AN EXPERIMENTAL STUDY ON EFFECT OF CCT ON SMALL TARGET VISIBILITY FROM DRIVERS' PERSPECTIVE: A NOVEL APPROACH

A thesis submitted towards partial fulfilment of the requirements for the degree of

MASTER OF ENGINEERING
IN
ILLUMINATION ENGINEERING

Submitted by
Atanu Naskar
REGISTRATION NO.: 154039 of 2020-21
ROLL NO.: 002010805016
EXAM ROLL NO.: M4ILN22016

JADAVPUR UNIVERSITY

Under the guidance of
Asst. Prof. (Dr.) SUDDHASATWA CHAKRABORTY

DEPARTMENT OF ELECTRICAL ENGINEERING
FACULTY OF ENGINEERING AND TECHNOLOGY
JADAVPUR UNIVERSITY
KOLKATA – 700032
INDIA
August, 2022

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "*AN EXPERIMENTAL STUDY ON EFFECT OF CCT ON SMALL TARGET VISIBILITY FROM DRIVERS' PERSPECTIVE: A NOVEL APPROACH"* is a bonafide work carried out by **Atanu Naskar** under my supervision and guidance for partial fulfilment of the requirement of *MASTER OF ENGINEERING IN ILLUMINATION ENGINEERING*, during the academic session 2021 - 2022.

Asst. Prof. (Dr.) SUDDHASATWA CHAKRABORTY
Illumination Engineering
Electrical Engineering Department
Jadavpur University
Kolkata- 700032

<u>Countersigned</u>

---	**--**
Prof. (Dr.) SASWATI MAZUMDAR	Prof. (Dr.) CHANDAN MAZUMDAR
Head of the Department	Dean
Electrical Engineering	Faculty of Engineering Technology
Jadavpur University	Jadavpur University
Kolkata- 700032	Kolkata- 700032

CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

Committee of final examination for evaluation of Thesis

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

It is hereby declared that this thesis contains literature survey and original research work by the undersigned candidate, as part of his MASTER OF ENGINEERING IN ILLUMINATION ENGINEERING, studies during academic session 2021-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

NAME : ATANU NASKAR

ROLL NUMBER : 002010805016

EXAM ROLL NUMBER : M4ILN22016

REGISTRATION NUMBER : 154039 of 2020-21

THESIS TITLE : **AN EXPERIMENTAL STUDY ON EFFECT OF CCT ON SMALL TARGET VISIBILITY FROM DRIVERS' PERSPECTIVE: A NOVEL APPROACH**

SIGNATURE: DATE:

Acknowledgement

I have immense pleasure in expressing my profound gratitude and sincere thanks to my respected thesis advisor **Asst. Prof. (Dr.) SUDDHASATWA CHAKRABORTY** for his valuable guidance, constant encouragement, useful suggestions, keen interest and timely help in completing this thesis successfully. It has been an excellent opportunity for me to work under his supervision.

I would like to acknowledge my sincere thanks and respect to **Mr. Santosh Sahoo**, Visiting Helper of Illumination Engineering Laboratory for his enormous support.

I would like to thank **Prof. (Dr.) Saswati Mazumdar**, Head of the Department, Electrical Engineering, Jadavpur University for providing the necessary facilities required to carry out this thesis.

I also want to express my thankfulness to **Mr. Aiswarya Dev Goswami**, Research Scholar, Illumination Engineering for helping me throughout the course of this project work and also for his untiring efforts for improvement of the work. I also thankfully acknowledge the assistance and help received from all the research scholar as well as lab assistants for their sincere, spontaneous and active support during the preparation of this work.

Last but not the least, I would like to thank **Mr. Jyotipriya Roy, Mr. Sourav Biswas** and **Mr. Anadi Mondal** and all my friends who helped me directly in completing my thesis successfully.

Further, I also take this opportunity to thank all the teachers who taught me and shared their knowledge with me. I must express my heartiest thanks to my juniors, seniors and my alma matter Jadavpur University.

Date : --

Place : Jadavpur University ATANU NASKAR

Kolkata – 700032

Abstract

Light is an important part of human life. The development of lighting technology has taken many different forms. In today's world LED lights are ruling the market. But in India, most of the street lights are High Pressure Sodium Vapour, Metal halide even incandescent lamps. These lights are of pre historic era. They have fixed lighting parameters, which cannot be changed according to human convenience. This leads to more consumption of electricity and a greater number of night time accidents. In the road lighting standard of India, illuminance gets the main priority and the energy saving criterion is based on that. If only illuminance is altered there is a high chance of reduction of visibility and ultimately leading to accidents. That is why the modern research area is more and more shifting towards luminance based design parameter. The luminance is more appropriate for human centric road lighting design.

Luminance is a basic parameter to measure how much light is coming towards eye reflected from a surface or directly from source. From this parameter contrast is measured. Contrast is the difference of luminance between the target object and its background. Contrast is the main parameter to measure visibility level and ultimately small target visibility. Since these parameters are comprehensively fused with human response, it is called the human centric approach.

This experiment is dealt with change of Visibility level, Small Target Visibility with respect to CCT of light. In a controlled laboratory environment, a street has been imitated. LED lights are mounted as street lights. These CCT and intensity of these LEDs can be changed. Participants volunteered to measure their reaction time for different CCT levels. The corresponding luminances has been measured. The visibility level and small target visibility is calculated using formula.

After processing the data, it is found that small target visibility is definitely correlated with CCT. Higher CCT is good for visibility. Maximum visibility of 45.98 achieved from the CCT 4000K of main source and 4500K CCT of peripheral source.

Overview of the thesis

Chapter 1 Contains general introduction of Road Lighting and the terminologies used in the thesis.

Chapter 2 Discussion about evolution of Street Lights.

Chapter 3 Provides basic concept of Human Centric Lighting and its advantages.

Chapter 4 Discussion about previous research done on human centric street lighting. The research gap analysis is done in this chapter. Experiment problem formulation is described in this chapter.

Chapter 5 Experimental Setup preparation is described in this chapter. Experiment steps and calculation of parameters process is also mentioned here.

Chapter 6 The data achieved from the experiment and the calculated parameters are represented here in tabulated form.

Chapter 7 The result data is further converted into the graphical form. The data comparison is also done in this chapter.

Chapter 8 Conclusions and Future Scope is discussed in this chapter.

Reference

Appendix 1 Brief discussion about the instruments and light used in the experiment.

Appendix 2 Contains the Java Script programming for calculating parameters.

LIST OF CONTENTS

LIST OF FIGURES

Chapter 1:

Chapter 2:

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 1

Introduction

1.1 Introduction

"Road Lighting" is a very important part of lighting design. It is the most important part of outdoor lighting. A road connects people between cities, between states and even between countries. So, a road is not only a transport medium but also a bridge between cultures. In India, roads are playing a central role in constant growth of economy. Unfortunately, the lamps used in these lights are backdated. Most of these are metal halides, sodium vapour lamps (SVL), or compact fluorescent lamps (CFL). The recent development in the technology of LED changes the design criterion and should change the design standards.

The main challenge faced by a designer is to find coordination in between road lighting parameter and how to turn roads safer for drivers and pedestrians. The current parameter used for road lighting is illuminance. Guidelines like CIE 115:2010 [1], EN 13201-1:2014 [2], EN 13201-2:2015 [3], IESNA/ANSI RP-8:2014 [4] and BS 5489-1:2013 [5] provides quantitative illuminance-based recommendations for road lighting. Illuminance is not a parameter directly linked with human interface. So, by focusing only illumination in roads human centric design is neglected. This leads to night time accident. More than a million people are being killed and tens of millions of people are injured due to road accidents in night time all over the world. Injuries due to road traffic accidents are the ninth leading cause of disability till 2000 [6]. India ranks first on the list of 199 countries in road accidental deaths and comprises of 11% of accidents related deaths globally. Road accidental deaths increased a whooping amount of 59.116% from 2005 to 2019 with a number of 151113 in 2019 [7]. This scenario indicates that Indian roadways, especially highways, need proper designing of lighting, which can ensure safety and can drastically decrease road accidents due to visibility factors.

Hon'ble Prime Minister, on 5th January, 2015 launched Street Lighting National Program (SLNP) to replace conventional street lights with smart and energy efficient LED street lights across India [8]. The government of India officially said that they have a target to build 25000 km of national highways in fiscal year 2022-23 under PM Gati Shakti National master plan. These planning of government can be more successful if proper design plan is maintained. In order to make a safe roadway, a proper road lighting is very important. Because of introduction of new technologies in the lighting system the existing standards for road lighting is becoming more and more irrelevant day by day.

The most flagship development in lighting industry is invention of LED. Besides being efficient, LED comes in variety of correlated color temperature. So, it is possible to do experiment with various levels of CCT and find the most suitable one for road lighting.

Fig 1.1 Example of Street lighting

There is still a problem that is by only using illuminance (commonly used parameter for road lighting design) as a parameter the most suitable level of CCT cannot be found. Luminance is another parameter which was first developed in 1970s and first recognized by CIE in 1982 [9] and IESNA adopted it in 1983 [10]. But even luminance cannot fully comply human conformance. Visibility Level approach is the most appropriate parameter for this task. Visibility Level is a human centric parameter which varies with CCT. By using this parameter, the most comfortable level of CCT can be found.

Another aspect of this experiment is that to explore whether energy saving can be done from this approach. The road lighting demands a huge amount of power. An approximation is up to 20 % to 40 % of total energy goes to maintaining street lights [11]. If higher level of CCT can be used more energy can be saved.

1.2 Overview

In today's road lighting system, the roads are lit with standard illuminance values. But in reality, illuminance have no relation with neither comfortability nor human response. The light should be adjusted according to the human convenience. The color temperature carries a great role to improve visibility level and reduce the probability of an accident.

Invention of Light Emitting Diodes (LED) unlocked new direction of street lighting. LEDs are more efficient than previously used High Intensity Discharge Lamps (HID). Moreover, LEDs can be found in various color temperature. So, to design a Human friendly road lighting LED is the best choice.

By varying color temperature of a smart LED light, it can be tested that which CCT is more suitable for better visibility level and better small target visibility. In a controlled environment of a laboratory subjects of different ages are invited to measure reaction time with different lighting condition. Then luminance value of the target and its background in measured. Then using formula stated in IESNA RP 8 visibility level and small target visibility is calculated. After that using graph, it is analyzed that which condition is best for road lighting.

It is found that higher color temperature values are more suitable for quicker object detection. Peripheral light sources also carry a significant role to improve visibility level.

1.3 Objective

1. **Finding the most suitable color temperature for road lighting** – The main objective of the study is to establish that there is a relation between CCT and small target visibility. STV as a parameter have a human centric approach for finding suitable lighting scene for lighting design. Here STV is the key parameter to finding most accurate road lighting condition in terms of CCT.
2. **Improving the visibility level of existing road lighting** – If a perfect CCT can be found and implemented as a standard for streel lighting design, the road lightings of streets can be very much improved.
3. **Optimizing the energy consumption by street lights** – It is a fact that the LED lights of higher level CCT consumes less energy than lower level CCT lights. By implementing perfect level of CCT a significant amount of energy can be saved.
4. **Reducing the number of accidents at night time** – A significant amount of night time road accidents happen because of improper road lighting. Object couldn’t detect in time or a road turning is missed are a common cause for crashes. These problems can be solved by setting a proper road lighting.

5. **Designing safe road for both drivers and pedestrians** – A proper illuminated area can avoid collisions if both the driver and the pedestrian can detect each other in right moment. So, it is essential to break the traditional road lighting design approaches and start preparing new parameters for a safer road.
6. **Improvement of existing road lighting standards** – From the above discussion it is clear that a new road lighting design parameter is essential. This experiment is an advancement of that. STV as an road lighting parameter can be a perfect fit for design.

1.4 Terminology

The terminologies used in this literature are described in this section.

Radiometry: It is the science of measuring radiant quantities.

Photometry: This is the special branch of radiometry where measurement of human visual response only considered.

Light: It is the electromagnetic radiation that is capable of exciting the human retina and creating a visual sensation. 380 nm to 780 nm wavelength of electromagnetic spectrum is visible to human eye.

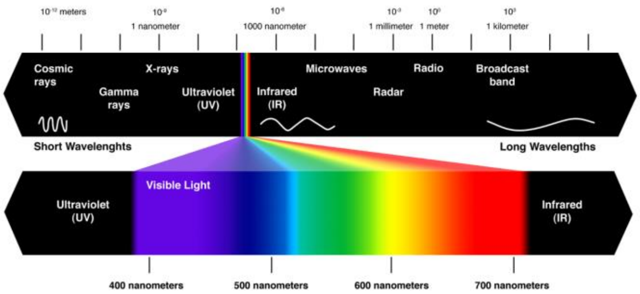


Fig 1.2 Visible Light Spectrum

Luminous Energy – The visually evaluated radiant energy travelling in the form of electromagnetic wave is called luminous energy. Unit is Lumen-sec.

Luminous Flux – The rate of flow of luminous energy responsible for luminous sensation is called luminous flux. Its unit is Lumen.

Luminous Efficacy – It is the ratio of total luminous flux emitted by the source and total lamp power input to the source. Unit is lumen/watt.

Illuminance – Incident luminous flux per unit area of a surface is called illuminance. Unit is lux.

Luminous Intensity – It is defined as the luminous flux emitted by the source per unit solid angle in a particular direction. This parameter is used to quantify the distribution of light from a luminaire. Unit is Lumen/steradian or Candela.

Luminance – Luminance is defined as luminous intensity per unit projected or apparent area of either surface of source of a light or illuminated surface. It gives information about how much object is brighter than others. Unit is candela/meter^2.

Spectral Composition – Different light source produce combination of different radiant power. This combination is called spectral composition. This can be represented in two ways:

- One Dimensional representation consist of brightness of a line and color of that wavelength. The lines can be continuous or separated.
- Two dimensional representation or Spectral Power Distribution Curve is widely used graphs to express spectral composition. The graph has magnitude of spectral power in y-axis and wavelength in x-axis. The nature of emitted energy of radiator body plotted over a range of wavelength is shown in SPD Curve. Thermal radiators give continuous SPD curve and Gas discharge lamps show line spectrum of discontinuous spectrum. It provides information about how much portion is visible and total amount of radiation.

Correlated Color Temperature - The absolute temperature of a blackbody whose color appearance most nearly resembles that of the light source is called Correlated Color Temperature or CCT. Unit is Kelvin.

Color Rendering Index - Different lamps have different spectral power compositions and therefore color objects can have variations in their colored appearance.

CRI is the measure of the degree of color shift objects undergo when illuminated by the light source as compared with the color of those same objects when illuminated by a reference source, of comparable color temperature.

Human Vision: In human body eye is the organ for vision. There are mainly two cells which are important for visual sensation. These are called photoreceptors, cones and rods.

Cones are to sense color. It has high resolution. Peak sensitivity of these photoreceptors is 555 nm. The light adapted spectral response of the eye is called spectral luminous efficiency function for Photopic vision. This is denoted by V_λ.

Rods are for seeing in the dark. These have no color sensitivity. Peak sensitivity is at 507 nm. The dark adapted spectral response of the eye is called spectral luminous efficiency function for Scotopic vision. This is denoted by V'_λ.

In accordance to the participation of rod and cone cells in seeing activity we can divide human vision into three types.

1) Photopic Vision – When the luminance level is greater than 3 cd/m^2 the cone photoreceptors dominate the viewing process. This is called photopic vision. In this kind of vision details of the scene is in high resolution.
2) Scotopic Vision - When the luminance level is less than 0.001 cd/m^2 the rod photoreceptors dominate the viewing process. This is called scotopic vision. The image is colorless and very dull.
3) Mesopic Vision – In this vision cone cells gradually decrease absolute sensitivity and rod cells take over the place. This results a decline in color vision and resolution. The luminance value of this vision is in between photopic and scotopic vision.

CIE Standard Observer - Using volunteers as their subjects, two UK academics named David Wright and John Guild developed and quantified a standard, or average, human observer's colour perception in the 1920s. Based on their findings, the CIE issued the 2° Standard Observer in 1931. Because subjects in the colour matching experiment peered through a hole with a 2° field of view, this Standard Observer is known as 2°. At the time, it was thought that all of the eye's color-sensing cones were situated within a 2-degree arc of the fovea, which was situated directly behind the retina. A screen was used for the trials, and colours from every region of the visible spectrum were shown onto it. Several people used a mix of red, green, and blue lights to match each spectrum colour light. The curves produced from this data gave rise to the 1932 CIE 2°

degree Standard Observer, which is composed of the bar x, bar y, and bar z functions.

Cones in the human visual system have a wider field of view than previously thought, it was discovered in the 1960s. W. S. Stiles, J. M. Burch, and N. I. Speranskaya performed the visual matching studies with this broader field of view, and the CIE 10° Standard Observer was published in 1964. It is suggested that the 10° Standard Observer serve as the best proxy for the spectral response of human observers. The 1931 2° Standard Observer, which is comparable to the 1964 10° Standard Observer and was not abandoned with the 1964 release since it was used in numerous industrial product requirements.

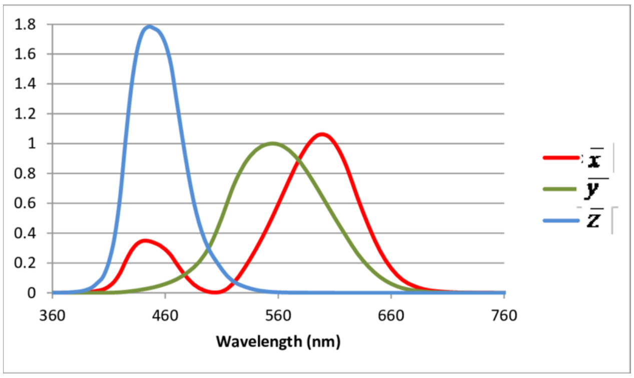


Fig. 1.3 1931 CIE Standard Observer

Reaction Time - The time between the introduction of stimuli (visual or aural) and a distinct response that is produced by the stimuli and provided using a response key is known as reaction time or response time [38]. That indicates that it is the time needed to recognise the stimuli, choose a specific action, and start the action by using a specific set of muscles [37]. RT is related to a subject's capacity for quick decision-making [39]. The RT of a driver should be low when driving at night, which calls for the driver to spot obstacles quickly and take appropriate action when necessary. According to a study, ambient illumination and contrast have a significant impact on reaction time [37]. Additionally, it depends on the age, mental health, neurological health, visual health, and muscle performance of the driver.

Visibility Level - The performance of automobile lighting is evaluated using the visibility level (VL), a quality index for road lighting design. The VL establishes a connection between lighting design and driving performance as distinct to illuminance levels. The detection of a small uniform target standing on a uniform background serves as the VL's benchmark performance (the road surface)[40]. To include the impacts of reaction time, age, glare, and the type of contrast (positive or negative) with the effect of contrast, the Small Target Visibility (STV) approach was developed. In his article, Dr. Ing. W. Adrian provided the formulas for calculating VL as well as a description of the STV method or VL calculation method and the impact of the aforementioned parameters. The quantified visibility parameter, or VL, is a complex unit-less metric that primarily obeys Ricco's law and Weber's law and is dependent on luminance difference between an object and its background, exposure time or reaction time (minimum time required for an observer to properly identify an object), observer age, contrast type (positive or negative), and glare.

Small Target Visibility – This is the weighted average of visibility level. Visibility level is calculated on each grid point of the road surface. Each point of the road surface do not carry same importance for driving vehicle. So a normal average can't be done. A weighted average is taken of VL which is termed as Small Target Visibility or STV. In IESNA RP 008, STV is considered as a design criterion for road lighting.

Chapter 2

Evolution of Street Lights

Lack of natural light during night time in the urban environment was always a problem. From basic inconvenience like “people cannot see where they are going to” to “greater chance of being attacked or mugged during the night” is also possible due to the poor lighting environment. Because the problem was there since humans started living together, history of street light is maybe longer than we think.

Street lights have its own history from the ancient Roman society. It is discovered that wealthy citizens used vegetable oil lamps to light the front of their homes. Special slaves were responsible for lighting, extinguishing and watching the lamps. These lamps served as street light in the Roman Empire.

This process continued into the Middle Ages when candle street lights, which came into play around 1417 (commissioned by Sir Henry Barton, Mayor of London), illuminated the major towns and cities in England. Each city would have a designated link-boy to light the candles ready for the hours of darkness. This marked the first organized public street lighting.

Fig 2.1 Candle Street Light

First streets were illuminated by old oil lanterns in 1684 in United Kingdom, when Lord Provost brought 24 lanterns from London and fitted it up in the High Street and Cowgate street. After that Edinburgh town council installed oil lantern, where it was sensed appropriate and appointed a lamp lighter in 1701. In 1786, Edinburgh town council were responsible for the maintenance of 307 lamps, after five decades of first street lighting installations. In October, 1820 a well-recognised standard (Specifications of cast iron pillars, lanterns and lamps for burning gas) for Edinburgh Street lighting was evolved by the Commissioners of Police for the city of Edinburgh. That was the first recognised standard or code for street lighting in Britain and as well as in world

[12]. In 1927, British standard specification 307, 1927 [13], [14] categorised eight classes of lighting depending upon minimum mounting height and maximum ratio between space and height. The illuminance range for these eight classes were defined from 0.1 lux to 21.5 lux. But these values did not have any experimental basis [13]. Again, this code was revised after 1928's milestone-experiment of Waldram [15].

Scottish inventor William Murdoch kicked off a movement toward more efficient street lighting in 1802. His coal-fuelled gas light illuminated the outside of the SoHo Foundry for a public presentation.

Five years later, London had its first gas-lit street. In 1816, Baltimore became the first U.S. city to install gas streetlights. Paris followed closely behind, in 1820. These early gas lights consisted of gas lanterns placed on poles.

Fig 2.2 Gas Street Light

The first electric street lighting employed arc lamps, initially the 'Electric candle', or 'Yablochkov candle' developed by a Russian, Pavel Yablochkov, in 1875. On 30 May 1878, the first electric street lights in Paris were installed on the avenue de l'Opera and the Place d'Etoile, around the Arc de Triomphe, to celebrate the opening of the Paris Universal Exposition. In 1881, to coincide with the Paris International Exposition of Electricity, street lights were installed on the major streets.

An arc is the discharge that occurs when a gas is ionized. A high voltage is pulsed across the lamp to "ignite" or "strike" the arc, after which the discharge can be maintained at a lower voltage. The "strike" requires an electrical circuit with an igniter and a ballast. The ballast is wired in series with the lamp and performs two functions.

First, when the power is first switched on, the igniter/starter (which is wired in parallel across the lamp) sets up a small current through the ballast and starter. This creates a small magnetic field within the ballast windings. A moment later the starter interrupts the current flow from the ballast, which has a high inductance and therefore tries to maintain the current flow (the ballast opposes any change in current through it); it cannot, as there is no longer a 'circuit'. As a result, a high voltage appears across the ballast momentarily, to which the lamp is connected; therefore, the lamp receives this high voltage across it which 'strikes' the arc within the tube/lamp. The circuit will repeat this action until the lamp is ionized enough to sustain the arc.

When the lamp sustains the arc, the ballast performs its second function, to limit the current to that needed to operate the lamp. The colour of the light emitted by the lamp changes as its electrical characteristics change with temperature and time.

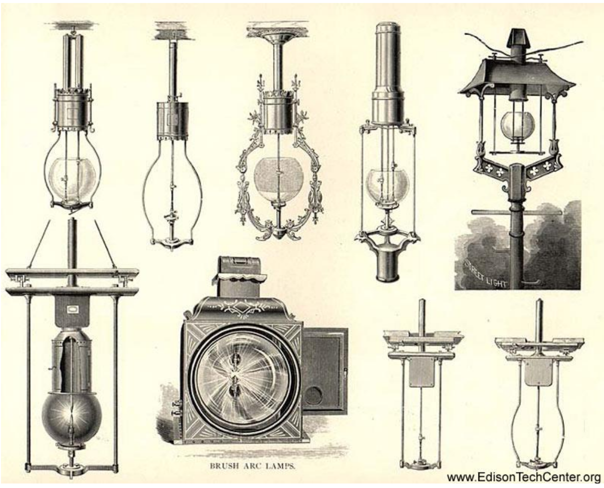


Fig 2.3 Yablochkov candle

The next phase of street light came in the form of incandescent lamp. Thomas Edison changed the world when he determined how to create a pure vacuum in his bulbs. Edison’s carbon-thread incandescent lamp, introduced in 1879, led to the development of light bulbs for streetlights.

An incandescent lamp is an electric light with a wire ‘filament’ heated until it glows. The filament is enclosed in a bulb to protect the filament from oxidation. Current is supplied to the filament by terminals or wires embedded in the glass.

A bulb socket provides mechanical support and electrical connections. It is made in various shapes and sizes, various voltage ratings or light outputs. It does not require any regulating equipment, has low manufacturing cost and can be operated both in alternating current and direct current.

These incandescent lamps are replaced by gas discharge lamps. Low-pressure sodium lamps were introduced in Europe in the 1930s. These lamps included a removable outer jacket and a vacuum layer for insulation, maintaining a high temperature to keep the sodium in vapor form. But due to its poor efficiency it soon replaced by high-pressure sodium vapour lamps.

Low-pressure sodium lamps are highly efficient electrical light sources, but their yellow light restricts applications to outdoor lighting, such as street lamps, where they are widely used. High-pressure sodium lamps emit a broader spectrum of light than the low-pressure lamps, but they still have poorer colour rendering than other type of lamps. Low-pressure sodium lamps only give monochromatic yellow light and so inhibit colour vision at night. It is the most popular street light for state and national high-way.

Fig 2.4 Low Pressure Sodium Vapour Lamp

In the meantime, of developing gas discharge lamps metal halide lamps were invented by Charles Proteus Steinmetz in 1912 and are now used in almost every city in the world. A metal-halide lamp is an electrical lamp that produces light by an electric arc through a gaseous mixture of vaporized mercury and metal halides. Like other gas-discharge lamps such as the very-similar mercury-vapor lamps, metal-halide lamps produce light by ionizing a mixture of gases in an electric arc. In a metal-halide lamp, the compact arc tube contains a mixture of argon or xenon, mercury, and a variety of metal halides, such as sodium iodide and scandium iodide. The particular mixture of metal halides influences the correlated colour temperature and intensity (making the light more blue or red, for example). When started, the argon gas in the lamp is ionized first, which helps to maintain the arc across the two electrodes with the applied starting voltage. The heat generated by the arc and electrodes then ionizes the mercury and metal halides into a plasma, which produces an increasingly-brighter harsh white light as the temperature and pressure increases to operating conditions.

The Ceramic or "C" in CMH lamps is the main distinction between MH and CMH lamps. This is referring to the ceramic substance that makes up the arc tube, which is comparable to the material used in HPS lights. This substance can sustain far greater temperatures, is more resistant to the corrosive salts, and is more stable than the quartz glass used in MH lamps. Efficiency, colour stability, and general light maintenance are all considerably enhanced by using a greater temperature inside the arc tube.

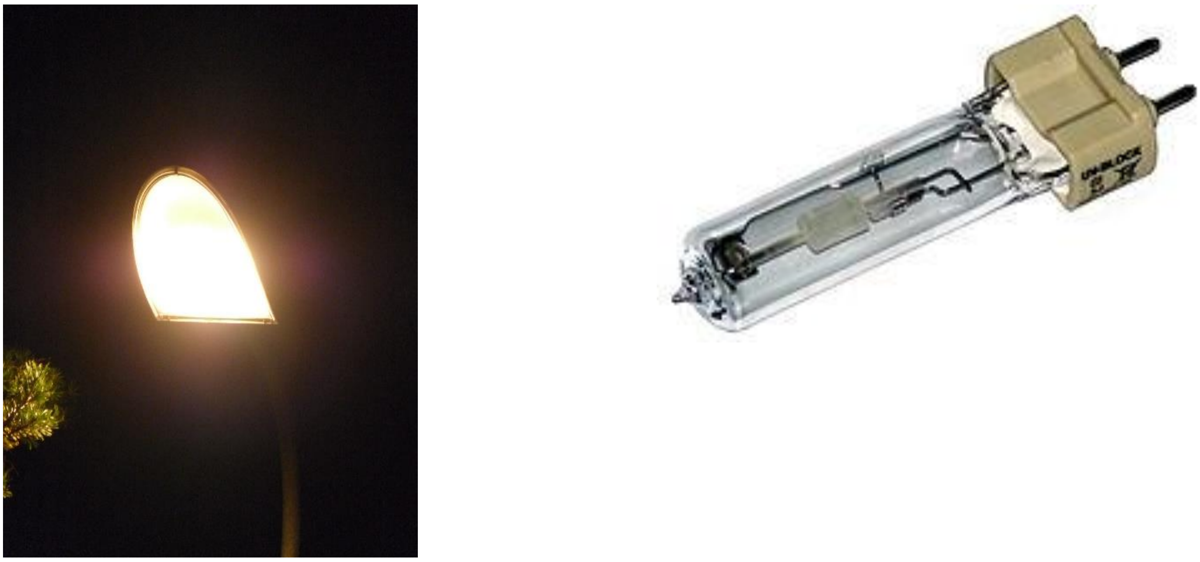


Fig 2.5 Ceramic Metal Halide Lamp

Next comes the fluorescent lamp in the commercial market. It was first demonstrated by Daniel McFarlan Moore in the year 1865. Decades of invention and development had provided the key components of fluorescent lamps: economically manufactured glass tubing, inert gases for filling the tubes, electrical ballasts, long-lasting electrodes, mercury vapor as a source of luminescence, effective means of producing a reliable electrical discharge, and fluorescent coatings that could be energized by ultraviolet light.

The fundamental mechanism for the conversion of electrical energy to light is the emission of a photon when an electron in a mercury atom falls from an excited state into a lower energy level. Electrons flowing in the arc collide with the mercury atoms. If the incident electron has enough kinetic energy, it transfers energy to the atom's outer electron, causing that electron to temporarily jump up to a higher energy level that is not stable. The atom will emit an ultraviolet photon as the atom's electron reverts to a lower, more stable, energy level. Most of the photons that are released from the mercury atoms have wavelengths in the ultraviolet (UV) region of the spectrum, predominantly at wavelengths of 253.7 and 185 nanometres (nm). These are not visible to the human eye, so ultraviolet energy is converted to visible light by the fluorescence of the inner phosphor coating. The difference in energy between the absorbed ultra-violet photon and the emitted visible light photon goes toward heating up the phosphor coating.

Fig 2.6 Fluorescent Lamp as Street Light

After some more innovation the fluorescent lamp started to come into compact form. These variants were named compact fluorescent lamp or CFL. Because of their small size, energy efficiency and good life span the started to be used in all form of indoor and outdoor lighting. The use of fluorescent lamp comes to an end after invention of light emitting diode or LED.

Electroluminescence as a phenomenon was discovered in 1907 by the English experimenter H. J. Round of Marconi Labs. This is the first step toward discovering light emitting diode. The first visible-spectrum (red) LED was demonstrated by J. W. Allen and R. J. Cherry in the year 1962. Then the world started to admire the possible potential in LED. The invention of commercially available LED is very discrete and have contribution of a large number of engineers and scientists. The next big step in this technology came from Isamu Akasaki and Hiroshi Amano of Nagoya University. They have invented a high power blue light source by GaN deposition. Now a days after so many research the material used most often in LEDs is gallium arsenide, though there are many variations on this basic compound, such as aluminium gallium arsenide or aluminium gallium indium phosphide.

Even though white light can be created using individual red, green and blue LEDs, this results in poor colour rendering, since only three narrow bands of wavelengths of light are being emitted. The attainment of high efficiency blue LEDs was quickly followed by the development of the first white LED. In this device a $Y_3Al_5O_{12}$:Ce (known as "YAG" or Ce:YAG phosphor) cerium-doped phosphor coating produces yellow light through fluorescence. The combination of that yellow with remaining blue light appears white to the eye. Using different phosphors produces green and red light through fluorescence. The resulting mixture of red, green and blue is perceived as white light, with improved color rendering compared to wavelengths from the blue LED/YAG phosphor combination. Experimental white LEDs were demonstrated in 2014 to produce 303 lumens per watt of electricity (lm/W); some can last up to 100,000 hours. However, commercially available LEDs have an efficacy of up to 223 lm/W as of 2020.

Fig 2.7 First Generation LED Street Light

Fig 2.8 Modern LED Street Light

In a light emitting diode, the recombination of electrons and electron holes in a semiconductor produces light (be it infrared, visible or UV), a process called "electroluminescence". The wavelength of the light depends on the energy band gap of the semiconductors used. Since these materials have a high index of refraction, design features of the devices such as special optical coatings and die shape are required to efficiently emit light. LEDs developed by Seoul Semiconductor can operate on AC power without a DC converter. For each half-cycle, part of the LED emits light and part is dark, and this is reversed during the next half-cycle. The efficiency of this type of HP-LED is typically 40 lm/W.

The LEDs are more efficient from its predecessor and comes in a variety of CCT. This gives the advantage to explore the possibility of CCT levels in accordance to the human convenience.

Chapter 3

Human Centric Lighting

3.1 The Concept of Human Centric Lighting

In the context of resent development, the term human centric lighting is becoming more important for lighting design. Some early researchers found that light not only have an impact over human visual performance but also have a significant role in non-visual performance like perception, mood and sleep cycle or circadian cycle. A new photoreceptor has been discovered named Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs). Unlike other ganglion cells, the ipRGCs can themselves convert the electromagnetic light signal into a neurochemical signal through their expression of melanopsin. Melanopsin is a photosensitive protein that have a roll in human non-visual responses.

As discussed earlier, light affects our mental and physical health. If light is not delivered at the appropriate time, may have unfavourable effects. In humans, light is perceived not only by rods and cones but also by a part of retinal ganglion cells. It expresses the photopigment melanopsin that renders them intrinsically photosensitive (ipRGCs). ipRGCs participate in contrast detection and play critical roles in non-image-forming vision. It performs a set of light responses that include circadian cycle stabilization, pupillary light reflex (PLR), and the modulation of sleep or alertness, and mood. ipRGCs are also found in the human retina, and their response to light has been characterized indirectly through the suppression of nocturnal melatonin and PLR. However human ipRGCs had not been investigated directly. This gap is progressively being filled as, over the last years, an increasing number of studies provided descriptions of their morphology, responses to light, and gene expression. Investigating ipRGCs is critical as it is one of the few cells play a major role in our well-being. The deeper knowledge of the function of ipRGC could help identify therapeutic approaches or develop diagnostic tools for lighting design. Overall, a better understanding of how light is perceived by the human eye will help deliver precise light usage recommendations and implement light-based therapeutic interventions to improve cognitive performance, mood, and life quality.

The terms circadian, neuroendocrine, and neurobehavioral responses were used by IES in 2018. Circadian responses refer to internal biological processes that occur on a roughly 24- hour cycle and regulate varied physiological responses including the sleep-wake cycle. It is found that light is the primary stimulus for human biological clock. Every morning light reset the sleep-awake cycle of human being and stimulates SCN (suprachiasmatic nucleus) responsible for circadian rhythm [16]. Neuroendocrine responses refer to how the brain regulates hormones. Neurobehavioral responses refer to the relationship between the action of the nervous system and human behaviour. All of these responses can be influenced by signals from rods, cones and ipRGCs, where the ipRGCs incorporate input from the rods and cones. So, it can be said that all three photoreceptors rod, cone and ipRGC has a combine role over human visual and non-visual responses.

3.2 The Factors involve in Human Centric Lighting

Any stimulus to the visual system can be described using the five factors of visual size, luminance contrast, colour difference, retinal image quality, and retinal illuminance. These characteristics play a significant part in deciding how well the visual information can be distinguished and detect the stimuli.

1) **Visual Size**: The visual size for detection is frequently provided by the solid angle that the stimulus subtends at the eye. It is simpler to recognise the stimulus the larger the solid angle. While shadows can be used to increase the effective visual size of some 3D objects, lighting conditions have little impact on the visual size of 2D items.
2) **Luminance contrast**: The luminance contrast of the stimulus expresses the luminance of an object in comparison to its immediate context. The stimulus is easier to perceive the higher the brightness contrast. By altering the luminances of a stimulus's component components and creating eye-disability glare, for example, lighting conditions can change the luminance contrast of a stimulus.
3) **Color difference**: A stimulus's own wavelengths have a significant impact on the colour it seems to be. Given how strikingly coloured the stimulus is from the backdrop, it is possible that a stimulus with 0% luminance contrast will still be recognised. Lighting may alter the colour difference between an item and its backdrop when many light sources with various spectra are used.
4) **Retinal picture quality**: As with other image processing systems, a crisp image is ideal for the visual system's performance. The stimulus' spatial frequency distribution can be used to gauge how sharp it is. For instance,

a crisp image will have high spatial frequency components, but a fuzzy image won't.

5) **Retinal illuminance**: This factor has a substantial impact on the visual system's capabilities and influences how well the visual system adapts.

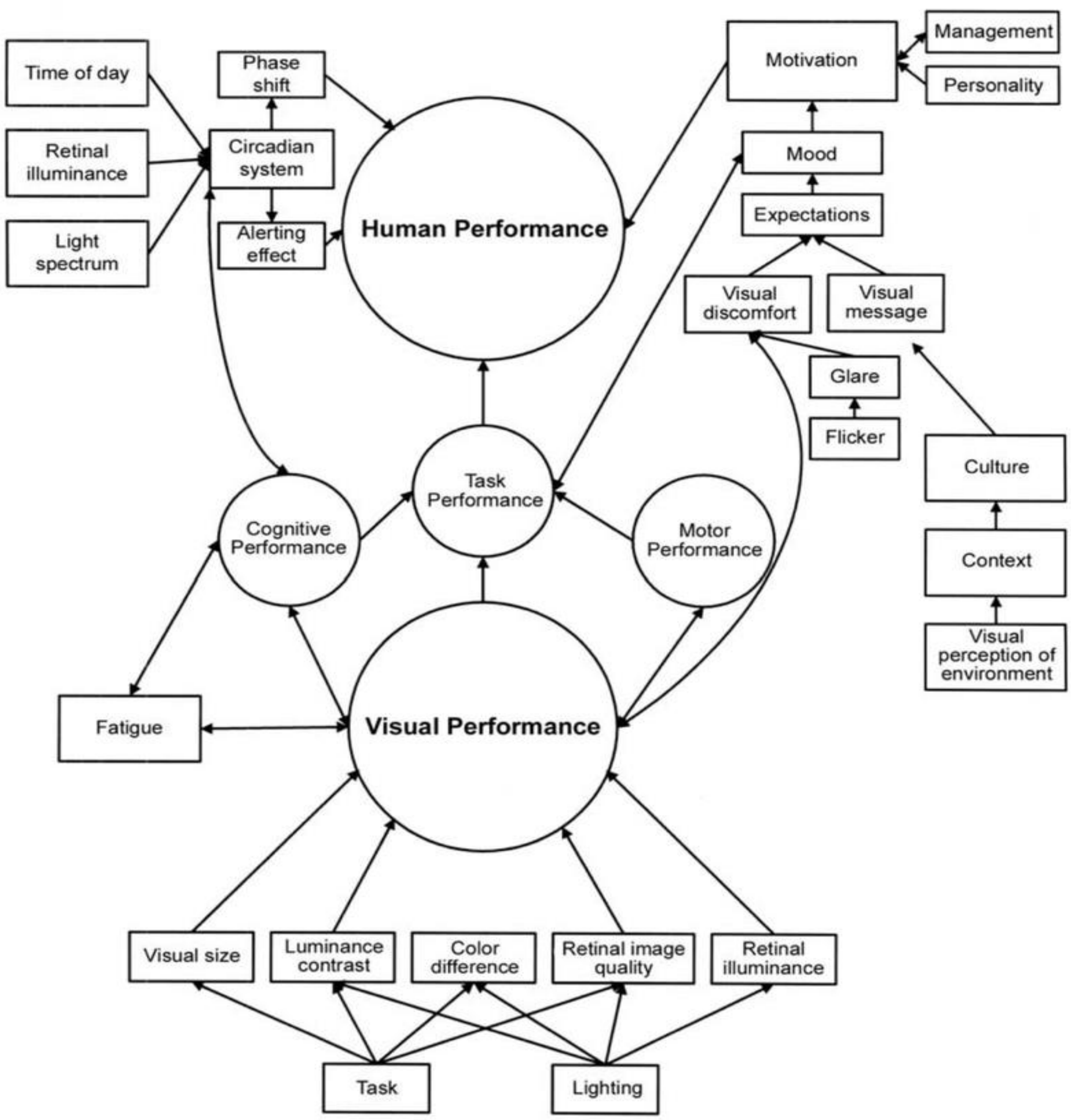


Fig 3.1 A conceptual framework setting out the three routes whereby lighting conditions can influence human performance. The arrows in the diagram indicate the direction of effect. (Source Lighting and Work by Peter Boyce)

The stimuli and the visual system's current state of function determine the level of visual performance that is possible. However, the narrative is not over yet. Visual, cognitive, and motor skills are the three elements that make up visual activities most obviously. The visual component is the process of employing the visual sense to obtain information necessary to finish the activity. The cognitive component includes the process through which sensory stimuli are assessed and the optimal course of action is selected. The motor component refers to the process by which information is extracted from inputs and chosen actions are carried out. Together, these three components create a complex pattern between stimulus and reaction, which in turn influences how the job is carried out. Each task has a different ratio of the visual, cognitive, and motor components, and each task's response to lighting conditions differs. Because each activity is unique, it is hard to generalise about how illumination impacts how well a task is performed.

Another way that ambient light may impact the work environment is through the non-image-forming system. The only part of the nonimage-forming system that is definitely known to have an effect on human performance is the circadian timing system. The sleep-wake cycle is the most blatant example of a circadian timing mechanism at action in nature. Light may be used in two separate ways to improve work performance by influencing circadian timing. Two examples are the acute effect of the hormone melatonin being suppressed during night time that heightens alertness (Campbell et al., 1995) [42] and the phase-shifting mechanism by which exposure to intense light at specific times can accelerate or delay the phase of the circadian rhythm (Dijk et al., 1995) [41].

It has also been investigated if cortisol levels may be affected by midday light exposure to enhance task performance. There is evidence that exposure to bright light levels soon after waking up boosts cortisol concentration (Scheer and Buijs, 1999) [43]. The implications on what happens the remainder of the day are less clear. Volunteers were exposed to 5000 lx between midday and 16.00 h by Ruger et al. (2006), who discovered that while alertness was favourably impacted, cortisol concentration was unaltered [44]. Kaida et al. (2007) reported similar results, showing that exposure to more than 2000 lx in the early afternoon increased alertness [45].

Mood and motivation are the third way that lighting may affect productivity. The visual system's construction of a model of the visual world may cause an emotional response. This emotional response has the ability to impact someone's mood and motivation for work, among many other things. Furthermore, when illumination creates visual discomfort, it can have a simple yet profound impact on motivation and mood.

3.3 Advantages of using Human Centric Lighting

The Human Centric lighting can be helpful for human being as well as for society mainly in six different ways.

First is to improve of **Circadian Rhythm**. The circadian rhythm is 24-hour body clock. This clock get data from the environment CCT level and process our sleep cycle. But because of invention of electrical lighting, we are exposed to a constant CCT lighting throughout the day and night. Human body is not accumulated to that. So, this phenomenon effect on our sleep cycle a lot. Not only this but the biological clock has a significant effect on several other hormone like Dopamine (controls pleasure, Alertness in day time), Serotonin (controls impulse control and carbohydrate craving), Cortisol (stress response). Malfunctioning of these hormone productions badly effect on body harmony. By controlling the ambient lighting according to our circadian rhythm can solve these problems.

Second is **mood**. *Gilles Vandewalle et al*[46] have found that certain colours or light can affect emotions, mood and cognition. Light has an effect on cognitive function. Spectral quality of light changes emotional responses in humans. If a person has control over task lighting (turning light on and off, changing CCT), his mood, satisfaction can be improved. Human emotions like anger, sadness, happiness can be acknowledged by human centric lighting.

Third advantage is **Visual Acuity**. The realization of any object depends on the quality of visual information received. Visual Acuity (VA) is the measure of the clearness or sharpness of the vision. Precisely it is the measure of the eye to distinguish between different shaped objects and their detailing when kept in a certain distance from the observer. The way that humans really perceive light, visual acuity can be improved using a higher CCT lighting keeping existing wattage in many applications. The amount of blue light significantly improves human visual acuity.

The fourth advantage is improvement of **perception**. In this field many works have already been done. The showrooms of different brands use this technique to present their product move efficiently. Lighting can improve the perception over goods.

Fifth advantage is **productivity**. Lighting can affect human alertness, mental satisfaction and good vision. These leads to increment of productivity. For different kind of task lighting if human centric lighting can be incorporated the performance can be improved. Street lighting is one of the examples. If the CCT of the street light is of optimum level drivers' response become more adequate, the chances of road accident become less. Similarly using a good lighting environment in a classroom student can be more attentive.

Last but not the least the advantage of **Energy Sustainability**. Earlier energy savings in lighting means reducing the intensity of lighting or turning off the light. But because of recent development in LED lighting changes that perception. A 5000K light saves more energy than a 3500K LED. So, by using suitable CCT for every task energy can be saved.

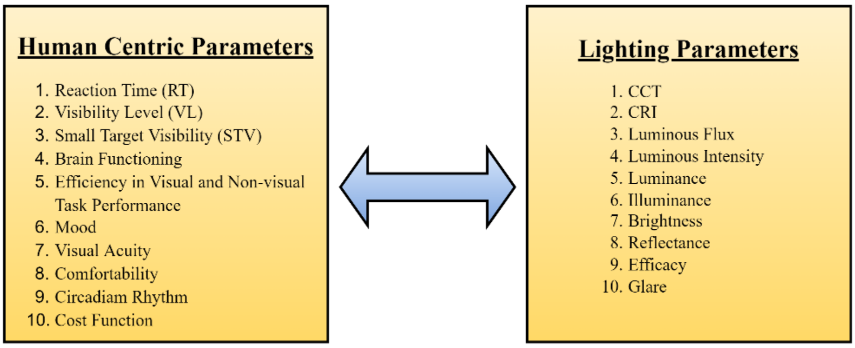


Fig 3.2 Interconnected Human Centric Parameters and Lighting Parameters

The main objective of the human centric lighting is to improve visual performance. Visual performance is interrelated with human performance. That's why by improving lighting structure with human satisfaction and need over all living quality can be improved. The following diagram shows how human visual performance is related with human performance and other human characteristics.

It is said that human centric lighting with daylighting and smart LED systems will become the future aspects of lighting technology in upcoming years. [17].

HCL combines the visual and non-visual responses of human being to improve human health, well-being and performance. It can be divided into three aspects:

1) Visual Benefits: good visibility, visual comfort, safety

2) Biological Benefits: alertness, concentration, deep and stable sleep wake cycle, cognitive performance

3) Emotional Benefits: improved mood, relaxation, impulse control [18]

3.4 Experimental approach for studying Human Centric Lighting

The study of human centric lighting has three fundamental approaches. The approaches can be assessed with two quality parameters i.e., face validity and generality. The approaches alone with their quality parameters are describes in table no.1.

Type of Approaches	Face Validity	Generality
Real Task Studies	High	Very Low
Laboratory Simulation based studies	Moderate	Low
Analytical approach towards developments of a model	Low	Very High

Table No. 1 Review on Human Factors in Lighting Research

To evaluate acceptance of certain road lighting installation by human being three different approaches can be done i.e., (1) Subjective Judgment with some questionnaires and Statistical Analysis of the data, (2) Behavioural Study and Statistical Analysis of the data, (3) A new methodology: Electroencephalography (EEG) based method along with the behavioural Study.

This study is based on the second approach which is Behavioural study and Statistical Analysis of the data. Here, the participant has given his perception of the particular installation and his reaction time was recorded. This data along with the luminance data measured are then statistically analysed.

In the context of road lighting, it is essential to determine the most appropriate lighting scene for a human being. The visibility level approach is most suitable for that. The visibility level has human factors like contrast, age, exposure time, reaction time. So, it is the most suitable function for human centric approach.

Chapter 4

Background of The Work

The street lighting has gone a long evolutionary path, but yet to reach the optimum level. The human centric approach for the road lighting has not been explored properly. How the lighting environment effect the driver and pedestrian still remains a question. This research experiment is done to explore the combinations of CCT of road lighting.

The LED can be manufactured with different CCT or CCT of a particular LED can be changed according to our needs. This gives the opportunity to experiment with all possible CCT levels. Small target visibility has been chosen as the parameter for this comparative study.

4.1 Literature review

Road lighting is a very essential part of lighting design. Under this subtitle some recent development on road lighting and its standards are going to be discussed.

First of all, it is essential to know about the purpose of proper road lighting. The commission Internationale de l'Eclairage (CIE) describes main two purpose for road lighting (1) to allow all road users, including operators of motor vehicles, motor cycles, pedal cycles and animal drawn vehicles to proceed safely; and (2) to allow pedestrians to see hazards, orientate themselves, recognise other pedestrians and give them a sense of security and the last one is (3) to improve the day and night time appearance of streets [19].

Gibbons R, Guo F, Medina A, Terry T, Du J, Lutkevich P, Corkum D, Vetere P. said in the "Guidelines for the Implementation of Reduced Lighting on Roadways" that it is evident that increase in luminance or light level decreases fatality of road accidents and the number of accidents because drivers can readily recognise hazardous blockade or object in their visual field at higher luminance as braking response occurs rapidly [20].

Despite the fact that both rods and cones are used by drivers and pedestrians for visual reactions, the night time road illumination condition should fall within mesopic conditions, however we used solely photopic photometry [21]. Photopic photometry only takes the response of cone photoreceptors into account. The CIE mesopic system is used to weigh the mixture of photopic and scotopic responses that make up the mesopic visual responses. The CIE mesopic system is used to weigh the mixture of photopic and scotopic responses that make up the mesopic visual responses.

In the paper Visibility of Targets: Model for Calculation Dr. Ing W Adrian stated about the process to calculate Visibility level of different targets with positive or negative contrast[22]. Contrast is the difference between object luminance and background luminance. If object luminance is more than the background luminance then the contrast is positive. If the background luminance is more than the object luminance then contrast is negative. Either way the difference between two luminance is the key factor of visibility calculation. The other factors to calculate visibility level are exposure time, age of the subject, veiling luminance, size of the target object and glare. The process of calculation will be discussed in details in upcoming chapters.

In the paper Evaluation of Visibility level Formula in Road Lighting with Field Measurement Onder Guler and Sermin Onaygil gave a brief discussion of the experiment they have done on the street of Istanbul Technical University Ayazaga Campus[23]. Here reflectance of the target is also considered. The visibility level was calculated and also evaluated by a rating system. It has been seen that correlation between calculated and evaluated visibility levels are determined approximately 0.75. It is also been proved that visibility level formula is valid for new road conditions.

The paper named Evaluation of Reassurance Gained by Higher Illuminance in Residential Streets using the Day-Dark Approach by S Fotios, A Liachenko Mointerio, J Uttley suggest about the comfortable illuminance level for pedestrian when walking after dark in an urban street. They have used Day-Dark method suggest by Boyce in the streets of Sheffield, UK. In the day-dark method ratings of reassurance captured both in day time and after dark and effectiveness of lighting is determined by the difference between them. It is seen that minimum illuminance is a better parameter than mean illuminance to express reassurance rating. The minimum horizontal illuminance is observed around 2 lux.[24]

In the paper named Obstacle detection : A Pilot study investigating the Effect of Lamp Type, Illuminance and Age by S Fotios and S Cheal showed us in which condition pedestrians can easily detect an obstacle at mesopic light levels. The results are as follows 1) 50% detection height is good at 0.2 lux than 20 lux. 2) Subjects less than age 45 years showed less 50% detection height than older age (greater than 60 years old age) at 20 lux illuminance. 3) At 0.2 lux illuminance better lamp S/P ratio deflects better detection.[25]

But it is noted that categorising street light by only illuminance could be a major challenge for incorporating both human factors and sustainability at the same time.

Yukio Akashi et. al. conducted a field study to gather fundamental data on visual performance at mesopic light levels to a driving context. Subjects drove a vehicle on a lighted street, beside that they are also performing a high-order decision making task. The task is to identify an off-axis target, moving toward or away from the street, and braked or accelerated accordingly. They use two types of light. One set made of five 60-watt CMH (Ceramic Metal Halide) lamps and the other set is made of five 60-watt HPS (High Pressure Sodium) lamps. They use an accurate smart GPS (Global Positioning System) and IR(Infra-Red) sensing system on car to trigger the target. The experiment was also conducted on day time for comparison. The results from the experiment showed that both braking and acceleration response time decreased monotonically with increased unified luminance and pointed out that unified luminance is a suitable rectifying variable for characterizing light levels for different light sources with respect to a complex visual task. But this whole experiment is done using two old light sources and with old technical setup. we can get even more better and crucial analysis if we do it using modern light sources like LEDs and modern equipment [26].

Reaction time under HPS and MH lamps are measured and compared by He et. al. The experiment resulted that a higher S/P ratio (A ratio between the scotopic lumens the lamp produces and the photopic lumens) gave benefit to the drivers at a luminance level under approximately 1.0 cd/m2 [27].

Hills et. al. suggested that the tail lights, road surface obstacle and pedestrians are important factors for decision making in driving and quantified those by the difference of luminance between target and background and visual size of the target [28].

Moreover, researches showed that VL (visibility level) plays an important role for object identification for drivers. VL is the ratio of actual difference in luminance between target and background and difference of the previously mentioned quantity at threshold. Whenever the value of VL increases above 1.0, target starts to appear in silhouette [29], [30]. This experiment needs further implication to know the minimum VL and CCT corelation to establish proper street light guidelines.

In the paper Laboratory Based EEG Study to Investigate the Influence of Light Source of Brain Processing for detection of Object Designed with Metal Halide and High Pressure Sodium Vapour Lamp the authors Dr. Suddhaswata Chakraborty, Rakesh Bishwas and Pratik Nath experimented about temporal process in the brain for an object detection and which kind of light is more preferable by a simple match-mismatch task. The result showed that object detection is faster in MH than HPS lamp. From this paper it is also established that Electroencephalography (EEG) is a valid and a futuristic approach for visual acceptance designing since it is irrespective of subject biasness.[31]

The paper named An EEG based comparative study on Drivers Performance Under the Influence of Metal Halide and High Pressure Sodium Vapour Light by Dr. Suddhaswata Chakraborty, Debtanu Roy and Ishan Palit showed us about drivers performance in an actual road condition illuminated the MH and HPS lamps. The experiment consists of behavioural study and EEG study on drivers response time. In the result it is found that metal Halide lamps have better human cognitive performance[32].

In the paper Determining Minimum Visibility Levels in Different Road lighting Scenarios by B Buyukkinaci, S Onaygil, O Gular, MB Yurtseven stated that minimum VL of 7 to 8.5 required for 100% critical object detection on M2 to M5 class of roads[33].

The Illumination Engineering Society of North America published a standard in the year 2000 named RP-8-00 [34] which contains basis of design of road lighting for road ways, adjacent bikeways and pedestrian ways. This specifies the streets by volume of users and road surface. Luminaire cutoff is also classified in this standard. But the most important of that it includes a new design criterion. It describes illuminance and luminance as important criterion and introduce a new standard name Small Target Visibility. STV is more likely to be weighted average of Visibility Level. Unlike other criterion STB mostly depend upon contrast. This can increase night time safety and night time drivers' performance. STV method of designing street light can significantly reduce energy consumption. The method and its advantages are discussed furthermore in this literature.

4.2 Formulation of the problem

There is a significant research gap remained in the concept of human centric street lighting. Since the human factors concept in the lighting design is quite new and started to get some acceptance, it is necessary to execute experiments with humans as subject in order to fully understand the effect of road lighting on human being.

Small target visibility along with visibility level should be new parameters to set a standard on road lighting. Unlike illuminance these parameters have a human centric approach and able to distinguish weather a road lighting is good for drivers or not.

Establishing a suitable photometric quantity, Luminance can be a basic parameter for the first stage in creating a solid experimental foundation on which street lighting design will be based. It provides a more accurate measurement of how well an object can be viewed than illumination [35].

After the consideration of luminance Adrian developed a visibility model based on detection of small object in the road. He defined a particular small object and calculated the visibility level (VL) of an array of these objects and found a weighted function as a single matric and named it as STV (Small Target Visibility) [22]. This method of design was incorporated in IESNA RP-8 in 2000 [34].

Furthermore, it can be said from previous experiments, for road lighting design it is important to look after the object detection, recognition and decision making by drivers or pedestrians [36].

On this note for establishing a proper relation in between CCT and STV for road lighting context before the experiment could be done in actual road lighting scene, it is necessary to do it in a controlled laboratory environment. So, a pilot experiment is designed in laboratory's-controlled environment. It is essential to simulate on-axis vision and peripheral vision of a real road light in the laboratory scenario. Because peripheral vision is equally important as on-axis vision.

Human vision can be split into two categories, on-axis vision and off-axis vision, depending on the area of coverage. The illumination that are in the frontal area of the eye of a viewer are included in on-axis vision, but the light sources that are in the peripheral area of the eye are responsible for off-axis vision for the same observer. Peripheral sources are any light sources that enable a person to see things that are not in their direct line of sight without having to turn their head or move their eyes. In actual road lighting the light in front of the driver is responsible for on-axis vision. The light above him or behind him is responsible for peripheral vision. When the vehicle moves towards next pole, the on-axis source become peripheral and the next source comes into on-axis. This process continues throughout the journey. In the laboratory environment where everything is static it is mandatory to simulate both the light source in laboratory in order to mimic actual road scenario.

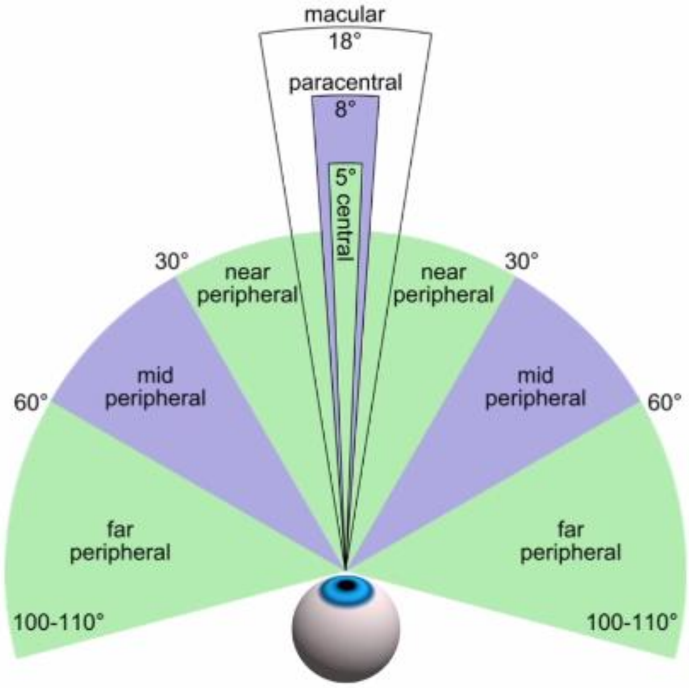


Fig 4.1 Peripheral Vision

The road light ahead of on-axis source is also significant. This act as glare to driver's eye. But it can be eliminated by choosing suitable distance between two poles. So, this parameter is neglected in simulation.

This is the background of the experiment. The details of the experiment are in next chapter.

Chapter 5

Experimentation

5.1 Work Flow Diagram

The experiment is to find the most appropriate correlated color temperature for street light. In this stage of experiment, it is tried to simulate the road lighting scenario in a laboratory simulated environment. The work flow diagram is shown in the figure 5.1.

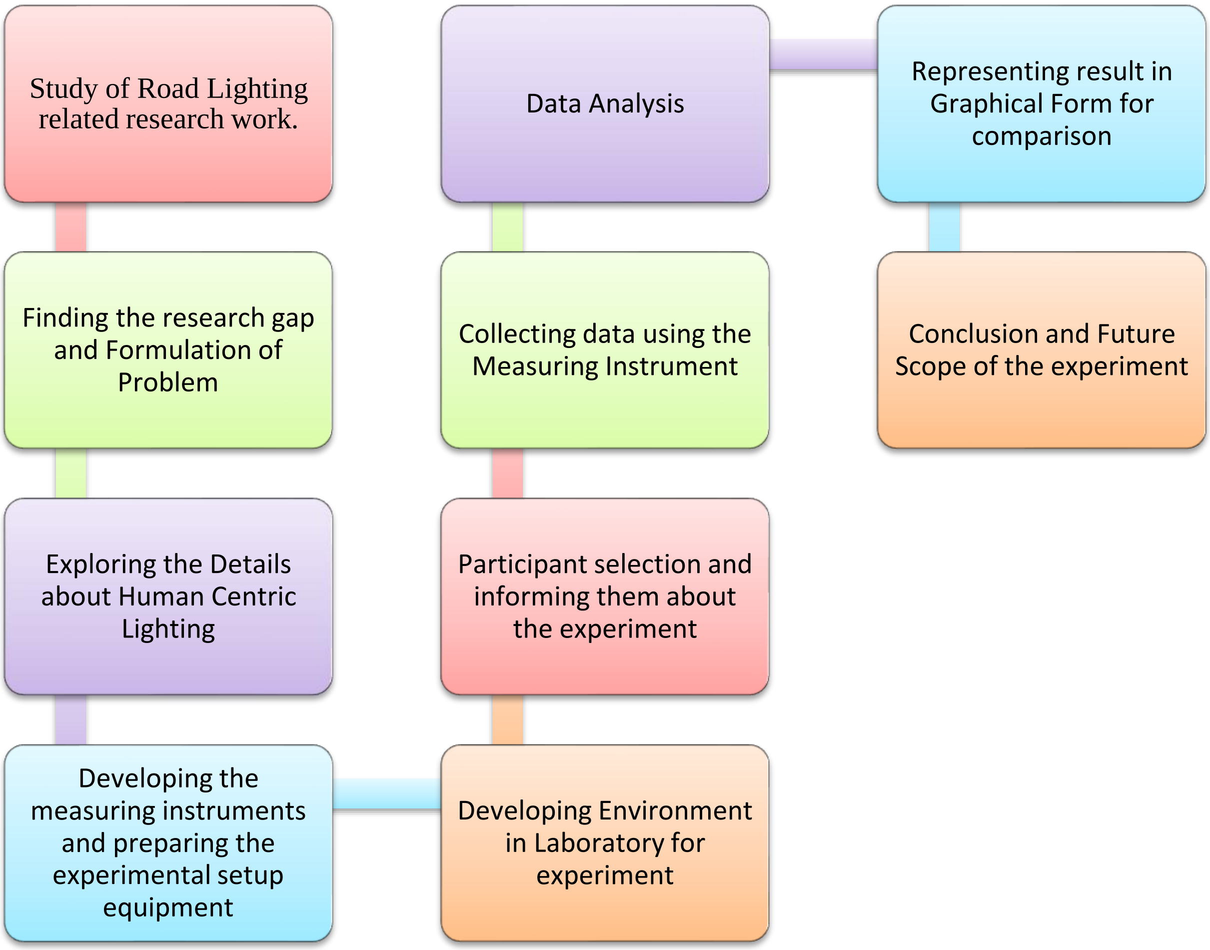


Fig 5.1 Work Flow Diagram

5.2 Experimental Setup

The experimentation was done in the Dark Room Laboratory of the Illumination Engineering laboratory of the Electrical Engineering Department of Jadavpur University. Laboratory setup is designed in such a way that it could mimic a street lighting. The walls, floors and celling are painted black.

The main light is mounted on a 2 m height pole. The peripheral sources mounted on a 1.5 m height pole. The peripheral sources positioned on the both side of the subject. We covered each light sources with a black paper like a baffle. So that no light can come directly to the subject's eye. The top view of the setup is as on fig. 5.1.

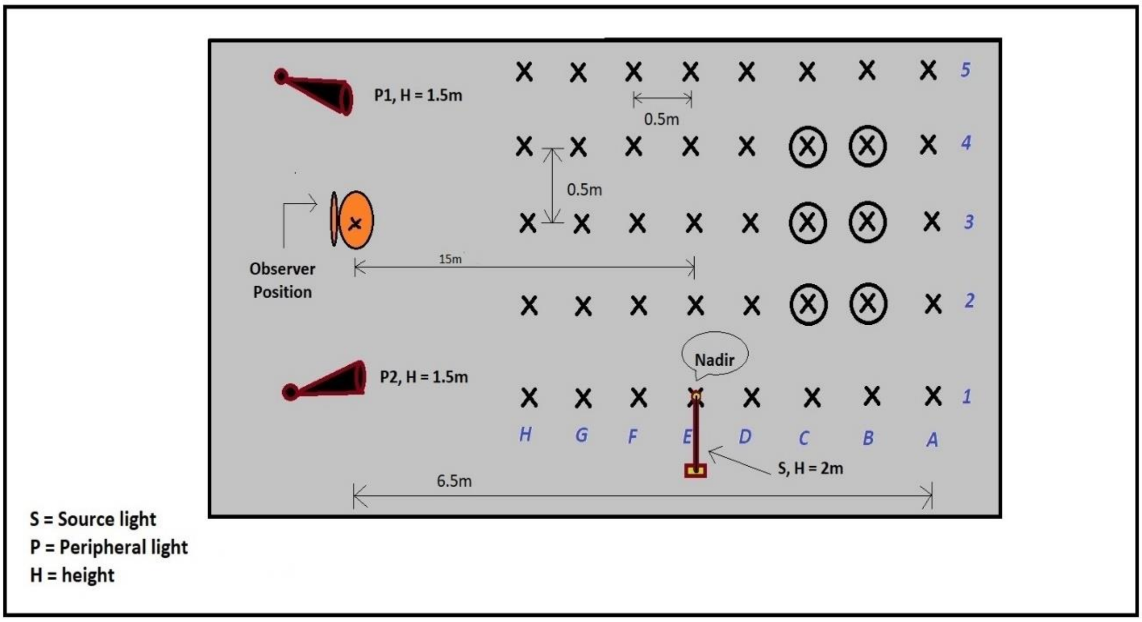


Fig 5.2 Top view of the Experimental Setup

A detailed grid is drawn keeping in mind CIE 140-2000. There are total 40 grid points, 5 rows and 8 columns. Three rows marked as 1 to 5. Five columns marked as A to H. The nadir point E1 located exactly below the main source.

The distance from the subject's position to the nadir point's column E is 15 meters. Each grid point is 0.5 meter apart from each other. The last column A is at 17 meter distance from the subject. The subject sited on a chair of height 1.25 meter. The eye height of the subject is near about 1.67 meters.

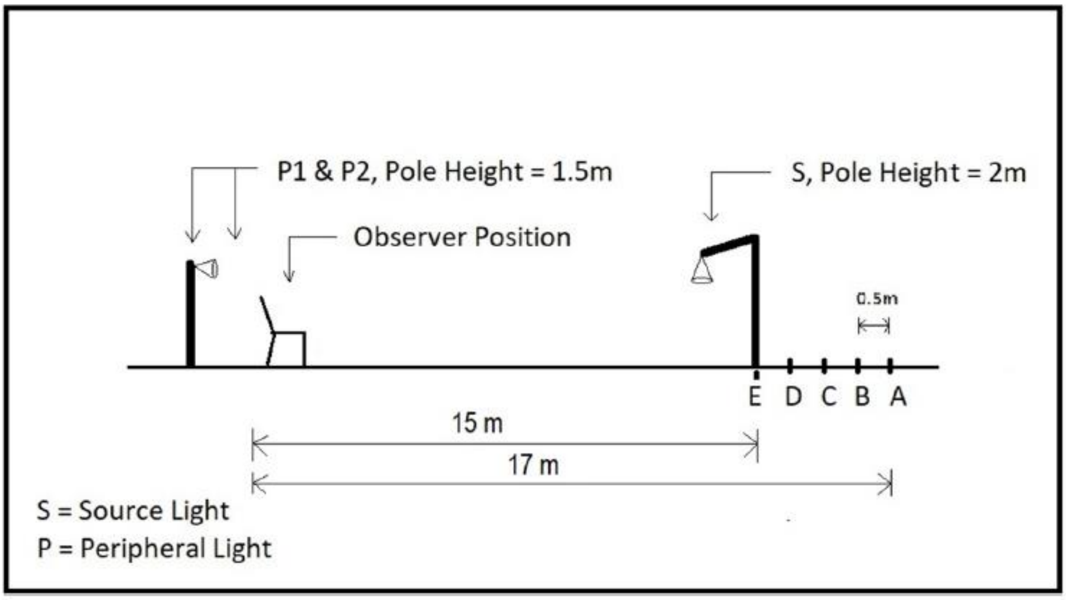
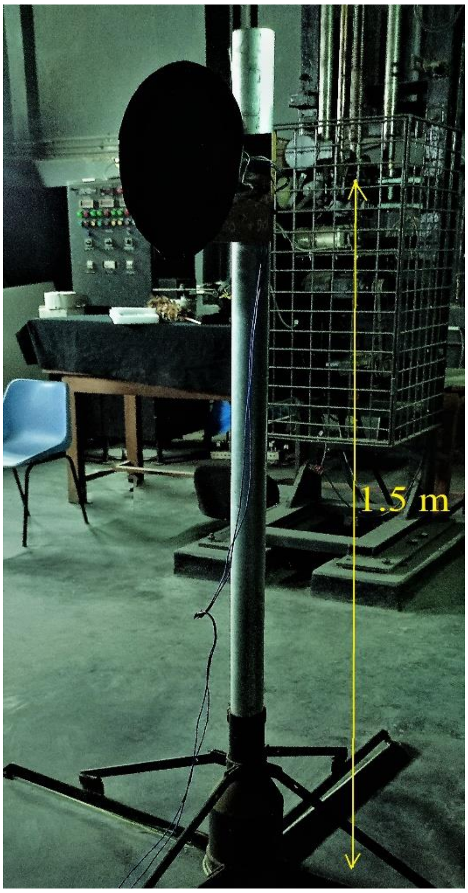


Fig 5.3 Side View of Experimental Setup



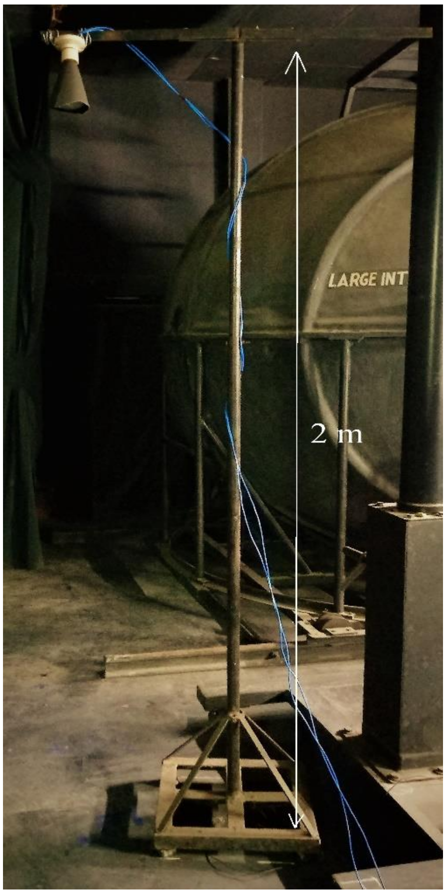


Fig 5.4 Peripheral (Left) and Main (Right) Source

The setup consists of three sources. One main source and other two are for peripheral source. The lamps used as sources are Halonix Smart LED Bulb. The CCT of individual bulb can be varied from 2500K to 6000K, which can be controlled via mobile application. Two peripheral sources bulbs are mounted on two poles of height 1.5 meter. And the main source is mounted on a 2 meter pole. A black baffle is used for each bulb. The baffle's primary function is to prevent direct light from reaching the subject's eye. Here in this experiment 3000K, 4000K, 5000K and 6000K CCT is used. The spectral composition of the light for these CCT (measured by Konica Minolta CL 70F) are shown in the figure 5.5 – 5.8.

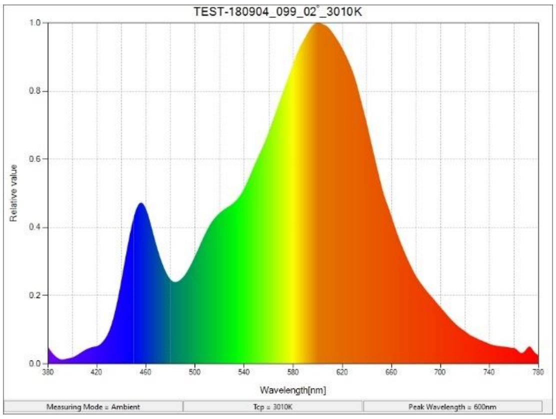


Fig 5.5 SPD of Light (CCT 3000K)

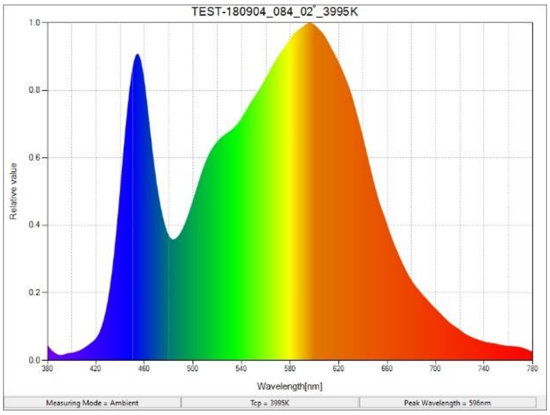


Fig 5.6 SPD of Light (CCT 4000K)

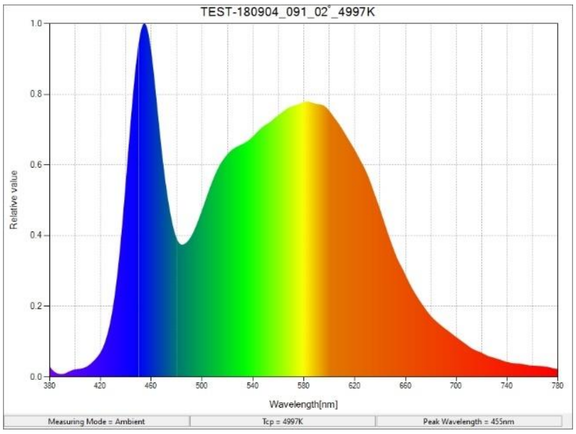


Fig 5.7 SPD of Light (CCT 5000K)

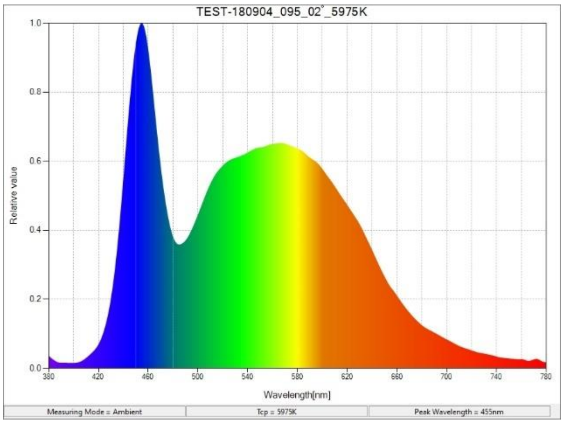


Fig 5.8 SPD of Light (CCT 6000K)

The illuminance values of the area are shown in table no. 2. The illuminance did not vary much with respect to CCT.

	1	**2**	**3**	**4**	**5**
A	6.5	6.4	5.2	4.1	2.9
B	12.5	11.8	9.3	6.6	4.4
C	22.9	20.8	15.6	10.3	6.2
D	36.2	31.8	22.6	14.5	8.0
E	43.2	38.7	27.0	16.1	8.7
F	39.9	36.0	25.6	15.0	8.3
G	29.4	26.9	19.1	11.6	6.8
H	17.6	15.8	12.1	7.9	4.9

Table 2 Illuminance Value of Simulated Street

The luminance meter is placed exactly in the place of the subject. The luminance meter mounted on a 0.83 meter height tripod. There was also a distance meter mounted on the same tripod to measure exact distance of the object from luminance meter.

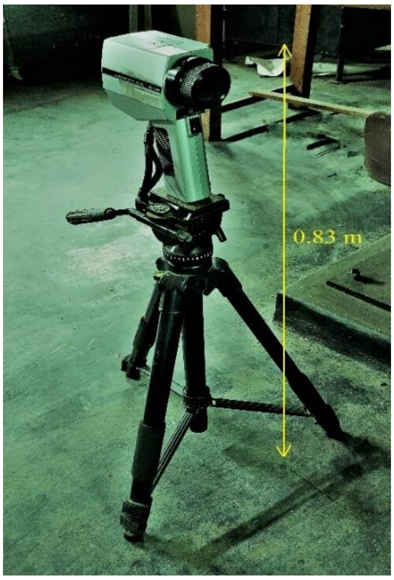


Fig 5.9 Positioning of Luminance Meter

The object used in the experiment is a cube. The cube is covered with a yellow art paper to keep the reflectance in desired value. Each side of the cube is of 8 cm. The object has a reflectance of 37.5 % in all CCT levels. Fig. shows the object.

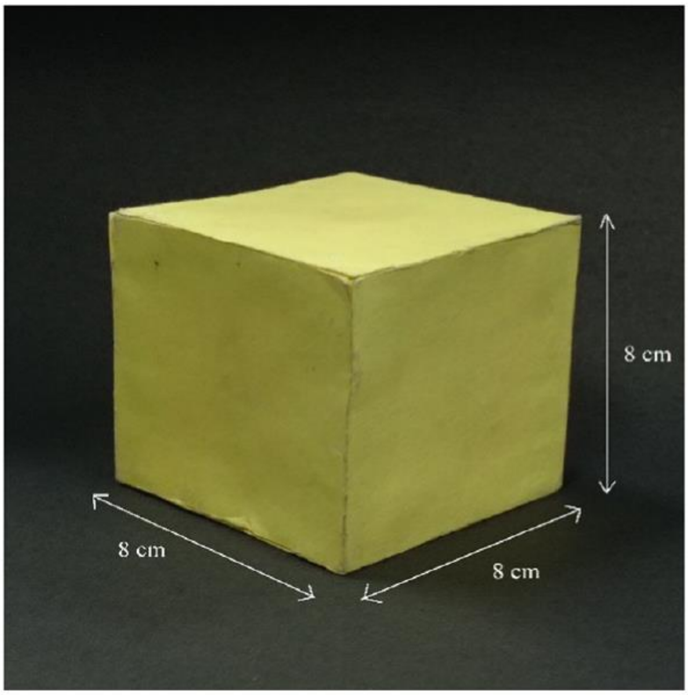


Fig 5.10 The object used in the Experiment

5.3 Experiment Steps

The experimental process can be divided into three parts. First the reaction time of the subject is procured. Then the contrast of the object in different grid point is measured. And lastly the calculation is done using a JAVA program.

5.3.1 Reaction Time Measurement: At first a healthy physiologically and neurologically intact subject is invited to the experiment. The age of the participant is 20 years. He has a normal vision. The subject was provided with detailed understanding of the entire experimental procedure and signed informed consent before participating in the experiment.

In the meantime, the environment was adjusted. The main source was kept at 3000 K and both of the peripheral source is also adjusted to 3000 K using the mobile application. Konica Minolta CL-70F is used to confirm the exact CCT of the sources. The CCT have accuracy of 95 %.

After all the formalities and setups are done, the participant is asked to sit on the subject's chair. He was provided with the active shutter glass and instructed to press the stop push button when he can identify the object.

After that one of our operators holding the start button of reaction time measuring instrument guard complete vision of the subject. Then the object was placed in one of the six positions mentioned earlier. Then the start button is pressed which allowed the subject to view the object. After seeing the object, the subject presses the stop button. We note the subject's reaction time from the LCD of the device. Then the operator presses the reset button which reset the timer.

For assuring the response time, the participant is asked some questions Which is stated below. To check whether the participant fully observed the object his answer is checked with the actual object. If the reaction time is less than 700 milliseconds, then it is considered as a valid reaction time.

The evaluation and performance were done in a questionnaire sheet for each and every run with the questions mention below.

1) What is the colour of the object?
2) What is the shape of the object?

This process repeated for six times with different locations of the object. After completion of the process, we get a set of six reaction time. The subject is sent to normal lighting condition for fifteen minutes.

After one set of operation, we prepare for the next set. Main source remains same but peripheral sources changes to 4500 K. The subject is invited once more for the second set.

In this way the experiment repeated for twelve times. The main source is changed for four times. The main source CCT is taken 3000K, 4000K, 5000K and 6000K. For each main source CCT the peripheral sources changed for three times. Value of peripheral CCT taken as 3000K, 4500K and 6000K. In this way we get twelve set of reaction time. Each set contains six values.

5.3.2 Contrast Measurement: Contrast is the difference between target luminance and background luminance. If the target luminance is higher than the background luminance then the contrast is said to be positive. If the background luminance is greater than the target luminance then it is called negative luminance. The concept of contrast is totally dependent upon luminance value of target and its background. To measure luminance of the target and background in every main source and peripheral source CCT, luminance meter is used. The formulation to calculate contrast is as follows

$$\Delta L = L_T - L_b$$

To measure the luminance, we use Konica Minolta Luminance Meter LS 100. Firstly, we use a 9 volt battery for power supply of the device. Then we use a tripod for positioning the luminance meter. The height of the luminance meter's lens after mounting to the tripod is 0.83 meter.

Then we positioned the whole setup exactly where the participant was sitting. The height of the luminance meter kept low to reduce the angle α.

Then setup is done for the environment of laboratory. At first the main source value is set at 3000K and peripheral source also set at 3000K. After that object is placed at another position.

By seeing through the luminance meter, the target is brought under focus. By pressing the trigger, luminance value of the object can be seen. Thus, we get the target luminance.

Then the object is put aside and luminance meter is focused on the position where the object was on. After that the cube is bring back to the position again. Then a laser is pointed on the top of the cube and after stabilization of the laser the cube is put aside keeping the laser fix. The point on the ground is marked where the laser is pointing. This point is now brought into the focus of luminance meter and luminance is measured.

The above process is repeated for all six positions in this lighting scene.

Then the peripheral CCT is changed to 4500K using the mobile application and CL-70F. And repeat the process to measure luminance. Like this we change peripheral source value to 6000K.

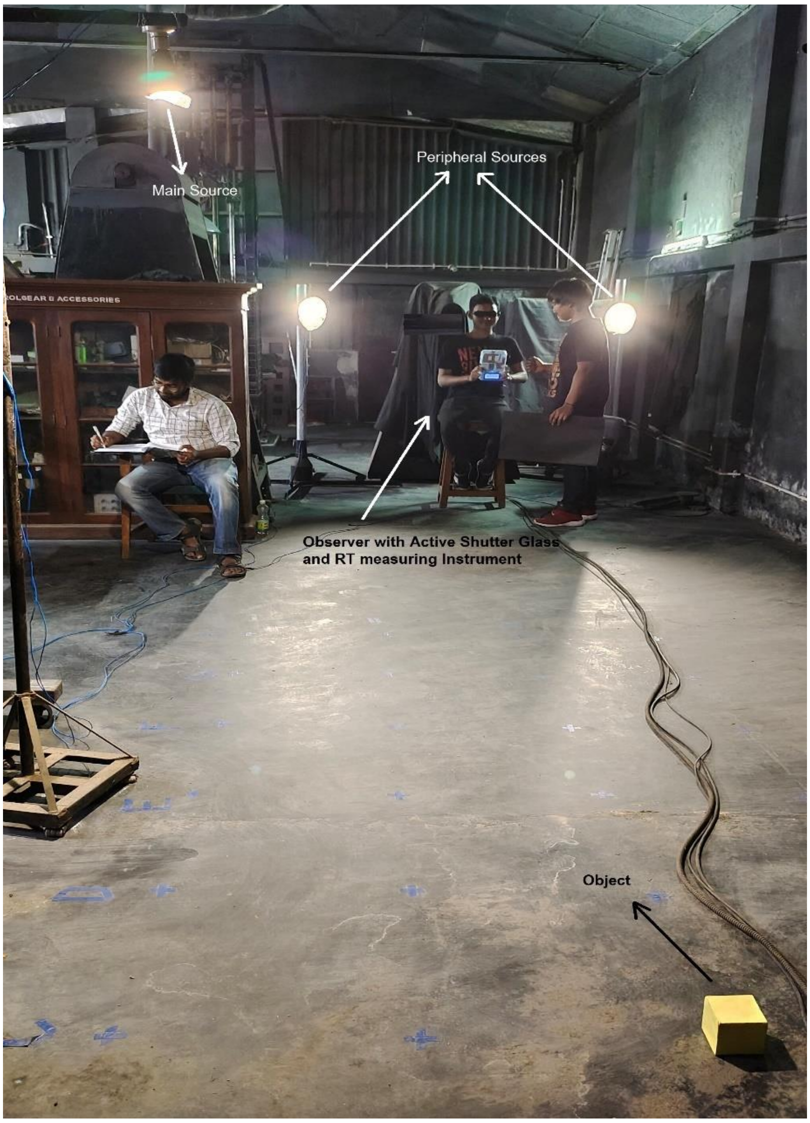


Fig 5.11 Experiment Environment

The experiment is done in twelve lighting scenes. The main source CCT is changed four times i.e., 3000K, 4000K, 5000K and 6000K. For every main source CCT peripheral CCT is changed three times i.e., 3000K, 4500K and 6000K.

In this way we get twelve set of luminance values. And in each set, we get eighteen luminance value. These values are kept in a excel sheet for later calculation.

The distance between luminance meter and object (for each position) is also measured by fluke laser distance meter. This data is also important to calculate Visibility Level.

5.3.3 Algorithm behind the calculation of STV

Small Target Visibility (STV) is a weighted average of the values of target Visibility Level over a grid of points on an area of roadway for one direction of traffic flow. Visibility Level (VL) for a target at a point for one viewing point and direction is the amount above the visibility threshold as seen by the observer. Visibility Level (VL) is a ratio and has no units.

To calculate STV for a grid of points and one direction of traffic flow, VL and Relative Weighted VL (RWVL) must be calculated for each point on the grid using the following steps.

Step 1 is to determine the target location at a grid point and the viewing position and direction as viewed by an observer located at a distance of 15 meters. The observer is an adult (20 years) with normal eyesight whose fixation time is 0.7 second. The target is an 8 cm by 8 cm square flat surface perpendicular to the road surface and to a horizontal line from the observer's position. The target reflects light in a Lambertian manner with a reflectance of 0.37.

Target luminance (L_t) is calculated for one point at the centre of the target. Background luminance (L_{b1}) is calculated at a point on the pavement adjacent to the centre of the bottom of the target, that is, the target's position on the floor. Background luminance (L_{b2}) is calculated at a point beyond the target, on a line projected from the observer's point of view through the point at the centre of the top of the target. L_{b1} and L_{b2} are each calculated, as if the observer were one degree above the plane of the floor. Background luminance (L_b) for the target is calculated in this document as the average of L_{b1} and L_{b2}:

$$L_b = (L_{b1} + L_{b2}) / 2$$

The values L_t and L_b are then used, together with constants for the target size, observer age, and fixation time, to calculate visibility level (VL).

Step 2 is the determination of the adaptation luminance (L_a), the Log_{10} of La (LL_a), and the visual angle (A) in minutes subtended by the target:

$L_a = L_b + L_v$ (Since we have done this experiment in a controlled environment so there is no veiling luminance L_V)

$LL_a = Log10(L_a)$

$A = \tan^{-1}$ (Target size / Distance observer to target) * 60

For the standard Target Size of 0.08 meters on a side and Distance of Observer to Target of 15 meters, "A" is 18.33 minutes.

Step 3 is the determination of the sensitivity of the visual system as a function of adaptation luminance. This is done by using one of three equations depending on the value of L_a:

If La = > 0.6

then $F = [\text{Log}_{10}(4.2841 * L_a^{\ 0.1556}) + (0.1684 * L_a^{0.5867})]^2$

and $L = (0.05946 * L_a^{0.466})^2$

If $L_a > 0.00418$ and $L_a < 0.6$

then $F = 10^{\{2*[(0.0866*LL_a^2)+(1.055*LL_a)-0.072]\}}$

and $L = 10^{[2*(0.319*LL_a-1.256)]}$

If La < 0.00418

then $F = 10^{(0.346*LL_a+0.056)}$

and $L = 10^{[(0.0454*LL_a^2)+(0.3372*LL_a)-1.782]}$

Step 4 is to calculate a number of intermediate functions using the following equations:

$B = \text{Log}_{10}(A) + 0.523$

$C = LL_a + 6$

$AA = 0.360 - \{(0.0972 * B^2)/[B^2 - (2.513 * B) + 2.789]\}$

$AL = 0.355 - \{0.1217 * [C^2/(C^2 - (10.40 * C) + 52.28)]\}$

$$AZ = \sqrt{\frac{(AA)^2 + (AL)^2}{2.1}}$$

$$DL_1 = 2.6[\frac{\sqrt{F}}{A} + \sqrt{L}]^2$$

Step 5 is to calculate M by one of three equations depending on the value of LL_a and determine the value of a negative contrast adjustment factor (FCP). Note that FCP is not accurate when LL_a is less than -2.4 (La, the adaptation luminance, less than 0.00418 cd/m2). In practice such low levels of adaptation are never encountered with negative contrast:

If LL_a > -2.4 and < -1

Then $M = 10^{-10^{-\{[0.075*(LL_a+1)^2]+0.0245\}}}$

If LL_a > = -1

Then $M = 10^{-10^{-\{[0.125*(LL_a+1)^2]+0.0245\}}}$

If LL_a < or = -2.4

Then FCP = 0.5 (TGB and FCP need not be calculated)

$TGB = -0.6(L_a)^{-0.1488}$

$$FCP = 1 - [\frac{(M)(A)^{TGB}}{2.4(DL_1)(AZ+2)/2}]$$

Step 6 is to adjust DL in accordance with the time of observation (T) which for this document is a constant 0.7 seconds:

$DL_2 = DL_1 * [(AZ + T)/T]$

Step 7 is to calculate the adjustment (FA) for the age of the observer (TA) and then adjust DL accordingly. TA is 60 years in this document:

If age is < or = 64

then $FA = [(TA - 19)^2/2160] + 0.99$

If age is over 64

then $FA = [(TA - 56.5)^2/116.3] + 1.43$

$DL_3 = DL_2 * FA$

Step 8 is to calculate the adjustment if the target is darker than the background (negative contrast):

If Lt is less than Lb

then $DL_4 = DL_3 * FCP$

or else $DL_4 = DL_3$

Step 9 is to calculate VL:

$VL = (L_t - L_b)/DL_4$

Step 10 is to calculate the relative weighted visibility level RWVL.

Visibility Level values are typically both positive and negative over an area on the roadway. A magnitude less than 1.0 (positive or negative) indicates that the target is below threshold for a standard observer who is allowed a fixation time of 0.7 seconds. Very large VL values indicate that the target is easier to see or can be seen faster, but a VL of 9.5 at one point and a VL of 0.5 at another are not equivalent to two points with a VL of 5. Relative Weighted VL is used so that large VL values are not counted as heavily as small ones in the computation of the summary of target visibility (STV).

$$RWVL = 10^{[- 0.1 * ABS(VL)]}$$

the Final Steps After all RWVL values are calculated for all grid points, calculate the Average RWVL:

ARWVL = (Sum of all RWVL)/ (Number of points in the grid)

Finally, calculate the Weighted Average VL, also known as Small Target Visibility or STV:

$STV = \text{Weighted Average VL} = -10 * \text{Log}_{10}(ARWVL)$

5.3.4 Calculation of data using Computer Programming

The above calculations have to be done for each grid point and for each main source and Peripheral CCT combination. So, a Java Script has been developed to automate the calculation. The calculation would be more accurate in this way. The program commands are described in appendix 2.

Chapter 6

Results

The target luminance, background luminances are measured by Luminance meter. Reaction time of the subjects are measured and averaged. After getting all the data VL and STV are calculated for each road lighting scenes. Then the data is tabulated for data analysis. The following table shows all the measured and calculated data.

Sl No.		Main CCT(K)	Peripheral CCT(K)	Pos.	L_a (Cd/m^2)	L_{b1} (Cd/m^2)	L_{b2} (Cd/m^2)	RT (sec)	VL	STV
1	a)	3000	3000	B-2	2.82	0.471	0.267	0.27	47.26811736	33.81924027
				B-3	2.439	0.434	0.285	0.3	42.11448603	
				B-4	2.089	0.372	0.256	0.12	26.27309431	
				C-2	3.5	0.6	0.432	0.26	49.05159002	
				C-3	3.05	0.55	0.374	0.32	48.43997389	
				C-4	2.38	0.511	0.348	0.79	46.12823504	
	b)		4500	B-2	2.857	0.467	0.246	0.26	48.5100563	37.84851701
				B-3	2.594	0.417	0.306	0.26	43.01164235	
				B-4	2.096	0.368	0.365	0.3	34.63803074	
				C-2	3.56	0.64	0.53	0.18	39.52727634	
				C-3	3.416	0.572	0.387	0.22	47.46221719	
				C-4	2.459	0.524	0.381	0.22	33.49244323	
	c)		6000	B-2	2.907	0.493	0.25	0.18	41.73166645	39.60972938
				B-3	2.654	0.428	0.206	0.22	45.46111533	
				B-4	2.299	0.382	0.229	0.38	47.14489621	
				C-2	4.074	0.595	0.446	0.23	55.66644911	
				C-3	3.359	0.519	0.398	0.32	54.52512547	
				C-4	2.271	0.53	0.328	0.24	32.71384682	
2	a)	4000	3000	B-2	2.847	0.431	0.267	0.26	49.02214803	38.25340625
				B-3	2.666	0.416	0.233	0.46	56.24365993	
				B-4	2.033	0.369	0.292	0.32	36.7796692	
				C-2	3.834	0.61	0.399	0.22	52.23630257	
				C-3	3.025	0.59	0.382	0.2	39.24362298	
				C-4	2.672	0.518	0.308	0.14	32.61832326	
	b)		4500	B-2	2.967	0.46	0.256	0.22	47.52958287	45.98624868
				B-3	2.716	0.439	0.231	0.36	52.85422401	
				B-4	2.18	0.36	0.191	0.26	42.34401247	
				C-2	3.785	0.716	0.422	0.3	52.27813547	
				C-3	3.323	0.527	0.421	0.3	51.53791136	
				C-4	2.684	0.527	0.35	0.3	42.43216303	
	c)		6000	B-2	3.044	0.47	0.324	0.26	48.41469855	23.51868634
				B-3	2.7	0.46	0.241	0.26	46.03009557	
				B-4	2.367	0.364	0.291	0.26	41.41352365	
				C-2	2.903	0.583	0.411	0.26	40.41658048	
				C-3	3.401	0.597	0.405	0.26	48.5222962	
				C-4	2.563	0.536	0.342	0.05	15.77254731	

Sl No		Main CCT(K)	Peripheral CCT(K)	Pos.	L_a (Cd/m^2)	L_{b1} (Cd/m^2)	L_{b2} (Cd/m^2)	RT (sec)	VL	STV
3	a)	5000	3000	B-2	2.855	0.429	0.322	0.24	45.46146838	30.00064194
				B-3	2.445	0.438	0.242	0.22	39.45147785	
				B-4	2.07	0.412	0.201	0.3	38.88105571	
				C-2	3.56	0.742	0.404	0.26	46.18391587	
				C-3	3.053	0.574	0.425	0.22	40.31820552	
				C-4	2.5	0.528	0.356	0.09	22.50974027	
	b)		4500	B-2	3.975	0.483	0.277	0.14	52.05435912	43.58530448
				B-3	2.781	0.427	0.25	0.18	42.28609807	
				B-4	2.297	0.38	0.271	0.34	43.71070444	
				C-2	3.846	0.638	0.409	0.34	58.83748904	
				C-3	3.414	0.521	0.387	0.22	49.34858751	
				C-4	2.562	0.533	0.339	0.26	38.47666219	
	c)		6000	B-2	3.055	0.422	0.366	0.22	46.00959288	40.36191731
				B-3	2.749	0.455	0.242	0.14	36.43187037	
				B-4	2.255	0.374	0.264	0.22	37.51192468	
				C-2	3.994	0.67	0.419	0.18	47.7913201	
				C-3	3.457	0.564	0.448	0.22	46.24953698	
				C-4	2.844	0.498	0.379	0.22	40.86901292	
4	a)	6000	3000	B-2	3	0.399	0.281	0.15	42.26759341	32.85295348
				B-3	2.643	0.4	0.182	0.2	46.0761559	
				B-4	2.16	0.371	0.231	0.42	45.46128138	
				C-2	3.742	0.569	0.392	0.26	55.85960491	
				C-3	3.167	0.556	0.376	0.14	36.49602141	
				C-4	2.629	0.534	0.344	0.1	25.57274397	
	b)		4500	B-2	3.086	0.426	0.282	0.32	56.87014267	27.2577131
				B-3	2.779	0.418	0.229	0.14	38.76004615	
				B-4	2.22	0.364	0.243	0.18	35.11978938	
				C-2	3.832	0.682	0.414	0.24	50.69939543	
				C-3	3.445	0.587	0.424	0.05	20.21466215	
				C-4	2.27	0.551	0.37	0.2	28.81780097	
	c)		6000	B-2	3.029	0.45	0.319	0.1	31.79066758	34.24632911
				B-3	2.777	0.443	0.248	0.1	30.96034531	
				B-4	2.209	0.43	0.273	0.27	36.78086174	
				C-2	4.003	0.715	0.415	0.09	32.75472035	
				C-3	3.272	0.55	0.388	0.2	44.20985102	
				C-4	2.811	0.488	0.348	0.34	48.20753306	

Table No. 3 Measured and Calculated Data

The data achieved here are in tabulated form. In order to analyse relation between VL, STV with CCT properly it is necessary to obtain graphical representation. In the next chapter the graphs have been plotted.

Chapter 7

Data Analysis

After obtaining the data in tabular form CCT vs STV graphs have been plotted.

The graphs plotted here are of two types. Firstly, taking a constant peripheral source CCT, changing STV with respect to CCT of main source are plotted.

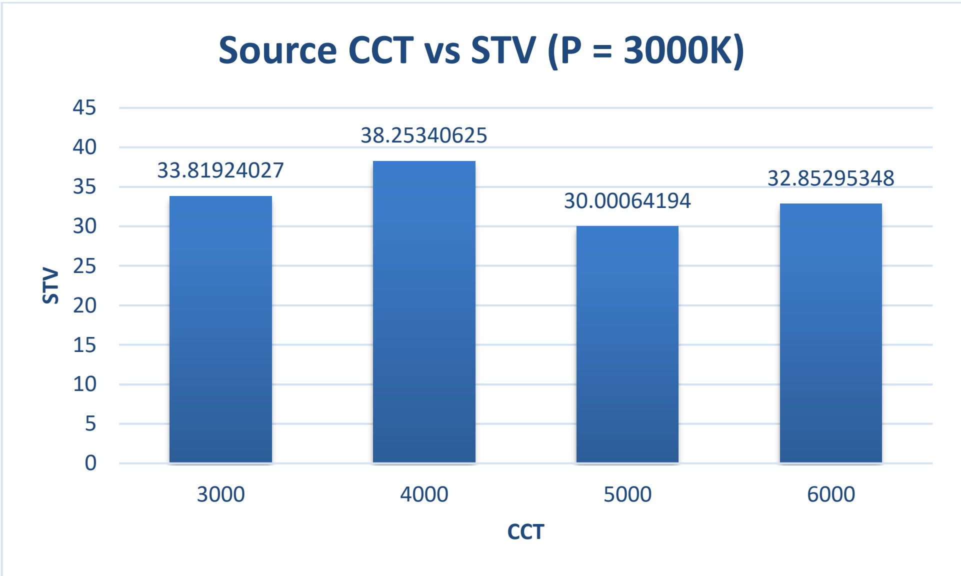


Fig 6.1 Source CCT vs STV (P = 3000K)

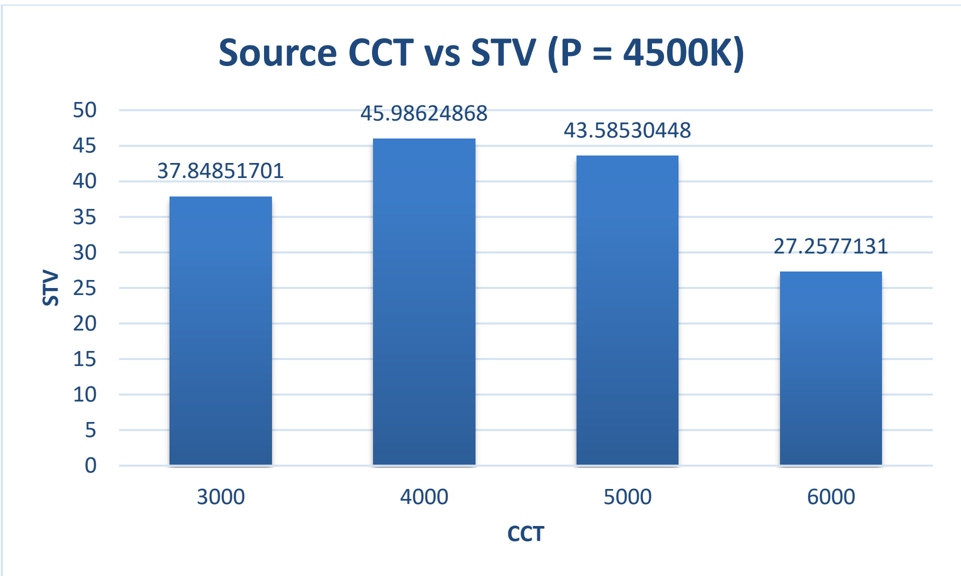


Fig 6.2 Source CCT vs STV (P = 4500K)

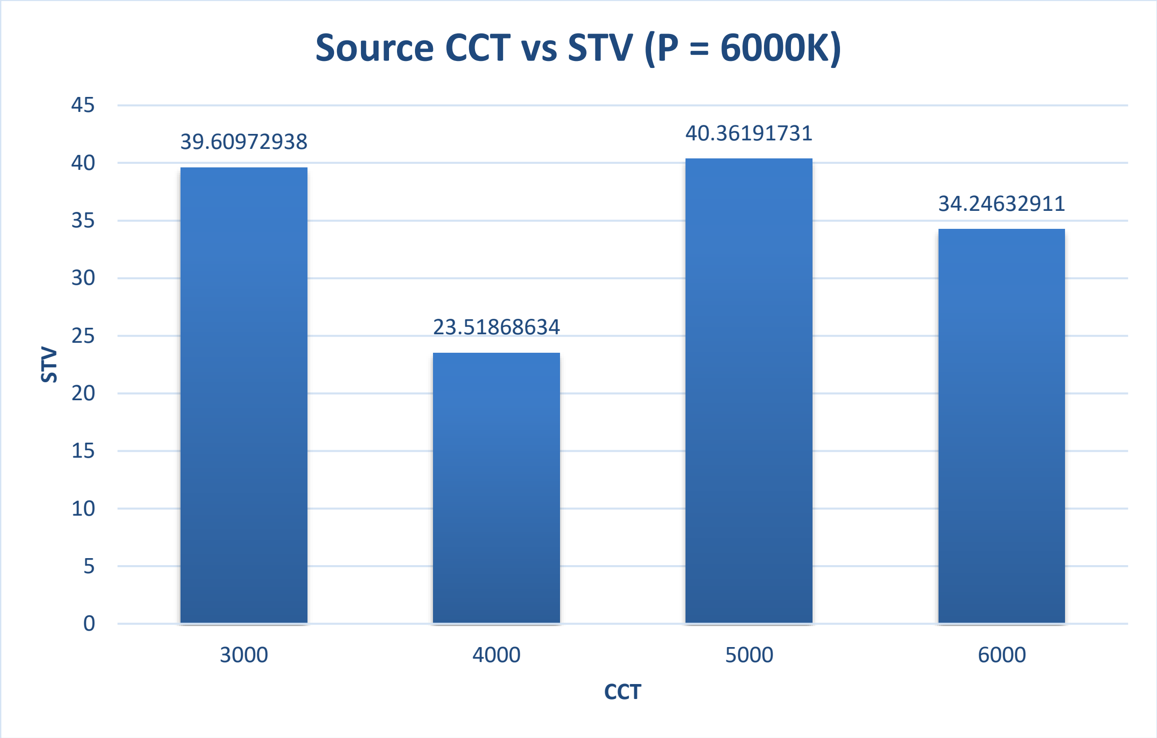


Fig 6.3 Source CCT vs STV (P = 6000K)

From these graphs it can be clearly seen that the main source CCT 4000K to 5000K gives the best STV

In the second type of graph main source CCT is kept constant and changing STV with respect to CCT of peripheral source are plotted.

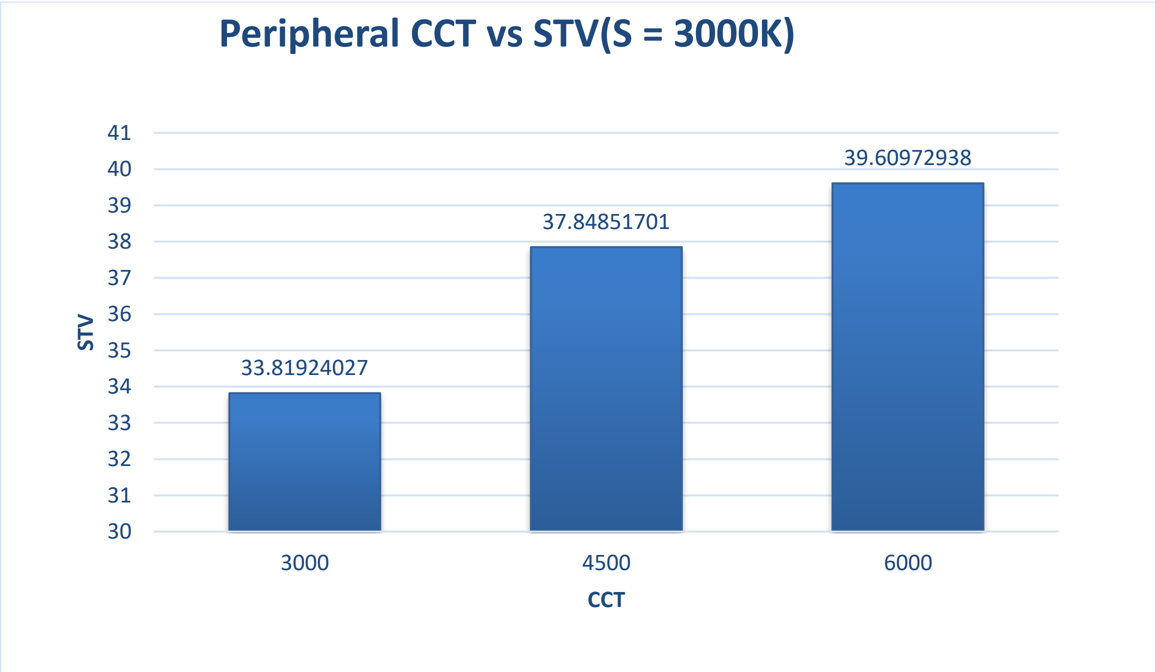


Fig 6.4 Peripheral CCT vs STV (P = 3000K)

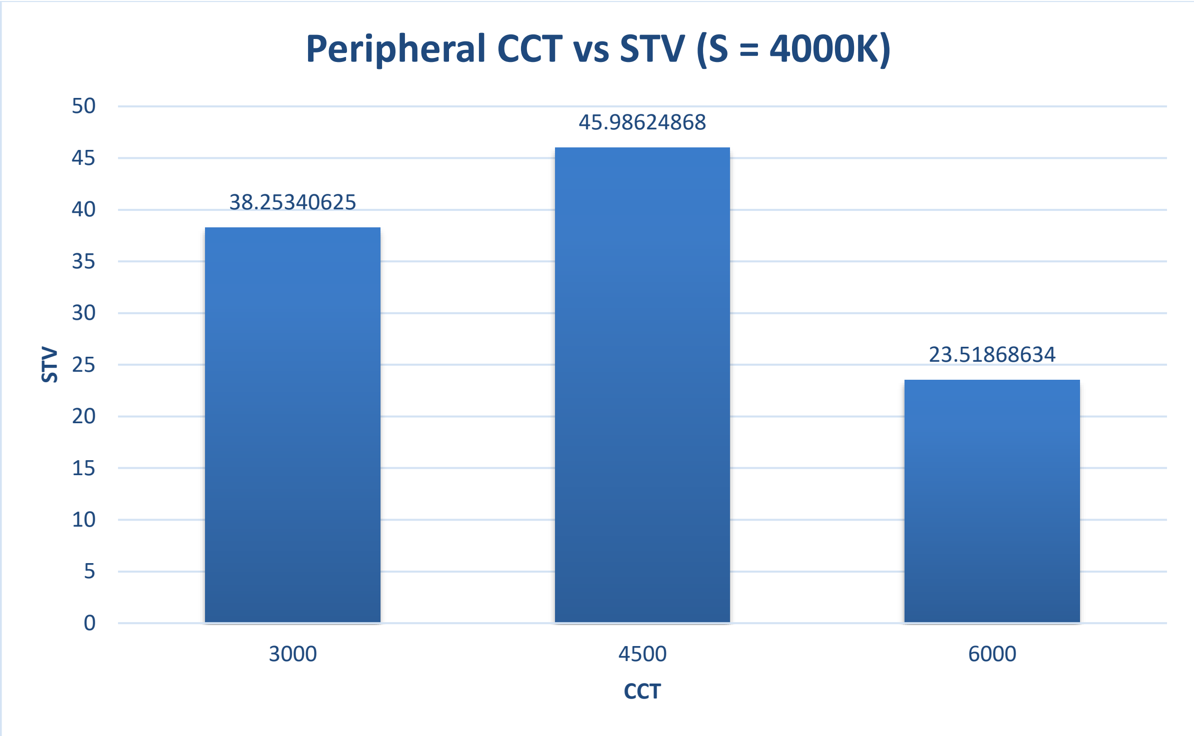


Fig 6.5 Source CCT vs STV (P = 4000K)

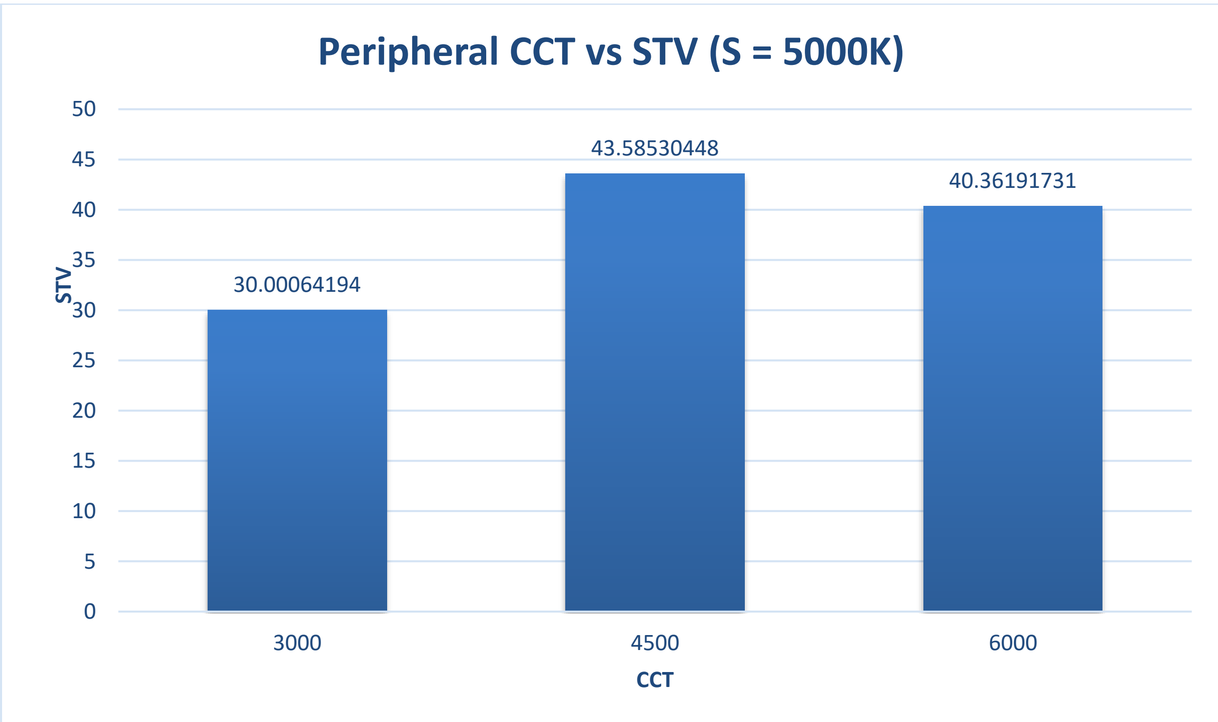


Fig 6.6 Source CCT vs STV (P = 5000K)

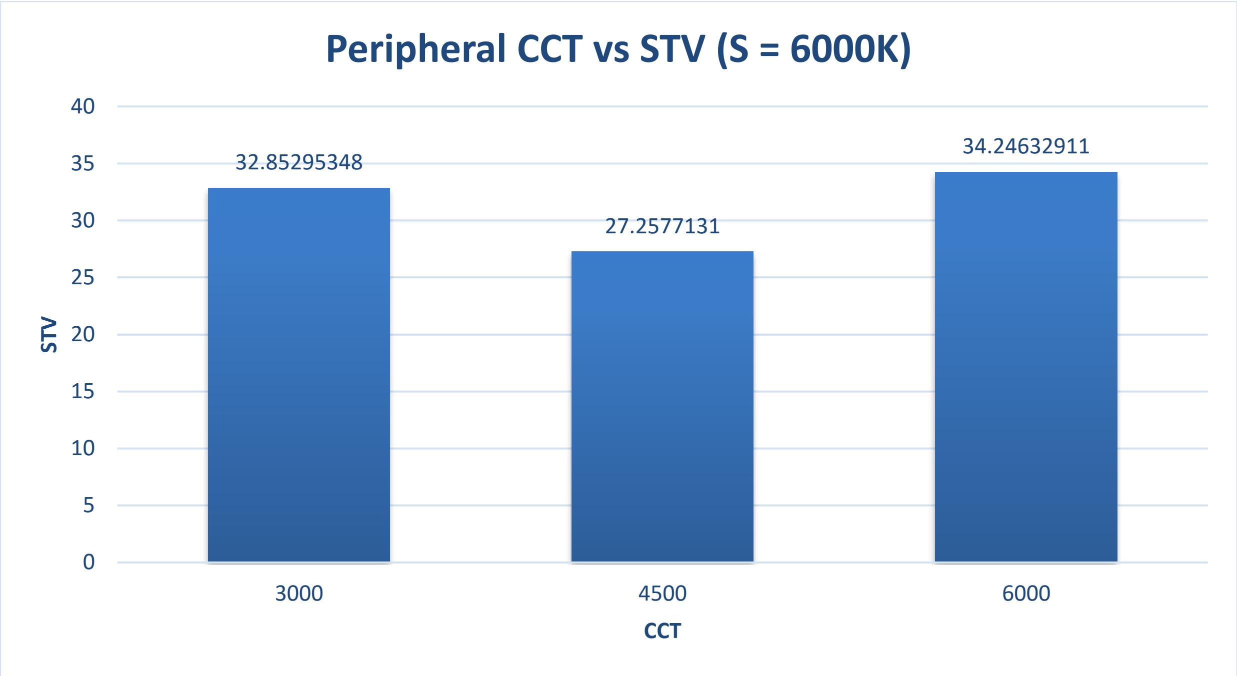


Fig 6.7 Source CCT vs STV (P = 5000K)

From these above graphs it is observed that 4500K to 6000K CCT gives the best values of CCT.

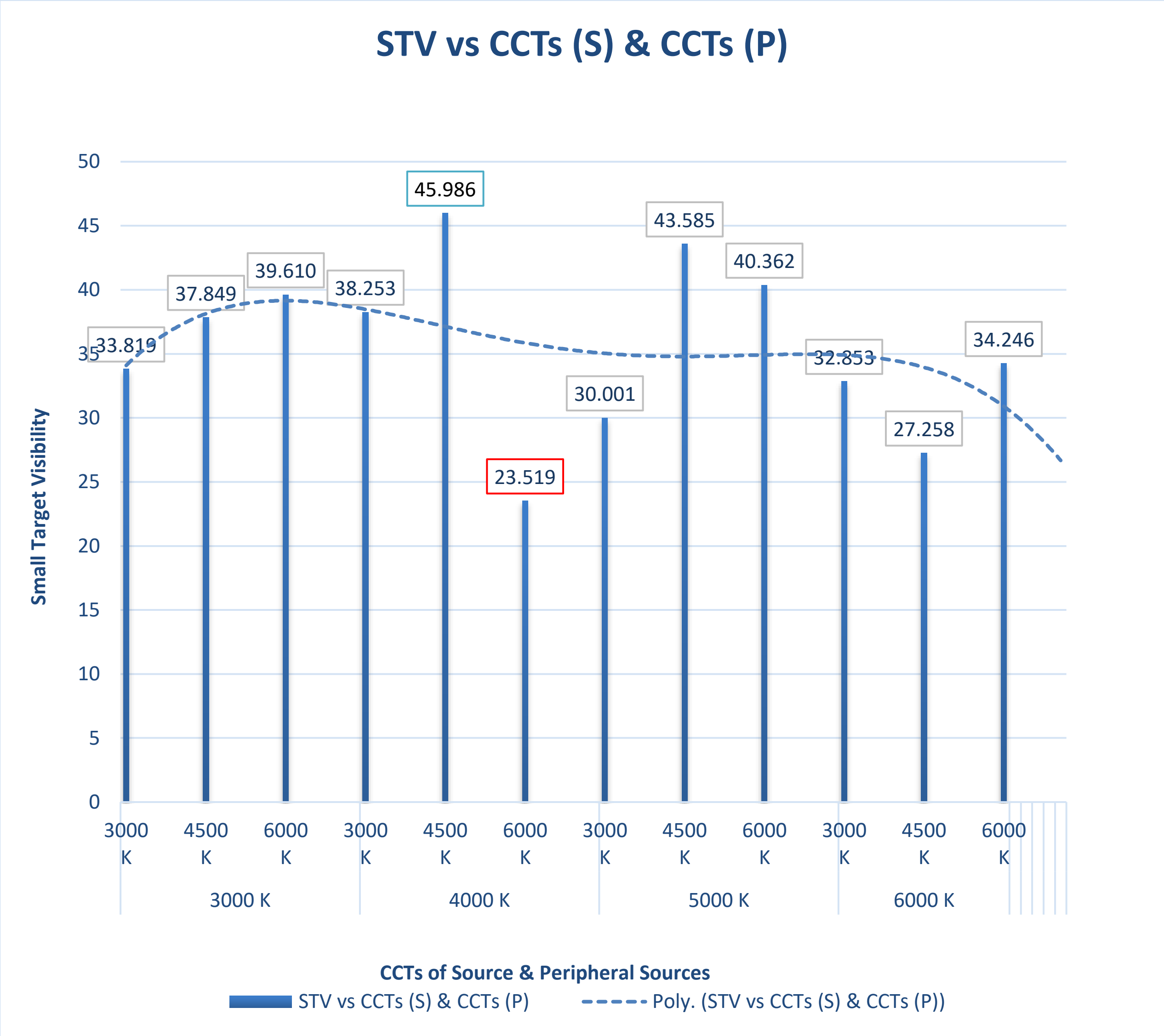


Fig 6.8 STV vs Sources CCTs and Peripheral CCTs

The above graph is the conjugated graph of all peripheral and main source CCT. X-axis shows the peripheral and source CCT values and Y-axis shows the STV values.

It is found in the result that there is a clear relation between CCT and visibility level as well as STV. This study indicates that CCT increases overall eye adoption level of human observer. Higher CCT levels improve STV. The highest STV of value 45.986 acquired from the main source CCT level of 4000 K and peripheral CCT of 4500 K.

Chapter 7

Conclusions

And

Future Scope

Night time road accident is a huge concern to the world. Even though the lighting system evolved tremendously in the last few decades, there is no significant changes in road lighting standards. Sustainability is another problem largely discussed now a days. Energy efficiency does not means only reducing the number of luminaires or reducing illuminance. In the road lighting context, human factors must be included. Both the safety of drivers and pedestrian must be the foremost priority of road lighting. Keeping in mind the safety of users the energy saving steps should be taken. Human centric parameters like visibility level must be incorporated in terms of designing road lighting.

But the main question arises here is which parameter is suitable for road lighting design. There are a few studies done on this purpose. Here in this study, it is attempted to establish CCT as a lighting parameter by small target visibility named human centric method for road lighting design. In this experimental approach it is tried to find the most appropriate CCT for the visibility level for driver as well as the pedestrians.

The visibility level and small target visibility calculated for different combination of CCT of the main and peripheral sources. Each combination is referred as different lighting scene for road lighting. As both on-axis source and peripheral sources play a crucial role for human vision it was necessary to control their CCT individually.

In the study it was proved that small target visibility and visibility level have definitely a relation with correlated colour temperature of street lights. It is found that the more CCT is the better for visibility level.

The best small target visibility of 45.986 is achieved when the main source CCT is 4000K and the peripheral CCT is 4500K. The second best STV is achieved at source 5000K and peripheral 4000K CCT. Talking about the lowest STV, it is obtained at source CCT 4000K and peripheral CCT 6000K and the value is 23.518. From this it is learned that combination of higher CCT of source and peripheral is required to get the best result in terms of STV.

The difference in higher and lower level of CCT is higher CCT have more blue light in it. So it can be said that blue light increase alertness in human.

So, from this we can conclude that in a street if the street lights have higher CCT the driver’s object detection can be improved and thereafter the number of night time accidents can be minimized.

The experiment is done in a controlled laboratory environment where all other parameters like veiling luminance are not considered. In future the experiment should be done in actual roadways for better understanding of CCT and VL, STV relation. The parameters like veiling luminance, glare can be incorporated. A moving target can be simulated instead of a fixed target. The CCT can be varied within a long range and short gap. Then the effect of CCT can be fully understand.

In order to get best reaction time and drivers muscle movement Electroencephalography based method is the best way. In the EEG method of analysis there are a number of electrodes which take brain signal from different nodes. Then the signals are amplified and separated into features. By analysing those features it can be very much possible to directly get the point when brain detect the object. So, it is a more accurate method.

If a particular CCT level for a perfect STV is found that can be act as a guideline for road lighting design.

The human centric approach has more depth in it. If smart system can be connected with HCL a proper lighting condition can be approach. There is a relation of vehicle number with luminance value as well as STV. An integrative system can be developed to detect the number of vehicles and the road lights CCT can also be adjusted accordingly. This is a scope for future study and an opportunity for better road lighting system.

References

1) Commission Internationale de l'E´ clairage. Lighting of Roads for Motor and Pedestrian Traffic. CIE 115:2010. Vienna: CIE, 2010.
2) British Standards Institution EN13201-1:2014. Road Lighting. Part 1: Guidelines on Selection of Lighting Classes. London: BSI, 2014.
3) British Standards Institution EN13201-2:2015. Road Lighting. Part 2: Performance Requirements. London: BSI, 2015.
4) Illuminating Engineering Society of North America. ANSI IESNA RP-8, Recommended Practice on Roadway Lighting. New York, NY: IESNA, 2014.
5) British Standards Institution BS 5489-1:2013. Code of Practice for the Design of Road Lighting Part 1: Lighting of Roads and Public Amenity Areas. London: BSI, 2012.
6) M. Peden, Richard S, D. Sleet, D. Mohan, A. A. Hyder, E. Jarawan, C. Mathers. World Report on Road Traffic Injury Prevention. World Health Organization, 2004.
7) Transport Research Wing. Ministry of Road Transport and Highways. Govt. of India. Road Accidents in India – 2019.
8) 'Street Lighting Programme lights up 50000 km roads with 3 million LEDs'; Energy World; Economic Times; 20/8/17; PTI
9) Commission International de l'E´ clairage. Calculation and Measurement of Luminance and Illuminance in Road Lighting. CIE 30.2:1982. Vienna: CIE, 1982. (Note: superseded by CIE 140:2000).
10) Illuminating Engineering Society of North America. ANSI IESNA RP-8, Recommended Practice on Roadway Lighting. New York, NY: IESNA, 1983.
11) Smart Cities: Optimize Street lighting in India; Devavrat Kulkarni; Analytics India Magazine; 7/4/2016
12) A History of Street Lighting in the Old and New Towns of Edinburgh World Heritage Site. Khrystyna Shakhmatova, Krzysztof Jan Chuchra, Steve Francey, original research by Andrew Kerr, February, 2012.
13) British Standard Specification 307: Street Lighting. 1927.
14) Jolley LBW, Waldram JM, Wilson GH. The Theory and Design of Illuminating Engineering Equipment. London: Chapman and Hall Ltd., 1930.
15) Waldram JM. The development of street lighting in Great Britain. Transactions of the Illuminating Engineering Society 1950; 15: 285–313.

16) MS Rea, MG Figueiro, JD Bullough, Circadian photobiology: an emerging framework for lighting practice and research. Lighting Res. Technol. 34,3 (2002) pp. 177–190
17) KW Houser, PR Boyce, JM Zeitzer, M Herf. Human-centric lighting: Myth, magic or metaphor?. Lighting Res. Technol. 2020; 0: 1–22.
18) International Association of Lighting Designers (IALD), LightingEurope. Joint position paper on Human Centric Lighting. February, 2017.
19) Commission Internationale de l’E´ clairage. Lighting of Roads for Motor and Pedestrian Traffic. CIE 115:2010. Vienna: CIE, 2010.
20) Gibbons R, Guo F, Medina A, Terry T, Du J, Lutkevich P, Corkum D, Vetere P. Report no. FHWA HRT 14 050. Guidelines for the Implementation of Reduced Lighting on Roadways. Virginia Polytechnic Institute and State University, Blacksburg: Federal Highway Administration, 2014.
21) Commission International de L’E´ clairage. Recommended System for Visual Performance Based Mesopic Photometry. CIE 191:2010. Vienna: CIE, 2010.
22) Adrian W. Visibility of targets: Model for calculation. Lighting Research and Technology 1989; 21: 181–188.
23) Önder Güler, Sermin Onaygil Evaluation of Visibility Level Formula in Road Lighting with Field Measurements
24) Fotios S, Castleton H. Specifying enough light to feel reassured on pedestrian footpaths. Leukos 2016; 12: 235–243.
25) Fotios, S. and Cheal, C.: Obstacle detection: A pilot study investigating the effects of lamp type, illuminance and age, Light. Res. Technol., 41-4, pp. 321–342 (2009).
26) Akashi Y, Rea MS, Bullough JD. Driver decision making in response to peripheral moving targets under mesopic light levels. Lighting Research and Technology 2007; 39: 53–67.
27) He Y, Rea M, Bierman A, Bullough J. Evaluating light source efficacy under mesopic conditions using reaction times. Journal of the Illuminating Engineering Society 1997; 26: 125–138.
28) Hills BL. Visibility under night driving conditions: Part 3. Lighting Research and Technology 1976; 8: 11–26.
29) Menard J, Cariou J. Road lighting: Assessment of an installation based on the contrast of a standard target. Lighting Research and Technology 1994; 26: 19–22.
30) Buyukkinaci B, Onaygil S, Guler O, Yurtseven MB. Determining minimum visibility levels in different road lighting scenarios. Lighting

Research and Technology. First published 17 May 2017. DOI: 1477153517709868.
31) Rakesh Biswas, Suddhasatwa Chakraborty, Pratik Nath. Laboratory Based EEG Study to Investigate the Influence of Light Sources on Brain Processing for Detection of Object Designed with Metal Halide and High-pressure Sodium Lamp. Journal of Science and Technology in Lighting Vol.41, 2017.
32) Suddhasatwa Chakraborty, Debtanu Ray, Ishan Palit. An EEG based comparative study on driver's performance under the influence of metal halide and high pressure sodium lighting. Optik - International Journal for Light and Electron Optics 245 (2021) 167676
33) Buyukkinaci B, Onaygil S, Guler O, Yurtseven MB. Determining minimum visibility levels in different road lighting scenarios. Lighting Research and Technology. First published 17 May 2017. DOI: 1477153517709868.
34) Illuminating Engineering Society of North America, ANSI IESNA RP-8. Recommended Practice on Roadway Lighting. New York, NY: IESNA, 2000.
35) S Fotios, R Gibbons. Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations. Lighting Res. Technol. 2018; Vol. 50: 154–186.
36) Fotios, S. and Cheal, C.: Obstacle detection: A pilot study investigating the effects of lamp type, illuminance and age, Light. Res. Technol., 41-4, pp. 321–342 (2009).
37) H. Steffan, Accident Investigation – Determination of Cause. Encyclopaedia of Forensic Sciences, Second ed., Elsevier Ltd, 2013, pp. 405–413.
38) T.A. Salthouse, Reaction Time. 2007 Elsevier Inc. All rights reserved, in: This Article Is Reproduced from the Previous Edition, vol. 2, Elsevier Inc, 1996, pp. 377 – 380
39) Juri D. Kropotov, Psychometrics and Neuropsychological Assessments. Functional Neuromarkers for Psychiatry, Elsevier Ltd, 2016.
40) Brémond, Roland, Vanessa Bodard, Eric Dumont, and Anaïs Nouailles-Mayeur. "Target visibility level and detection distance on a driving simulator." Lighting Research & Technology 45, no. 1 (2013): 76-89.

41) Dijk, Derk-Jan, and Charles A. Czeisler. "Contribution of the circadian pacemaker and the sleep homeostat to sleep propensity, sleep structure, electroencephalographic slow waves, and sleep spindle activity in humans." Journal of Neuroscience 15, no. 5 (1995): 3526-3538.
42) Campbell, Scott S., Derk-Jan Dijk, Ziad Boulos, Charmane I. Eastman, Alfred J. Lewy, and Michael Terman. "Light treatment for sleep disorders: Consensus report: III. Alerting and activating effects." Journal of biological rhythms 10, no. 2 (1995): 129-132.
43) Scheer, F. A. J. L., and Ruud M. Buijs. "Light affects morning salivary cortisol in humans." Journal of Clinical Endocrinology and Metabolism 84 (1999): 3395-3398.
44) Ruger, Melanie, Marijke CM Gordijn, Domien GM Beersma, Bonnie de Vries, and Serge Daan. "Time-of-day-dependent effects of bright light exposure on human psychophysiology: comparison of daytime and nighttime exposure." American Journal of Physiology-regulatory, integrative and comparative physiology 290, no. 5 (2006): R1413-R1420.
45) Kaida, Kosuke, Masaya Takahashi, and Yasumasa Otsuka. "A short nap and natural bright light exposure improve positive mood status." Industrial health 45, no. 2 (2007): 301-308.
46) Vandewalle, Gilles, Sophie Schwartz, Didier Grandjean, Catherine Wuillaume, Evelyne Balteau, Christian Degueldre, Manuel Schabus et al. "Spectral quality of light modulates emotional brain responses in humans." Proceedings of the National Academy of Sciences 107, no. 45 (2010): 19549-19554.

Appendix 1

❖ Different Instruments and light source used in the experiment

Luminance meter: Luminance meter Konica Minolta LS 100 is a portable meter for taking luminance measurements of light source as well as objects and surfaces. This meter is extremely accurate because it has advanced optics and electronics. The device has a 1˚ acceptance angle which is clearly marked in the lens. The optical system reduces flare, so that the measurements are virtually unaffected by light outside the indicated measurement area. Although our experiment has been done in a controlled environment, so there was a very little influence of stray lights. The silicon photocell measures the light receives by the lens and is filtered to match CIE relative Photopic Luminosity response. Then the signal is processed by the processor and luminance is measured. The measured value is displayed in both external display and viewfinder display.

CRI Illuminance Meter: Konica Minolta CL-70F is a measuring instrument to measure illuminance, color temperature and color rendering index of various illuminance source such as LEDs and fluorescent lamps. We used this instrument mainly to measure the color temperature and SPD. The sensor used here is CMOS linear image sensor. It has a spectral wavelength of 380 nm to 780 nm. It has a utility software of communicate with PC. The date recorded by the instrument is being extracted by this software.

Response Time measuring Device: This device we made in our laboratory. The device consists of two parts.

Active Shutter Glass and its control device gives the subject a 0.7 sec of time to detect the object. The glass itself have liquid crystals in it which become opaque when voltage is applied, otherwise transparent. Its control device has a 555 timer IC which act as a monostable multivibrator. It gives 9 volts to the glass but after pressing the push button it turns of the supply to the glass for a span of 0.7 sec. This gives a time of 0.7 sec to the subject for seeing the object.

There is also a timer circuit which record the time of the subject's response. It contains a Arduino Microcontroller and a LCD screen.

The device works like this way, when the start push button is pressed the shutter glass become transparent and a timer starts counting in microsecond. After recognizing the object the subject press the stop button which stops the timer.

Halonix Smart LED Bulb: It is a Wi-Fi enabled 12 watt smart bulb. It can be plug in to a B-22 holder. The bulb can be controlled using a mobile application. It can be illuminated in over a million color. It also has ability to change white color from warm to cool. The CCT can be varied from 2500 K to 6000 K. The intensity or brightness can also be controlled using the mobile application.

Fluke Distance Meter: This is a laser distance meter. This can measure distance, calculate area and also volume. It can measure maximum 60 meters. We used the distance meter to measure distance from luminance meter to the object.

Appendix 2

❖ Java Script used to calculate data

```
import java.math.*;

import java.util.Scanner;


public class Atanu {

    public static void main(String[] args) {

        float dist,height,lt,lb1,lb2,target_size,lb,lla,la,F,
L,B,C,AA,AL,AZ,DL1,DL2,DL3,DL4,FA,TGB,FCP,RT,TA,M,VL,RWVL;

        F = 0;

        L = 0;

        FCP = 0;

        Scanner sc = new Scanner(System.in);

        System.out.println("Enter LT");

        lt = sc.nextFloat();

        System.out.println("enter target size");

        target_size = sc.nextFloat();

        System.out.println("enter distance");

        dist = sc.nextFloat();

        float temp = (float) Math.atan(target_size/dist);

        System.out.println(temp);

        float A = (float)
(Math.atan(target_size/dist)*60*180/3.14);

        System.out.println("A = "+A);

        System.out.println("enter lb1");

        lb1 = sc.nextFloat();

        System.out.println("enter lb2");
```

```
        lb2 = sc.nextFloat();
        lb = (lb1+lb2)/2;
        System.out.println("lb = "+lb);
        lla = (float) Math.log10(lb);
        System.out.println("lla = "+lla);
        la = lb;
        System.out.println("Enter reaction time RT");
        RT = sc.nextFloat();
        System.out.println("Enter age");
        TA = sc.nextFloat();
        if(la>=0.6){
        F = (float)
Math.pow(Math.log10(4.2841*Math.pow(la,0.1556))+
                (0.1684*Math.pow(la,0.5867)),2);
            L = (float)
Math.pow(0.05946*Math.pow(la,0.466),2);
        }
        else if(la > 0.00418 && la < 0.6){
            F = (float) Math.pow(10,2*(0.0866*Math.pow(lla,2)+
                (0.3372*lla)-0.072));
            L = (float) Math.pow(10,2*(0.319*lla-1.256));
        }
        else if (la<0.00418){
            F = (float) Math.pow(10,(0.346*lla+0.056));
            L = (float) Math.pow(10,0.0454*Math.pow(lla,2) +
                (1.055*lla)-1.782);
        }
        System.out.println("F = "+F);
```

```
System.out.println("L = "+L);
B = (float) (Math.log10(A)+0.523);
C = lla+6;

AA = (float) (0.360 - ((0.0972*Math.pow(B,2))/
             (Math.pow(B,2)-(2.513*B)+2.789)));
AL = (float) (0.355 - (0.1217*(Math.pow(C,2))/
             (Math.pow(C,2)-(10.40*C)+52.28)));
AZ = (float) Math.pow((Math.pow(AA,2)+Math.pow(AL,2))/
             2.1,0.5);
DL1 = (float) (2.6*Math.pow((Math.pow(F,0.5)/A)+
             Math.pow(L,0.5),2));

System.out.println("B = "+B);
System.out.println("C = "+C);
System.out.println("AA = "+AA);
System.out.println("AL = "+AL);
System.out.println("AZ = "+AZ);
System.out.println("DL1 = "+DL1);



DL2 = DL1 * ((AZ+RT)/RT);

System.out.println("DL2 = "+DL2);

if(TA<64){
    FA = (float) ((Math.pow(TA-19,2)/2160)+0.99);
```

```
}
else{
 FA = (float) ((Math.pow(TA-56.5,2)/116.3)+1.43);
}

System.out.println("FA = "+FA);
DL3 = DL2 * FA;
System.out.println("DL3 = "+DL3);
TGB = (float) (-0.6*Math.pow(la,-0.1488));
System.out.println("TGB = "+TGB);
if (lla > -2.4 && lla < -1){
    M = (float) Math.pow(10,-Math.pow(10,-
         (0.075*Math.pow(lla+1,2))+0.0245));
    FCP = (float) (1- ((M*Math.pow(A,TGB)) /
           (2.4*DL1*(AZ+2)/2)));
}
else if(lla>=-1){
    M = (float) Math.pow(10,-Math.pow(10,-
         (0.125*Math.pow(lla+1,2))+0.0245));
    FCP = (float) (1- ((M*Math.pow(A,TGB)) /
         (2.4*DL1*(AZ+2)/2)));
}
else if(lla<=-2.4){
    FCP = 0.5F;
}
System.out.println("FCP = "+FCP);
```

```
        if(lt<lb){
            DL4 = DL3*FCP;
        }
        else
            DL4 = DL3;

        System.out.println("DL4 = "+DL4);
        VL = (lt-lb)/DL4;

        RWVL = (float) Math.pow(10,-0.1*VL);
        System.out.println("vl value is "+VL);
        System.out.println("rwvl value is "+RWVL);
    }
}
```