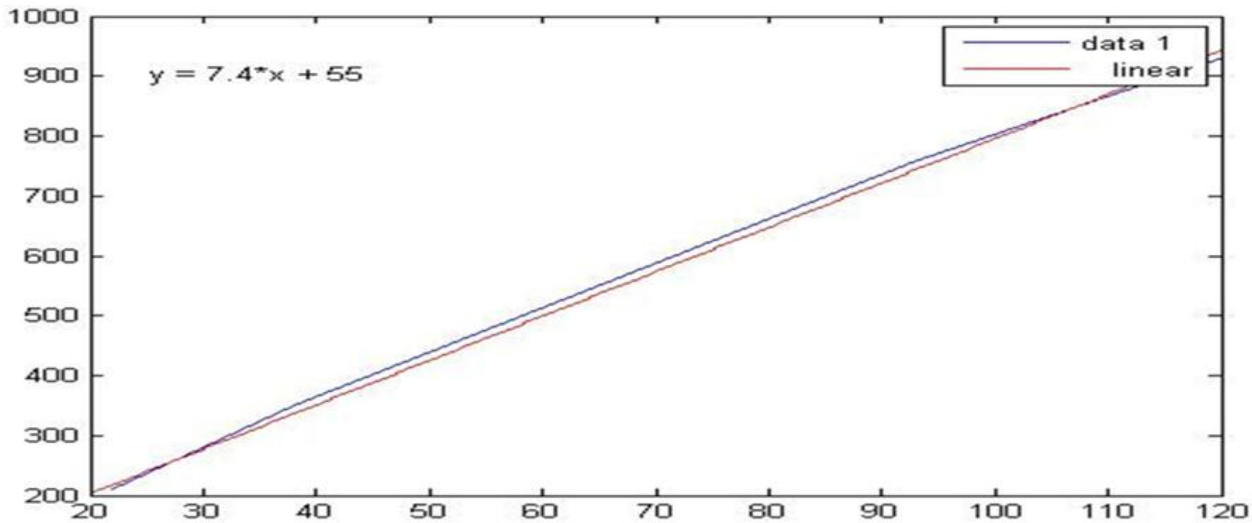


Figure 35: Relationship between Lux (x-axis) and Rated Lumen (y-axis) for large cylinder

The result shows a deviation within ±5% of the rated value for the cylindrical method

A curve for luminous flux over illumination is drawn and the equation derived.

Equation found from our cylinder, Total luminous flux = 7.4*illuminance + 55

Determined **K factor** for large cylinder is **7.4**and the offset is **55**

	Measured lux	Rated lumen:	Calculated Lumen :	Deviation from goniophotometer method
Lamp 1	20 lux	210 lumen	203 lumen	3.33%
Lamp 2	22lux	210 lumen	217.8 lumen	3.71%
Lamp 3	38lux	350 lumen	336.2 lumen	3.94%
Lamp 4	93lux	757.67 lumen	743.2 lumen	1.9%
Lamp 5	120lux	931.35 lumen	943 lumen	1.25%

Table 4: Calculated Lumen and the Percentage Deviation with the Rated Lumen for Large Cylinder

5.4 Result Analysis

For the small, medium and large cylinderthe result shows a deviation within ±5% of the rated value for the cylindrical methodandthe **K factors** we had found are 3.9, 6.2 and 7.4 consecutively. It is observed that with the **Diameter** the **K factor** varies. The relationship between Radius of the cylinders and K factors is plotted and the relationship diagram is given below-

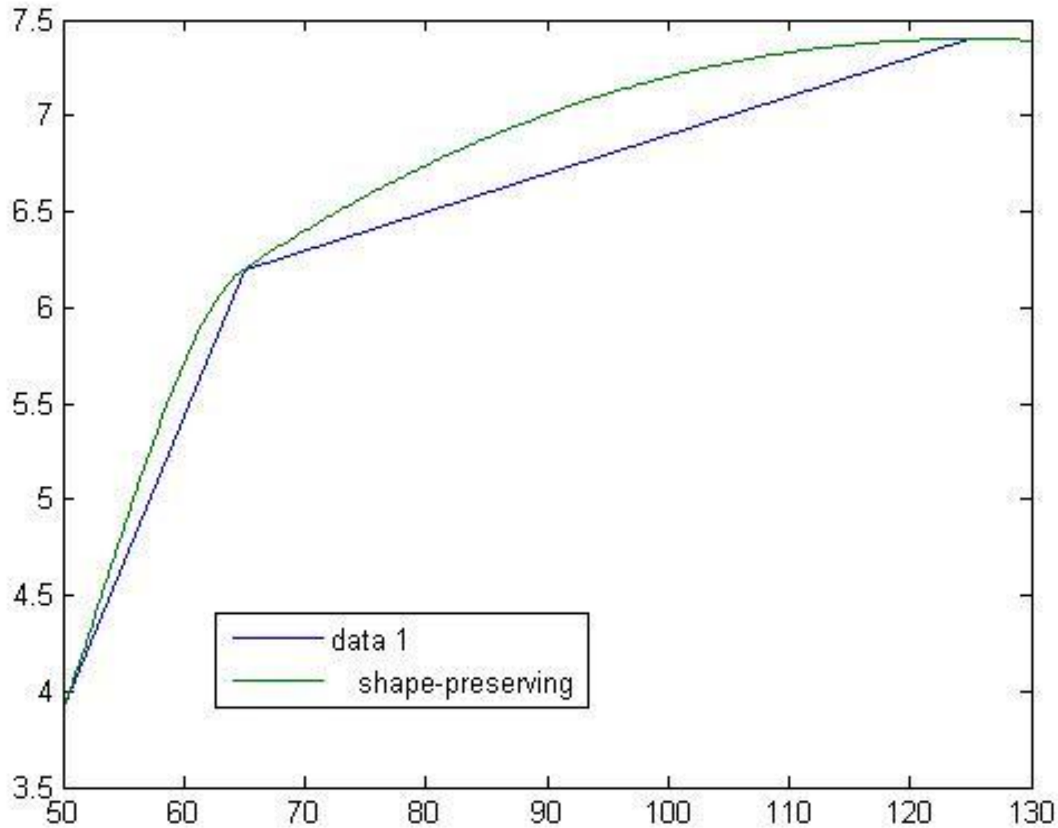


Figure 36: The relation between Diameter and K factors

From the diagram we can see that the K value Increases as the diameter increases and it is a nonlinear relationship.

5.5Cost Efficiency

Solar Home system (SHS) in last 15 years has offered a tremendous contribution in Bangladesh; specifically in off grid areas.[1] In our country there is a couple of supply of solar energy due to its geographical location. In both business and Social sector Solar home system has gained a huge popularity as it has improved our country's economy and ensured our social security.[1]

A financial institution established by Government of Bangladesh manages the SHS project. [1]The number of partners of IDCOL has expanded in numbers. At present there is a numerous number of companies manufacturing charge controller, Lamp, Batteries etc.[1] On the other hand the testing facilities for Solar Home System components are fixed in numbers and not increasing. That's why poor quality components are losing efficiency. Expensive testing equipment are must for setting up testing lab. [1]Our research is about a low cost Lumen testing of LED lamps and its impact on Bangladesh.[1]

Due to having several Solar Home System component manufacture in Bangladesh, overall quantity of LED lamps varies from organization to organization so the unstable quality is increasing within the number of Solar Home System and as a result the system is inefficient. [1] Hence Lumen testing of Solar Home System is required.

Since Bangladesh is a developing country with a GDP and GNP not that impressively high so high price of testing equipment is a core obstacle to set up testing laboratory in our country.

Through this Cylindrical Lumen Testing the cost of Equipment can be narrowed down from Some Thousand Dollars to a Few Hundred Dollars, keeping the percentage error within the margin.

5.6 Cost Comparison

A standard 1m integrating sphere imported from China can cost about **1000 USD** excluding shipping cost, equipment for measurement of luminous flux cost extra **5000 USD**. Building the Small cylinder cost us just about 30 USD, equipment used for measurement of luminous flux cost extra 100 USD

Cost saved= 6000 USD – 130 USD = 5870 USD.

Building the Medium cylinder cost us just about 50 USD, equipment used for measurement of luminous flux cost extra **100 USD**

Cost saved = 6000 USD – 150 USD = 5850 USD.

Building the Large cylinder cost us just about **175 USD**, equipment used for measurement of luminous flux cost extra **100 USD**.

Cost saved = 6000 USD – 175 USD = 5835 USD.

6. CONCLUSION AND CONTINUATION

From the results we have got the total luminous flux by determining the K factor for each light which deviates ±5% from its rated value. It gives almost the same result in each of the tested cylinders. Therefore, we can conclude that our cylindrical method ensures successful readings that can provide with quality LED products at budgeted prices. Not only this resourceful technology will drastically reduce costs, but it is easy to construct.

Numerous small scale companies in our country import the technology and due to budget constraint it becomes difficult to safeguard to high end results. However, they can then use this method and due to lower consumption and set up costs provide up to the mark service. Moreover, the next step in this research includes the discovery, innovation and inclusion of modern automated technology in the most economic method possible.

As a SHS product Led Bulbs has done a tremendous progress so far in our country. Led bulbs served best in the off grid areas because of its high efficient Bright light producing ability and most importantly less power consumption. Since Bangladesh is a developing country with a GDP and GNP not that impressively high so high price of testing equipment is a core obstacle to set up testing laboratory in our country. In future we are planning to work more on this project to make it work more accurately and ensure good quality LED bulbs.

7. REFERENCES

1. Khan, S.A; Rahman, R.; Shabnam, F.; Azad, A, "Low cost cylindrical lumen testing procedure in Bangladesh perspective," *Global Humanitarian Technology Conference (GHTC), 2013 IEEE* , pp.78,81, 20-23 Oct. 2013

2. Available at-http://wenku.baidu.com/view/a4f5e102de80d4d8d15a4fa0.html **On 23/8/2014**

3. Available at-http://www.light-measurement.com/basic-photometric-quantities/ **Accessed on 23/8/2014**

4. Available at-http://www.fastonline.org/CD3WD_40/CD3WD/ELECTRIC/GTZ024E/EN/B609_5.HTM**Accessed on 23/8/2014**

5. Available at-http://www.madebydelta.com/imported/images/documents/ICAM/I105%20Measurering%20illuminance.pdf**Accessed on 23/8/2014**

6. Available at-http://bwtek.com/spectrometer-part-5-spectral-resolution/**Accessed on 23/8/2014**

7. Available at-http://www.cormusa.org/uploads/4_CORM_Workshop_YZ.pdf**Accessed On 23/8/2014**

8. Available at-http://www.nist.gov/calibrations/upload/sp250-37.pdf**Accessed on 23/8/2014**

9. Available at-http://www.megavolt.co.il/Tips_and_info/types_of_bulbs.html**Accessed on 23/8/2014**

10. Available at-http://www.giangrandi.ch/optics/lmcdcalc/lmcdcalc.shtml **Accessed on 23/8/2014**

11. Available at-http://www.led-professional.com/resources-1/articles/measurement-of-leds**Accessed on 23/8/2014**

12. Available at-http://www.jensign.com/LEDIntensity/index.html**Accessed on 23/8/2014**

13. Available at-http://www.prc-krochmann.com/index.php/photometers**Accessed on 23/8/2014**

14. Available at-http://www.optronik.de/fileadmin/editors/downloads/Products/OptronikLine_GoniophotometerSystems.pdf**Accessed on 23/8/2014**

15. Available at-http://ledlight.osram-os.com/wp-content/uploads/2011/01/Radiometry-Photometry.pdf**Accessed on 23/8/2014**

16. Available at-http://eartheasy.com/live_energyeff_lighting.html**Accessed on 23/8/2014**

17. Available at-http://energy.gov/energysaver/articles/tips-lighting**Accessed on 23/8/2014**

18. Available at-http://metrology.hut.fi/quality/Qmlm.pdf**Accessed on 23/8/2014**

19. F. Sametoglu, "*Construction of Two-Axis Goniophotometer for Measurement of Spatial Distribution of a Light Source and Calculation of Luminous Flux*", ACTA PHYSICA POLONICA, vol no. 119 , issue 6, pp 783,784,785, 2011.

8. APPENDIX

JSF 3W

		Parallel Angles (ϕ)							
		0	45	90	135	180	225	270	315
	10	28	120	30	9	11	100	17	61.3
	20	38	217	42	40	19	221	55	51
Meridian	30	39	235	123	150	31	256	140	126
Angle	40	60	202	204	203	47	207	197	194
(θ)	50	51	180	165	160	43	191	188	113
	60	44	149	142	146	32	137	51	100
	70	38	82	80	84	94	83	87	82
	80	32	31	26	23	22	22	21	30
	90	29							

G Power 6W

		Parallel Angles (ϕ)							
		0	45	90	135	180	225	270	315
	10	209	184	37	210	218	232	95	115
	20	257	237	168	286	238	357	316	300
Meridian	30	251	223	235	273	307	325	285	299
Angle	40	199	172	124	170	313	307	243	235
(θ)	50	142	164	156	154	258	219	132	114
	60	90	96	86	92	123	101	74	87
	70	26	27	44	28	31	47	30	37
	80	62	64	60	57	58	57	62	65
	90	66							

Solar IC 5W

			Parallel Angles (ϕ)						
		0	**45**	**90**	**135**	**180**	**225**	**270**	**315**
	10	97	85	73	84	76	99	84	97
	20	143	129	243	135	166	199	228	225
Meridian	**30**	170	180	228	185	220	220	256	223
Angle	**40**	188	203	229	281	238	235	220	219
(θ)	**50**	130	186	152	206	202	207	157	128
	60	102	87	126	150	167	157	123	92
	70	48	30	50	57	62	67	78	36
	80	59	61	62	62	61	58	65	62
	90	68							

3W lamp

			Parallel Angles (ϕ)						
		0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**
	10°	6	5	2	7	3	6	1	6
Meridian	**20°**	40	60	24	53	50	60	132	100
Angle	**30°**	147	156	268	283	110	158	333	365
(θ)	**40°**	256	270	282	296	257	263	356	376
	50°	280	290	297	289	230	297	317	335
	60°	223	216	284	210	191	206	210	204
	70°	119	125	115	119	124	110	109	104
	80°	101	110	98	102	105	98	97	85
	90°	75							

Solar IC 6W

		Parallel Angles (ϕ)							
		0°	45°	90°	135°	180°	225°	270°	315°
	10°	6	5	2	7	3	6	1	6
Meridian	20°	40	60	24	53	50	60	132	100
Angle	30°	147	156	268	283	110	158	333	365
(θ)	40°	256	270	282	296	257	263	356	376
	50°	280	290	297	289	230	297	317	335
	60°	223	216	284	210	191	206	210	204
	70°	119	125	115	119	124	110	109	104
	80°	101	110	98	102	105	98	97	85
	90°	75							

Solar IC 6W High

		Parallel Angles (ϕ)							
		0°	45°	90°	135°	180°	225°	270°	315°
	10°	4	0	0	20	7	23	4	0
Meridian	20°	53	25	82	5	25	48	100	78
Angle	30°	107	80	160	182	177	211	259	220
(θ)	40°	153	170	215	260	290	274	367	250
	50°	170	190	210	280	315	318	297	242
	60°	155	160	188	196	227	235	207	184
	70°	90	94	100	112	110	120	112	95
	80°	110	114	106	109	116	113	99	116
	90°	109							

Solar IC9W (757.63 lm)

			Parallel Angles (ϕ)						
		0°	45°	90°	135°	180°	225°	270°	315°
	10°	78	80	28	78	109	69	18	63
Meridian	20°	98	94	73	97	125	92	50	76
Angle	30°	96	92	84	107	123	98	67	86
(θ)	40°	90	95	87	103	103	94	75	74
	50°	66	62	70	77	70	65	62	50
	60°	71	68	74	62	64	61	58	59
	70°	78	76	82	80	75	79	67	69
	80°	94	100	90	98	92	94	80	78
	90°	93							

Solar IC 9W

			Parallel Angles (ϕ)						
		0°	45°	90°	135°	180°	225°	270°	315°
	10°	86	76	19	73	100	62	25	62
Meridian	20°	90	87	68	94	107	87	52	74
Angle	30°	94	93	101	45	117	94	71	75
(θ)	40°	79	90	83	98	103	88	76	71
	50°	54	65	67	74	76	71	63	60
	60°	52	66	60	67	62	58	61	61
	70°	79	79	80	81	71	82	72	74
	80°	91	85	94	105	78	105	80	90
	90°	120							