STUDIES ON THE EFFECT OF THE CORRELATED COLOUR TEMPERATURE ON HUMAN TASK PERFORMANCE- AN ANALYTICAL APPROACH

A THESIS
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR A DEGREE OF

MASTER OF ENGINEERING
IN
ILLUMINATION ENGINEERING

SUBMITTED BY

SADDAM HUSSAIN

EXAMINATION ROLL NO.- M4ILN22020

REGISTRATION NO.–154043 of 2020-2021

UNDER THE SUPERVISION OF

Dr. SUDDHASATWA CHAKRABORTY

Assistant Professor, Jadavpur University

ELECTRICAL ENGINEERING DEPARTMENT

FACULTY OF ENGINEERING AND TECHNOLOGY

JADAVPUR UNIVERSITY

KOLKATA –700032

AUGUST, 2022

JADAVPUR UNIVERSITY
FACULTY OF ENGINEERING AND TECHNOLOGY
ELECTRICAL ENGINEERING DEPARTMENT

RECOMMENDATION CERTIFICATE

This is to certify that the thesis entitled **“STUDIES ON THE EFFECT OF CORRELATED COLOUR TEMPERATURE ON HUMAN TASK PERFORMANCE- AN ANALYTICAL APPROACH”** submitted by **SADDAM HUSSAIN**, (Examination Roll No. **M4ILN22020,** Registration No.**154043 of 2020-2021)** of this University in partial fulfilment of requirements for the award of the degree of Master Of Engineering in Illumination Engineering, Department of Electrical Engineering, is a bonafide record of the work carried out by him under my guidance and supervision.

____

(Thesis supervisor)
SUDDHASATWA CHAKRABORTY
Assistant Professor
Electrical Engineering Department
Jadavpur University
Kolkata-700032

____

PROF. SASWATI MAZUMDAR
Head of the Department
Electrical Engineering Department
Jadavpur University
Kolkata: 700032

____

PROF. CHANDAN MAZUMDAR
Dean
Faculty of Engineering and Technology
Jadavpur University
Kolkata: 700032

JADAVPUR UNIVERSITY
FACULTY OF ENGINEERING AND TECHNOLOGY
ELECTRICAL ENGINEERING DEPARTMENT

CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering, carried out and presented by **SADDAM HUSSAIN**, in a manner of satisfactory warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned does not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

FINAL EXAMINATION FOR EVALUATION OF THESIS

BOARD OF EXAMINERS

……………………………………

……………………………………

……………………………………..
(Signature of Examiners)

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

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 thesis rules and conduct, I have fully cited and referenced all material and results which are not original to this work.

NAME	**:**	**SADDAM HUSSAIN**
EXAMINATION ROLL NO.	**:**	**M4ILN22020**
REGISTRATION NO.	**:**	**154043 of 2020-2021**
THESIS TITLE	**:**	**"STUDIES ON THE EFFECT OF THE CORRELATED COLOUR TEMPERATURE ON HUMAN TASK PERFORMANCE- AN ANALYTICAL APPROACH".**
SIGNATURE WITH DATE	**:**	

ACKNOWLEDGEMENT

I take this opportunity to express my deep sense of gratitude and indebtedness to **Dr. Suddhasatwa Chakraborty**, Assistant Professor, Department of Electrical Engineering, Jadavpur University, Kolkata, without his mission and vision, this project would not have been possible.

I would like to acknowledge my sincere thanks to **Dr. Biswanath Roy**, Professor of Illumination Engineering, Electrical Engineering Department, Jadavpur University, Kolkata and, **Sangita Sahana**, Assistant Professor of Illumination Engineering, Electrical Engineering Department, Jadavpur University for their constant guidance and supervision. I would also like to thank them for providing me with their valuable time and helpful suggestions.

I would like to acknowledge my sincere gratitude to **Prof. (Dr.) Saswati Mazumdar**, Head of the Department (HOD) of Electrical Engineering Department, Jadavpur University, Kolkata for providing me with the opportunity to carry out my project work in Illumination Engineering Laboratory, Jadavpur University.

I am also thankful to **Mr. Pradip Pal** of the Illumination Engineering Laboratory for his co-operation during my project work.

A special thanks to **Subhajit Dutta**, who has contributed immensely to the successful completion of the experiment. He has been a constant source of motivation and a strict criticizer of my work improving the quality of the work.

At last, I want to convey my thanks to **Joy Das**, and **Souran Sadhukhan** who helped me directly in completing my thesis successfully.

Last but not least, I wish to convey my gratitude to my parents, whose love, teachings and support have brought me this far…

Place: Jadavpur University
Kolkata, 700032

SADDAM HUSSAIN

Date:

Abstract

Regarding both the psychological and physiological needs of the tenant, correlated colour temperatures (CCT) of the light source in an interior setting are crucial. CCTs are of particular relevance since they are one of the factors that determine illumination quality, which has an impact on the standard of work, learning in the classroom and any critical human work or performance.

The aim of this study is to determine the effects of warm white light (WWL) (CCT = 2500K), and cool white light (CWL) (CCT = 6500K) on the performance, subjective alertness level, and visual comfort level of human. A controlled laboratory experiment was carried out on a total of 15 participants who agreed to take part in a series of tests using two distinct CCTs, namely, 2500K and 6500K of white light sources. Performance on the visual task was evaluated using Landolt's ring chart.

In comparison to the 2500K CCT condition, a considerable improvement in the time response of detection (64 sec) was seen under the 6500K CCT condition. Respondents did much better in terms of fewer time taken under 6500K CCT than 2500K CCT for counting the right Landolt's ring chart, and fewer mistakes. Under 6500K CCT, followed by 2500K CCT, errors were made at the lowest rates. The data were then statistically analysed, and the response time and error ratings under the 2500K CCT and 6500K CCT were plotted on a single factor ANOVA. Under 6500K CCT lighting, the ANOVA results showed that the response time and error were significantly lesser ($F = 9.192472$, p-value 0.001) and ($F = 7.692015$, p-value 0.001).

Therefore, it was determined that the lighting condition best suited for enhancing human task performance is 6500K CCT of the white led light.

Additionally, an EEG-based study had been carried out for the same experiment set up but the correlated colour temperature was 4500 K. This was done to check the brain activity under such lighting conditions.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER-1

1 INTRODUCTION

1.1What is Light?

Light is simply a veritable small part of the electromagnetic spectrum, squeezed between ultraviolet and infrared radiation. The visible portion of the electromagnetic spectrum extends from about 380 to about 780 nanometers. This part of the electromagnetic spectrum is called visible light. Visible light is the most important part of the electromagnetic spectrum because it allows seeing any object. Radiation in this region is absorbed into human eyes and causes them to send signals to the brain. Human brains then interpret these signals as images. **IESNA** defines light as "radiating energy that excites the retina and produces a visual sensation". Lighting can do so much further than illuminating. It can enhance form and function, enhance safety and security and produce flexible spaces that adjust to the task at hand. This definition makes sense because human see things by shining light on them. Humans do not see the light itself. [1]

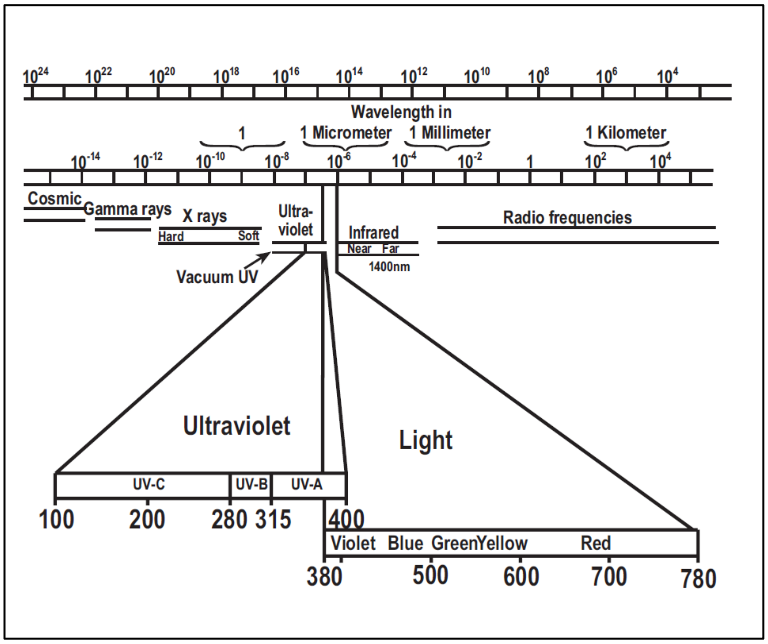


Figure (1.1)- *The Electromagnetic Spectrum*

1.2 Definition of Colour

The visual perception feature known as colour corresponds to the categories red, green, blue, and other colours in humans. The interaction between the spectral sensitivities of the light receptors in the eye and the light spectrum (distribution of light energy versus wavelength) is what gives light its colour (Brodie, n.d.). Light waves of various durations that reflect off material, alive, and inanimate objects create the seven colours of the spectrum (Marberry, 1995, p. 15). Colour and light simply depend on vibrational frequency. This connection is studied by chromatics, the science of colour (Graham, 1990). [2]

From 380 nm to 760 nm, the little range of Electromagnetic spectrum that the human eye can see. All wavelengths of colour are produced by sunlight. Human eyes see colour when they translate the light wavelengths reflected from an object (Day & Rich, 2009). Wright (2008) defines colour as, “colour is light, which travels to us in waves from the sun, on the same electromagnetic spectrum as radio and television waves, microwaves, x-rays etc.” Over 7 million different colours may be distinguished by the human eye. These colours are derived from the fundamental components of primary, secondary, and tertiary colours.

Primary Colours: Red, blue, and yellow are the three fundamental colours that make up primary colours (Aves & Aves, 1994). These colours are the foundation for all the various shades of colours that they produced and cannot be produced by mixing other colours. Black is the only colour that results from mixing the fundamental colours equally.

Secondary Colours: These colours are produced by combining two primary colours in an equal proportion. There are three secondary hues: violet (a mixture of red and blue), orange (a mixture of blue and yellow), and green (a mixture of red and yellow).

Tertiary Colours: By combining an equal ratio of primary and secondary colours, tertiary colours are created. There are six tertiary colours: lime, which is a combination of green and yellow; purple, which is a combination of violet and red; saffron, which is a combination of orange and red; lavender, which is a combination of violet and blue; amber, which is a combination of yellow and orange; and turquoise, which is a combination of green and blue.

1.3 Colour and the Spectrum: Their relationship

Only a limited section of the electromagnetic spectrum—between 380 and 780 nanometers—can be seen by the human eye. Cone cells and rod cells, two different types of photo-receptors found inside the eye, transform radiation in this range into electrical signals that are sent to the brain. Cone photoreceptors also translate light into colour based on the wavelength of the light. Colour is not a property of light that is inherent; rather, it is a result of the brain's interpretation of the signals from the cones. While the human eye can detect light with shorter wavelengths (between 400 and 480 nm), the brain perceives these as "blue." Through the visible spectrum, as wavelength increases, the corresponding colour changes continuously from "green" to "yellow" to "orange" to "red." The difference in light radiation wavelengths is what causes us to perceive colour. [1] The colour of visible light can vary depending on its wavelength, which can range from 380 nm to 780 nm (Figure 1.3).

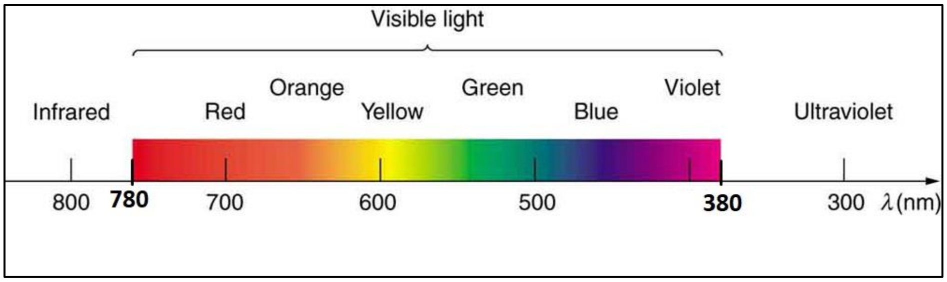


Figure (1.3)*: Figure of colour variation according to wavelength*

1.4 Spectral Sensitivity

The human visual system's sensitivity varies from wavelength to wavelength between 380 nm and 780 nm. Additionally, the spectral sensitivity of the eyes differs from person to person, and as age increasing, the eyes' visual strength also weakens. Cone and rod photoreceptors, which make up the two types of photoreceptors in the human eye, have varied spectral sensitivity ranges at various brightness levels. The term "photopic vision" refers to the type of vision that results from the activation of cone cells at luminance/brightness levels of more than 3 cd/m2. Rod cells are active when the luminance/brightness level is less than 0.1 cd/m2, which is called scotopic vision. Mesopic vision is the term for the condition that occurs between photopic and scotopic vision, and its luminance/brightness level ranges from 0.1 to 3 cd/m2. Cone cell sensitivity peaks at 683 lm/W at 555 nm in the yellowish-green spectrum (photonic vision). In contrast, the sensitivity of rod cells (scotopic vision) peaks at 1700 lm/w at 507 nm, in the bluish-green portion of the colour spectrum depicted in (figure 1.4.1). [2]

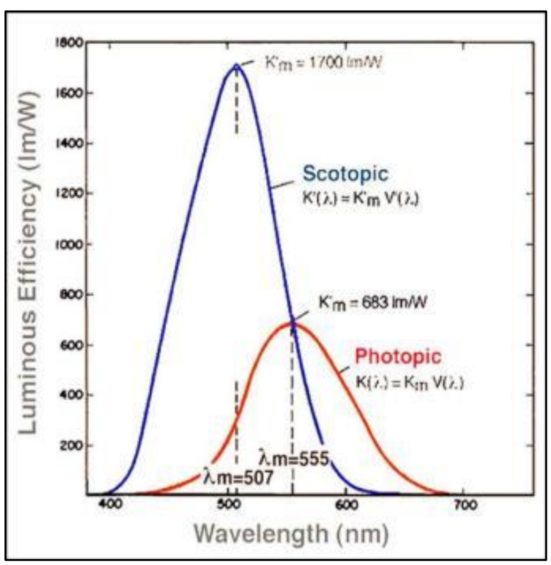


Figure (1.4.1)*: Figure of Photopic Vision and Scotopic Vision*

The luminous efficacy functions V (λ) and V ′(λ), which are determined by a standard photopic observer and a scotopic observer, respectively, have been introduced by the CIE

(Commission Internationale de l'Eclairage). These efficiency functions are normalised to 1 or 100% at their highest level. The CIE standard observers' comparative sensitivity ranges are shown in (Figure 1.4.2).

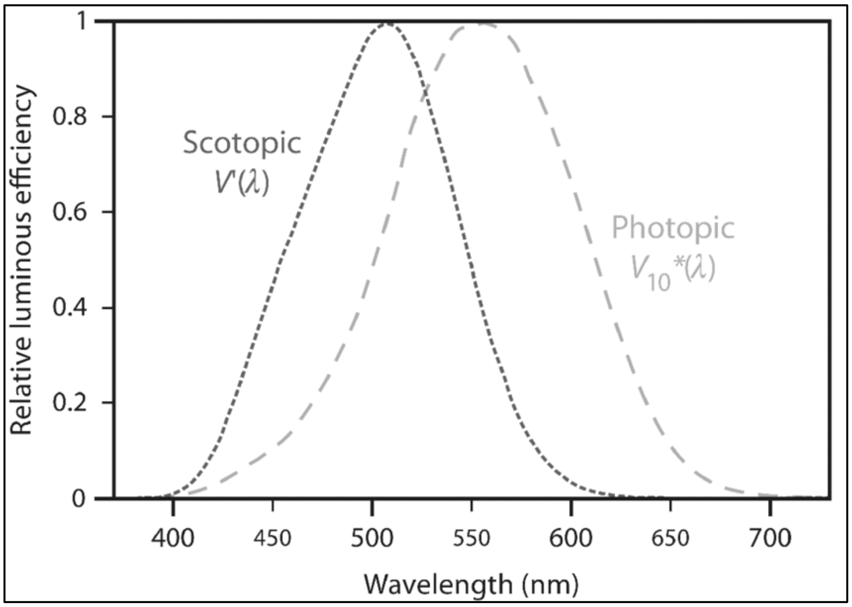


Figure (1.4.2)*: Relative CIE standard Photopic and Scotopic luminous efficacy functions*

1.5 CIE Colour Space and Chromaticity Diagram

The CIE 1931 colour spaces contain the earliest discovered quantitative correlations between the distributions of electromagnetic visible spectrum wavelengths and physiologically perceived colours in human colour vision. The mathematical relationships that define these colour spaces are crucial colour management tools for working with coloured inks, lit screens, and recording devices like digital cameras. The system was developed in 1931 by the "CIE". [23]

The CIE colourimetry system's cornerstone is colour matching. The CIE Colour Matching Functions, which are the comparative spectrum sensitivity curves of the human observer with normal colour vision, serve as another example of a standard observer. The mathematical structures known as CIE colour matching functions represent the relative spectral sensitivity required to ensure that all wavelength combinations that are perceived as having the same colour occupy the same position in the CIE colourimetry system and that all wavelength combinations that are perceived as having a different colour occupy different positions. (Figure 1.5.1) displays two sets of colour matching functions. The colour matching function values at various wavelengths make up the spectral tristimulus values. [24][25]

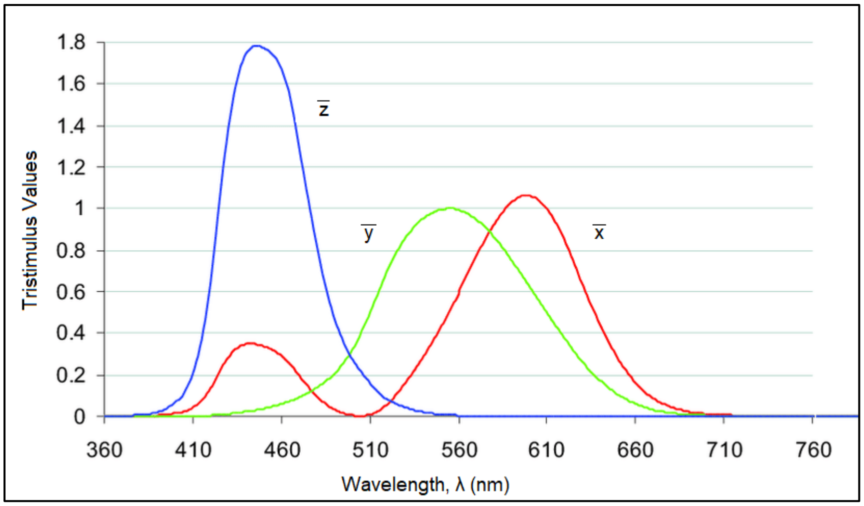


Figure (1.5.1): *The CIE Colour Matching or Tristimulus Value of CIE 1931 Standard Observer*

By multiplying the spectral power distribution of the light source by each of the three colour-matching functions x(λ), y(λ), and z(λ) wavelength by wavelength, as shown in the equation below, one can determine the amounts of the three fictitious primary colours X, Y, and Z required to match the colour of the light source. Equations for X, Y, and Z are represented by:

$$X = h\sum s\,(\lambda)x(\lambda)\lambda$$

$$Y = h\sum s\,(\lambda)y(\lambda)\lambda$$

$$Z = h\sum s\,(\lambda)z(\lambda)\lambda$$

where:-

S(λ) = spectral radiant flux of the light source (W/nm)

x(λ), y(λ), z(λ) = spectral tristimulus values from the appropriate colour matching function

λ = wavelength interval(nm)

h = arbitrary constant.

Once the X, Y, and Z values have been determined, the next step is to express each value as a percentage of the total, i.e.

$$x = \frac{X}{(X+Y+Z)}$$

$$y = \frac{Y}{(X+Y+Z)}$$

$$z = \frac{Z}{(X + Y + Z)}$$

The three numbers x, y, and z are known as the CIE chromaticity coordinates. Since (x + y + z) = 1, just two of the coordinates are required to define the chromaticity of a colour. By convention, the x and y coordinates are used. Since colour can be specified by two coordinates, all colours can be represented on a two-dimensional surface. (Figure 1.5.2) shows the CIE 1931 chromaticity diagram. The spectrum locus is the outer, curving edge of the CIE 1931 chromaticity diagram. All wavelength-only or pure colours fall under this curve. The deepest purples can be found along the purple boundary, which is a line that connects the ends of the spectrum. The equal energy point, which is the figure's centre, has a colourless surface. A curve that is near the equal energy point is known as the Planckian locus. The chromaticity coordinates of objects that behave as black bodies are covered by this curve, which means that the light source's temperature alone affects its spectral power distribution. The CIE 1931 chromaticity diagram can be compared to a map that depicts the locations of distinct colours in relation to one another. [26] The saturation of a colour increases as the chromaticity coordinates shift from the equal energy point toward the spectrum locus. The hue of a colour depends on the direction in which the chromaticity coordinates move. The CIE 1931 chromaticity diagram, which provides an approximate indication of how a colour would appear, is an important tool (CIE Publication 107:1994). In order for signal lights and surfaces to be recognised as red, green, yellow, and blue, it supplies chromaticity coordinate bounds. The CIE 1931 chromaticity diagram is not consistent with the human eye. While green colours are dispersed over a large area, red colours are concentrated in the bottom right corner. Due to this apparent non-uniformity, any attempt to measure large colour variations using the CIE 1931 chromaticity diagram is futile.

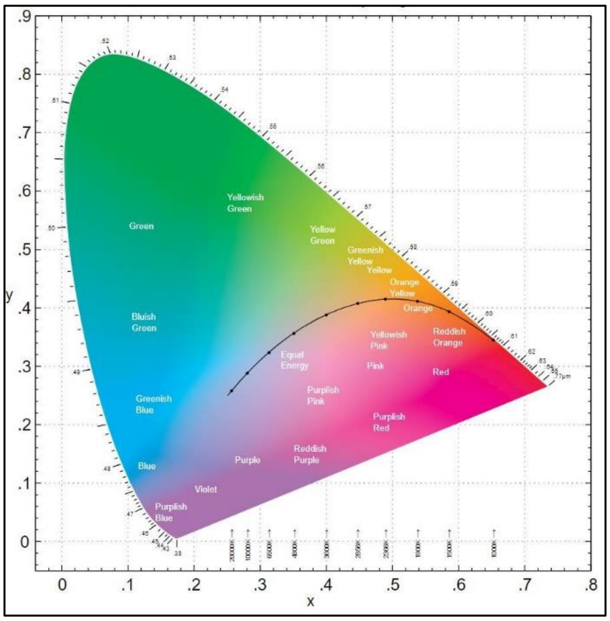


Figure (1.5.2): *The CIE 1931 Chromaticity Diagram Showing the Spectrum Locus, The Planckian Locus*

In an effort to address this issue, the CIE first introduced the CIE 1960 Uniform Chromaticity Scale (UCS) diagram and subsequently, in 1976, promoted the adoption of the CIE 1976 UCS diagram. Both representations just linearly alter the CIE 1931 chromaticity diagram. The formulas are on the axes of the CIE 1976 UCS diagram.

$$u' = \frac{4x}{(-4x + 12y + 3)}$$

$$v' = \frac{9y}{(-4x + 12y + 3)}$$

where x and y are the chromaticity coordinates from CIE 1931. The CIE 1976 UCS diagram is shown in (figure 1.5.3). [27]

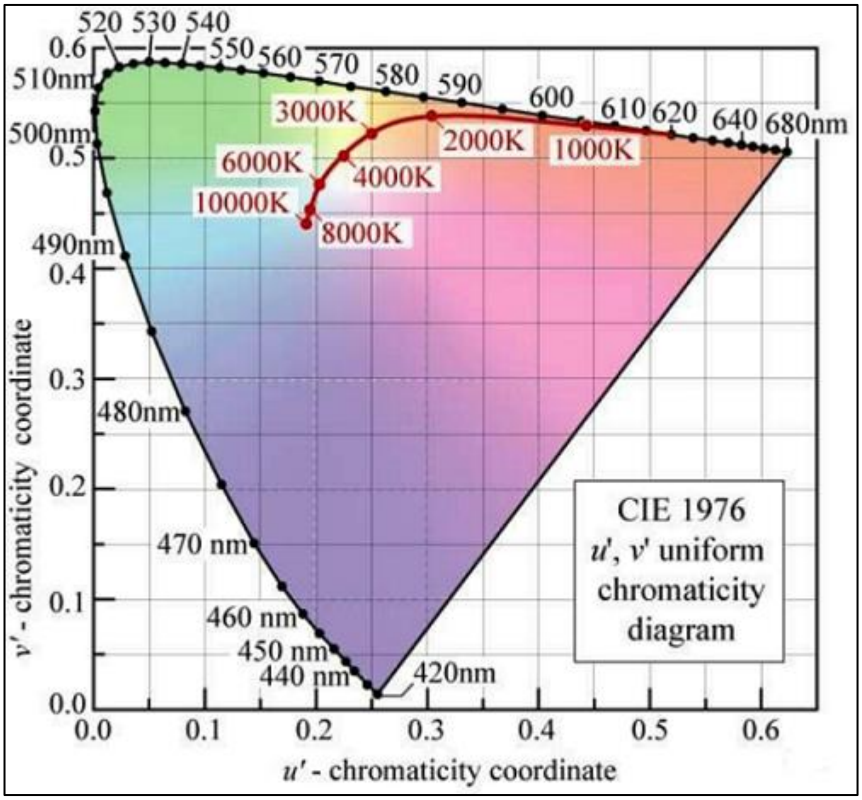


Figure (1.5.3): *The CIE 1976 Uniform Chromaticity Scale Diagram*

1.6 Correlated Colour Temperature From CIE1931 Chromaticity Diagram

Although the CIE colourimetry system is the most accurate way to measure colour, it is complicated. The lighting industry has therefore developed two single-number metrics to describe the colour characteristics of light sources using the CIE colourimetry methodology. The associated colour temperature is a measure used to describe how a light source's light seems to be coloured. This measurement's basis is the fact that a black body's spectral power distribution is only dependent on temperature because it is determined by Planck's Radiation Law.

A portion of the CIE 1931 chromaticity diagram is given in (Figure 1.6.1), along with the Planckian locus. The curving line connecting the chromaticity coordinates of black bodies at various temperatures is known as the locus. It is iso-temperature lines that intersect the Planckian locus. When a light source's CIE 1931 chromaticity coordinates fall exactly on the Planckian locus, the colour temperature—that is, the temperature of the black body with the same chromaticity coordinates—expresses the colour appearance of that light source. The associated colour temperature, or the temperature of the iso-temperature line that is closest to the actual chromaticity coordinates, is used to quantify the colour appearance of light sources that have chromaticity coordinates close to the Planckian locus but not on it.

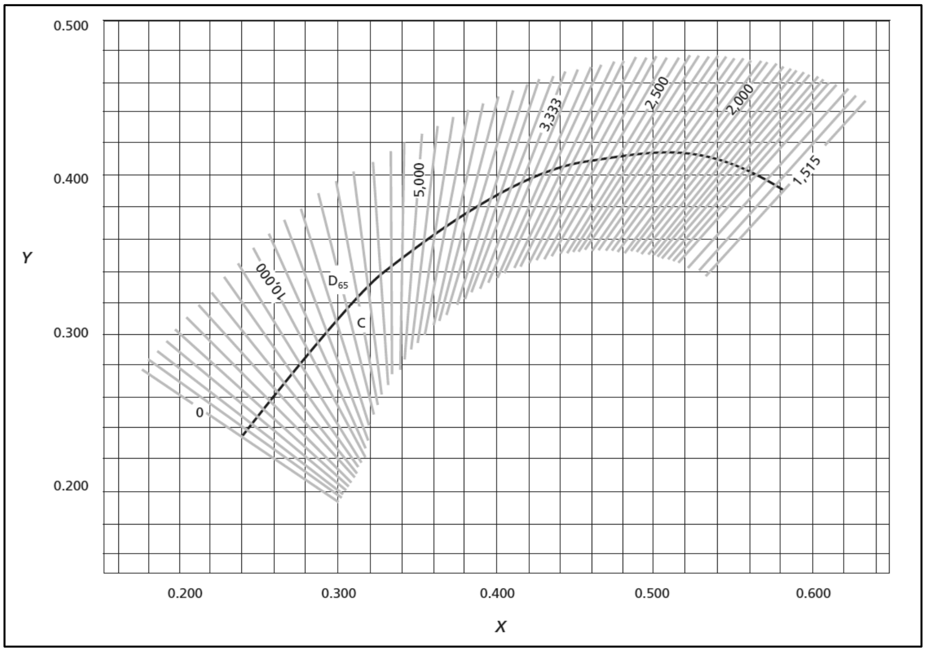


Figure 1.6.1: *The Planckian locus and lines of constant correlated colour temperature plotted on the CIE 1931 (x,y) chromaticity diagram. Also shown are the chromaticity coordinates of CIE Standard Illuminants, A, C, and D65 (from the IESNA Lighting Handbook).*

The corresponding colour temperatures of nominally white light sources range from 2,700 K to 7,500 K. A light source with a 2,700 K colour temperature, like an incandescent lamp, will seem yellowish and be referred to as "warm," whereas a light source with a 7,500 K colour temperature, like some types of fluorescent lamps, will appear blue and be referred to as "cold," It is crucial to understand that light sources shouldn't be assigned a correlated colour temperature if their chromaticity coordinates fall outside the boundaries of the iso-temperature lines depicted in (Figure 1.6.1). When the chromaticity coordinates are above the Planckian locus, the light from such light sources will appear green, and when they are below, it will appear purplish.

Figure 1.6.2: *Representation of CCT*

1.7 An Overview of Lamps / Bulbs

Light is the only thing the human eye needs to see anything. A portion of the incident light that strikes an object or surface reflects in a variety of ways. If the light enters the eyes and reaches the retina, it first passes through the cornea, pupil, and lens. Millions of photoreceptive cells, including Rod and Cone cells, transform light when it enters the retina into an electrical signal that is then transmitted to the brain by the optic nerves. The received signal is interpreted by the brain, which then converts it into visible images. Because of this, lighting has always focused on illuminating areas and delivering good visual performance. However, new research has demonstrated that the retina has a third type of photoreceptor known as intrinsically photosensitive retinal ganglion cells (ipRGC). These cells provide information to the suprachiasmatic nucleus (SCN), a structure in the hypothalamus that controls mammalian circadian rhythm, rather than the human visual system. There is also ample proof that light influences a wide range of non-visual reactions. As a result, lighting solutions are being developed to provide a balance between better mood, sleep quality, and other variables, as well as visual satisfaction. Although the sun is the primary source of all light and energy, artificial lighting has a long history and a fascinating progression. For instance, near the location of Koobi Fora in Kenya's Lake Turkana region, researchers discovered many centimetre-deep oxidised spots on the ground. The patches, which have a purported formation date of between 1.5 and 2 million years ago, clearly demonstrate evidence of controlled fire. After people discovered how to manage fire, it was introduced as a source of light in addition to the sun's natural light. Since then, because technology made it possible to illuminate a space without access to natural light, artificial lighting has come into existence. In addition, as science and technology evolve, artificial light sources are improved to have a longer lifespan and eliminate all safety issues.

Some hollow artefacts from the prehistoric age were filled with leaves and moss and then soaked in animal fat to make flares. The ancestors were able to survive and hunt at night due to the flare that was produced when the ignition was lit. However, this type of light source had the drawback that it was not very safe to use and produced a lot of smoke. All of these drawbacks are constantly being addressed by modification thanks to civilization and technological progress. Oil lights were first used approximately 4500 BC, and candles weren't invented until 1500 BC. Then, in 1780, Ami Argand significantly improved traditional oil lamps. The lamp's name was Argand. William Murdoch created the first gaslight fourteen years later.

Humphry Davy invented the carbon arc lamp in the first decade years of the nineteenth century. The electric arc was then effectively contained inside a gas discharge tube known as the Geissler tube in the year 1856 [Figure 1.7.1]. Different types of gas discharge lamps were also created along with the Geissler tube. Alexandre-Edmond Becquerel made the first demonstration of fluorescent lighting in 1867. Alexander Lodygin developed the incandescent light seven years later, and Thomas Edison patented the carbon-thread incandescent lamp, which had a 40-hour lifespan, in 1879. One year later, he created a 16-Watt incandescent bulb with a nearly 1500-hour lifespan. Due to the high cost and short lifespan of all other lamps at the time, this invention was groundbreaking. Edison resolved all of these issues, which aided in the widespread use of electric lamps. The invention of several artificial light sources occurred during the 20th century, which was the most significant period. Peter Cooper Hewitt created the first mercury-vapour lamp for use in commerce in 1901. The tungsten filament for incandescent lamps was created three years later by Alexander Just and Franjo Hanaman [Figure 1.7.2]. The Metal-Halide lamp (Figure 1.7.4) [was next developed by Charles P. Steinmetz in 1912.

Figure 1.7.1*- Geissler tube*

Figure 1.7.2- *incandescent lamps*

The Sodium-Vapour lamp was next created by Arthur H. Compton in 1920 [Figure 1.7.5 (a)]. The contemporary fluorescent lamp [Figure 1.7.3] was patented by Edmund Germer six years later. Elmer Fridrich created the Halogen light bulb in 1953 after that. Kurt Schmidt created the high-pressure sodium vapour lamp [Figure 1.7.5 (b)] ten years later. Next, in 1976, working with General Electric, Edward E. Hammer developed the Compact Fluorescent Lamp (CFL) [Figure 1.7.6 (a)]. For the same level of light output, CFLs utilised less power than incandescent bulbs and had a longer lifespan. However, it was made of mercury, which is harmful to human health and contained additional fluorescent lamps.

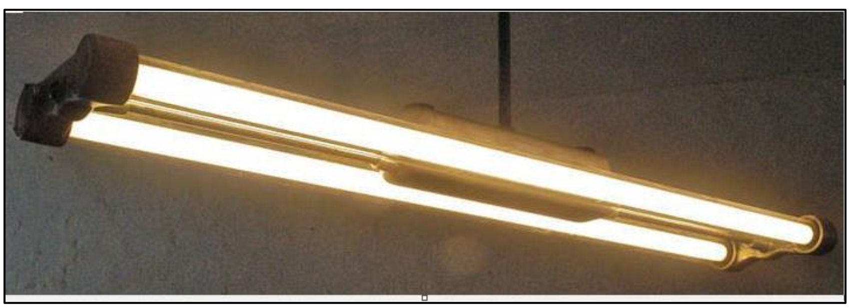


Figure 1.7.3 - *Fluorescent Tube Light*

Figure 1.7.4- *Metal Halide Light Bulb*

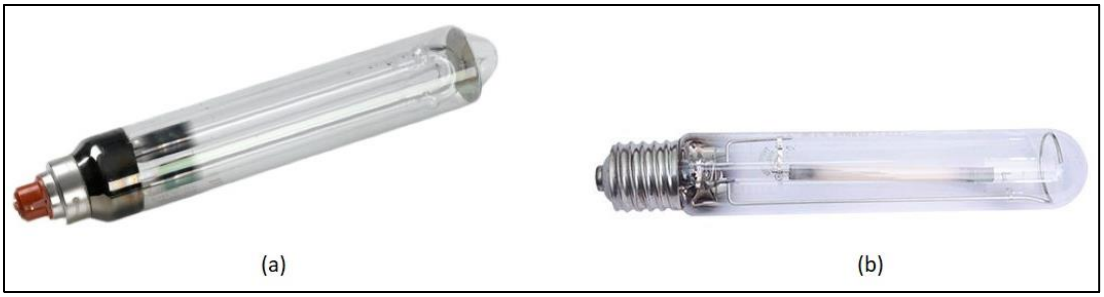


Figure 1.7.5- *(a) Low-Pressure Sodium Vapour Lamp (b) High-Pressure Sodium Vapour Lamp*

Semiconductors were being tested even before the development of incandescent and gas discharge lighting. Henry Joseph Round noticed a faint yellow light in 1907 when silicon carbide was exposed to direct electricity. However, the light it produced was so feeble that it was useless. Later, Oleg Losev saw the same occurrence and thoroughly investigated it. Finally, he published his research on the process through which an LED emits light. Robert Biard and Gary Pittman accidentally created an infrared LED in 1961 while working on laser diodes. A year later, Nick Holonyak created an LED with a substrate made of gallium arsenide that could produce visible red light. The first LED to be used in real life was that one. Then M. George Craford combined two chips made of gallium phosphate to generate an LED that could provide a soft yellow light. On a gallium phosphate substrate, pure green light-emitting LEDs were also developed by the late 1980s. The first blue LED was created by Shuji Nakamura using a Gallium Nitride substrate, and this was the defining moment. Later, blue and green LEDs with greater brightness were created using indium gallium nitride. The development of Red, Green and Blue LEDs allowed for the creation of white light-emitting LEDs [Figure 1.7.6(b)], which combine the three fundamental colours. As a result of LEDs' ability to resolve every issue that existed with the other commercially available light sources, the lighting industry as we know it was entirely revolutionised. LED luminaires are now the primary source for lighting design, despite the fact that producing them was more expensive than using other light sources due to their energy efficiency, durability, and other benefits. As a result, incandescent and fluorescent light sources have been phased out of the market.

Figure 1.7.6*: (a) CFL Bulb (b) LED Bulb*

In addition to being the greatest option for light fixtures in commercial and industrial organizations, LEDs are currently frequently used for research purposes. Numerous lighting research initiatives were only made practical with the development of the LED. LED lights have simplified lighting management with the advent of numerous lighting control protocols. By altering the contribution of the red, blue, and green colours, the spectrum composition, spectral power distribution, and colour appearance of an LED source may all be altered. It is possible to tailor various lighting parameters (such as SPD, CCT, CRI, etc.) to the requirements of the study, enabling accurate inferences to be drawn from the data. For the past few years, scientists have been examining how light impacts human health and wellbeing. There is currently a lot of study being done on human-centric lighting in order to reconcile the non-visual and visual effects of light on overall work performance.

1.8 Human Centric Lighting

The development of LED technology has made it simpler to alter the photometric and colourimetric characteristics, such as colour appearance, correlated colour temperature (CCT), etc. To better understand how the human body reacts to various illumination conditions, numerous experiments have been conducted in recent years. Studies currently being conducted tend to concentrate more on the non-visual effects of lighting on task performance, suggesting that the reaction might not merely be visual. Therefore, a lighting setting that offers sufficient illumination and enhances overall task performance is known as human-centric lighting. The primary goal of human-centric lighting is to assist in providing users with the necessary set of visual, biological, and behavioural reactions. [5] A lighting design that satisfies the four fundamental criteria of spatial patterns, light spectrum, light level, and temporal patterns can accomplish this. In a three-dimensional light field, spatial patterns show how the light sources' luminances are distributed, whereas the light level shows how the workspace is illuminated horizontally. The colour rendering index (CRI), correlated colour temperature (CCT), chromaticity, etc. are all determined by the light spectrum. The timing and length of the light exposure make up the temporal pattern. Better lighting quality is produced by a lighting design that properly balances these four factors, which also improves non-visual reactions.

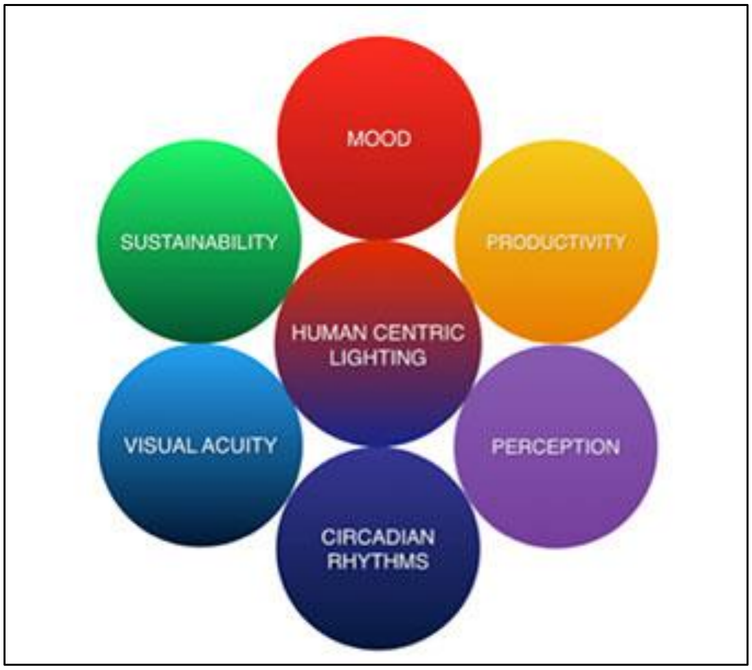


Figure (1.8): *Human Centric Lighting*

1.9 Effect of Lighting on Human Performance

Light has different biological effects depending on the colour temperature, and intensity. This may be the reason for its differing effects. To comprehend the link between lighting and work, it is necessary to first define the pathways via which lighting can influence human performance. There are three possible pathways: the visual system, the circadian timing system, and mood and motivation from (figure 1.9.1). [6]

The path through the visual system is shown in the lower portion of figure 1.9.1. It explains how the three components of task performance—visual, cognitive, and motor—combine to yield the five metrics that constitute visual performance. Illumination and task parameters also play a role in this process. The upper left corner of figure 1.9.1 displays the second pathway via the circadian system. This shows how the circadian system, which impacts how well people perform generally by altering their circadian phase or being more alert at night, is affected by the retinal illuminance, light spectrum, timing, and length of exposure to light. In the top right of the figure 1.9.1, the third path through the perceptual system is depicted. The "message" conveyed by this technique stems from two sources: visual pain and the way people typically interpret their environment. Both types of perception are linked to expectations, which are linked to feelings of motivation and attitude and, ultimately, to how well people perform in general. [4]

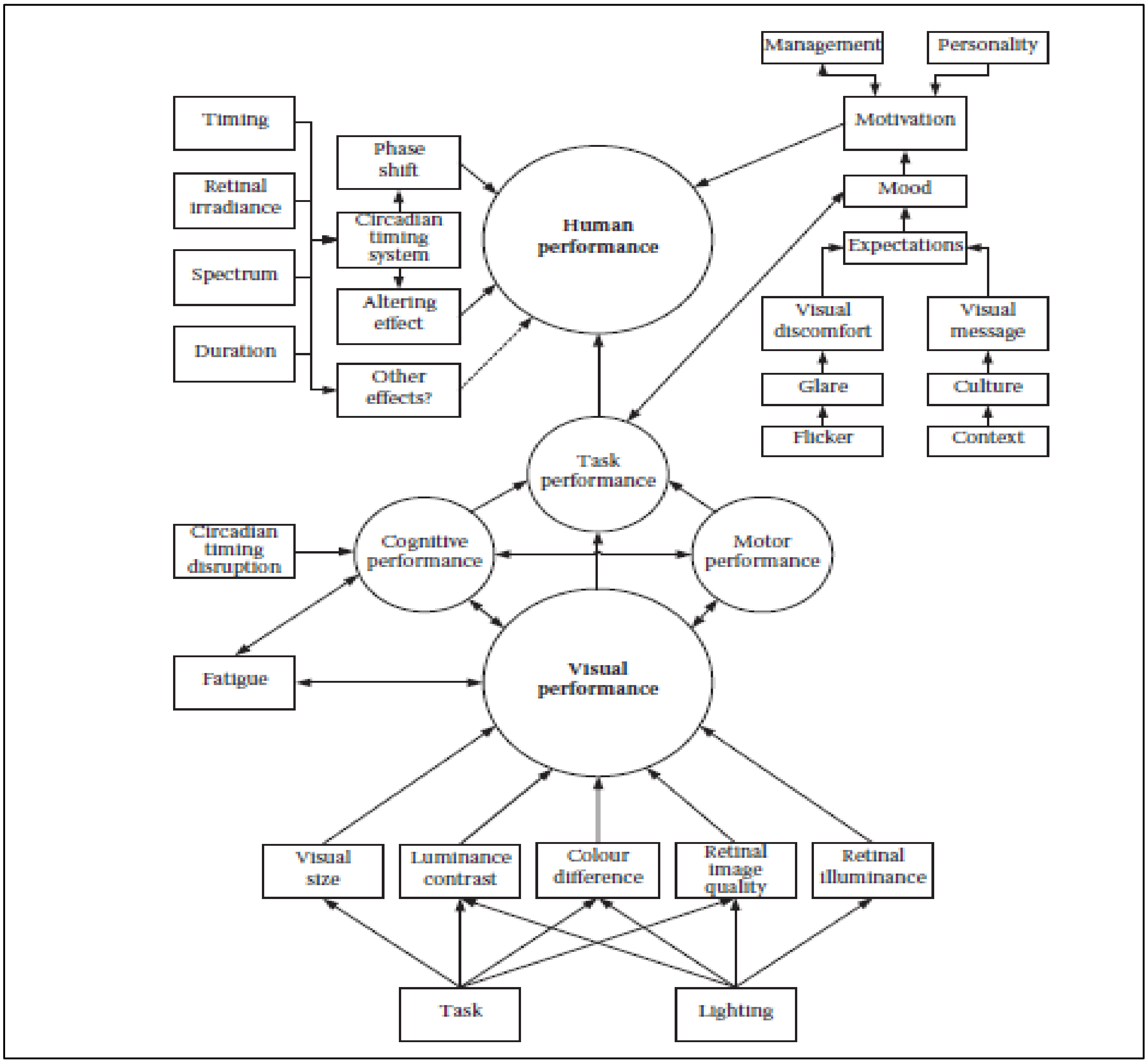


Figure (1.9.1)- *A conceptual framework setting out the three routes whereby lighting conditions can influence human performance. The arrows in the diagram indicate the direction of the effect.*

1.8.1 Visual Effect of Light

The effect of light on the visual system is one of the three above-mentioned channels and is a very frequent and well-known phenomenon. There are five different aspects that must be taken into account in order to determine how much a stimulus affects the visual system. These factors include visual size, brightness contrast, colour difference, retinal picture quality, and retinal illuminance.

The visual size of an item is an angular quantity that can be represented in a variety of ways depending on the application. It can be described as the solid angle that the object at the eye assumes while being detected. If any little features need to be discerned, the visual size should be defined as the angle subtended by the important dimension of the object at the eye. As a result, when the visual area is broader, the eyes can notice things and gather information more readily.

Luminance contrast is the distinction between the luminance of an object and its background luminance. Therefore, the contrast will be stronger the better the item can be detected. However, it's crucial to remember that lighting might change the luminance contrast, which could lead to glare or distracting reflections for the viewer.

Every object or light source emits a spectrum of wavelengths that together make up its colour. The object can therefore be recognised even if there is no brightness difference between it and its background due to the colour difference. The colour appearance of an object may change if the lighting's wavelengths do not match the wavelengths of emission from the object since each light source has a distinct colour appearance.

The quality of the retinal image is influenced by the image's sharpness. The medium through which the light after it has been reflected off the item has travelled is crucial in terms of the clarity of the picture since light is dispersed as it passes through a media. When scattering is significant, it becomes more challenging to focus the light on the retina. It has been found that shorter wavelength light is associated with smaller pupil widths and clearer retinal pictures. It also predicts that there will be less chromatic and spherical distortion and a better understanding of the depth of field increase.

The amount of light entering the eye from the lit surfaces in the field of vision determines the retinal illuminance. It demonstrates how the visual system adapts to the surrounding surfaces. As a result, altering retinal illuminance can have an impact on how well the visual system works.

These five traits allow one to determine the level of visual performance for a lighting stimulus. To understand the physical changes a person's body goes through when engaging in a visual activity, however, visual performance alone is insufficient. The bulk of visual tasks consist of visual, cognitive, and motor components. First of all, the visual component denotes performance in the visual domain, which is achieved by using the eyes to view all the data needed for the activity. The process of cognitive processing continues with the interpretation of the information and the selection of the best course of action. The motor component is ultimately the act of doing the selected activities. Task performance is the consequence of the three elements working together, and lighting conditions may have an impact depending on how essential the visual component is.

1.8.2 Non-Visual Effect of Light

The effects of light can also be wholly or partially independent of the visual system. Human circadian photo reception is influenced by the biological impacts of light, commonly referred to as the non-visual, non-image forming (NIF) effects of light. [7] [8]

Researchers studying circadian biology and illumination have paid particular attention to the intrinsically photo-receptive retinal ganglion cell (ipRGC), a rare third photoreceptor found in 2002. [9]

Along the "visual route," light is transmitted via rods and cones. Through polysynaptic pathways, electrochemical signals from incoming light information (electromagnetic rays) are transformed and sent to the visual cortex. The paths of visual and NIF effects in the brain are schematically shown in (Figure 1.9.2), where intrinsically photosensitive ipRGC transmit light via NIF pathways to the Suprachiasmatic Nucleus (SCN) and other brain regions, including the pineal gland that synthesises melatonin.

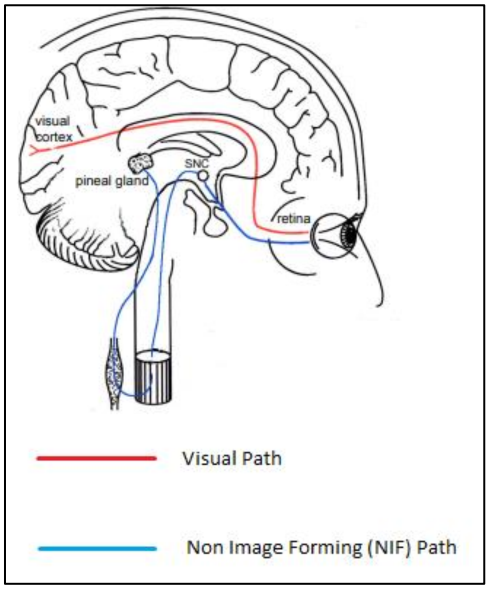


Figure (1.9.2): *Schematic overview of visual (red) and NIF (blue)pathways in the human brain.*

The main photoreceptor responsible for exposing people to the ambient light/dark cycle as well as other biological effects has been identified as the ipRGC. It closes a significant hole in the theory explaining how light and darkness influence biological activities. Light may therefore be thought of as an external stimulus that tells the body's internal clock how to run properly. The biological clock of the human body regulates the majority of daily rhythms in physiology and behaviour. Hormone secretion, core body temperature, and sleep/wake patterns are among them. It conveys data that regulates virtually every hormone's production, including cortisol, the nocturnal pineal hormones melatonin and serotonin, among many others. The ipRGCs have also been associated with the pupillary reflex, alertness, mood, and human performance in addition to the endogenous clock's phase changing in response to light. There is evidence to support the claim that short-wavelength light is the best regulator of the biological clock. There is currently a great deal of research being done on the possibility of using blue-enriched light to affect human reactions and behaviour, such as attentiveness and mood. Despite substantial research on the subject, the mechanism causing the observed reactions is still a mystery. [10][11][12]

Researchers still don't fully comprehend how light's biological effects on human performance work. [13][14][15] There is still much research to be done on the non-visual effects of light and how to account for them in lighting methods. A fuller understanding of how different lighting effects interact with cognitive and behavioural visual tasks, as well as how the biological effects of lighting may be related to these reactions, will come from further research. [16][17][18][19]

Compared to rods (505 nm) and cones, the ipRGCs exhibit the highest sensitivity in the blue region of the spectrum between 460 and 480 nm (555 nm). The strength of NIF effects is also affected by other physical properties of the visible electromagnetic spectrum, including luminous intensity, timing, and exposure time to light. To optimise indoor lighting settings, it is vital to understand the principles of the luminous qualities that influence NIF effects. To regulate NIF effects such as circadian, circannual (seasonal), pupil light reaction, and hormone release, environmental light serves as a signal.

The quality of work may also be affected by light via motivation and mood. It has been found that a workspace's illumination may elicit an emotional response that reveals the task's purpose and mood. [15][20] For instance, if a workspace's light source creates a glare that interferes with tasks, it causes pain to the eyes. Disparate cultural standards and expectations can sometimes cause discomfort that is more psychological in nature. Lighting acting as a glare source is one of the most straightforward examples of how light influences mood and motivation. In studies conducted by C. Cajochen, there is strong evidence of enhanced mood and visual comfort when an LED matching sunshine spectrum is used. [21][22]

1.10 Effect of Light on Productivity

Lighting should create the ideal visual conditions for people to perform visual tasks efficiently, safely, and comfortably. People's physiological and psychological characteristics are impacted by the light environment through a variety of mechanisms, which also have an impact on their performance and productivity. [3]

The impact of illumination on productivity is debatable. It is difficult to draw a connection between lighting and productivity because so many other factors affect productivity at the same time. These components include managerial relationships, employee motivation, and the level of individual control over working conditions. [4] It is possible to improve visual abilities and prevent discomfort from inadequate lighting. This may lead to increases in productivity as well as improvements in visual and task performance. Field investigations in operational settings present challenges due to the level of experimental control required. Numerous studies have looked into how better lighting affects how well workers perform. However, there are a lot of other elements that go into creating the lighting conditions. Controlling and analysing the lighting changes, including the illuminance, spectrum, co-related colour temperature and luminance distribution, as well as if other characteristics of the working environment are also altered at the same time, is crucial (such as working arrangements, people, and work supervision). Recent studies have looked at how the different light spectrums affect human performance and the possibility of employing blue-enriched light to improve performance via non-visual impacts of light. Additionally, the colour temperature has an impact on human performance. The psychological effects of CCT variation on people are depicted in the picture below (figure 1.10), and as a result, productivity may vary. Inadequate lighting can soon lead to production costs for the employer that are much higher than the annual ownership cost of lighting. Employee productivity losses caused by poor lighting can quickly translate into production costs.

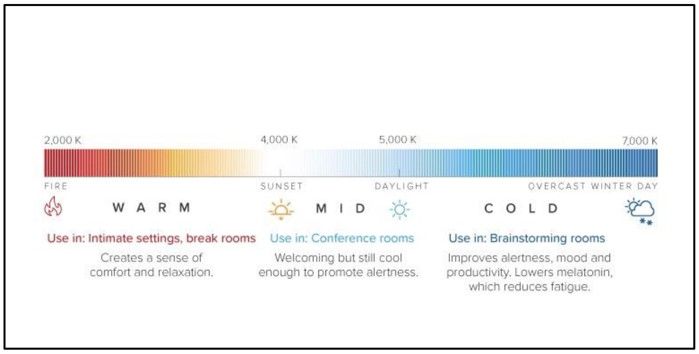


Figure (1.10)*: Effect of Light on Productivity*

Light constantly functions, and its effects extend beyond the aesthetic and emotional to the biological. Humans are guided throughout the day by lighting solutions that regulate the colour and intensity of illumination. increase people's productivity, stimulate their imaginations, and people remain composed in tense circumstances.

1.11 Landolt's C-Chart

The Landolt C is an optotype, which is a standardised sign used to assess vision. It is sometimes referred to as a **Landolt ring, Landolt broken ring, or the Japanese vision test**. It was created by ophthalmologist **Edmund Landolt**. The Landolt C is made up of a ring with a gap, giving it the appearance of the letter C. The test subject's objective is to determine which side the gap is on. The gap can be in a variety of positions (often left, right, bottom, top, and the 45° positions in between). Up until the subject commits a predetermined rate of errors, the C's size and its gap are lowered. The gap's smallest perceivable angle is used to calculate the visual acuity. It is generally practised in the laboratory. [35]

The gap width is the same, and the stroke width is one-fifth of the diameter. [36] This corresponds to a Snellen chart's letter C exactly. In much of Europe, the Landolt C optotype is the norm for acuity measurements. It was standardised as DIN 58220 by the German DIN, along with measurement techniques (now EN ISO 8596). Despite being regarded as the gold standard, this optotype has its own intrinsic issues. These issues may be caused by greater brain function, which causes the gap to appear closed close to the limit of resolution, particularly when the gap is at 6 o'clock. Astigmatic errors and the structure of the cornea or lens are not to blame for this. [37] [38]

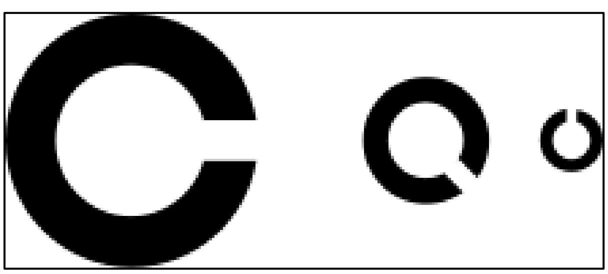


Figure 1.11: *Landolt's C-Ring*

CHAPTER-2

2. LITERATURE REVIEW

Many experimenters interested in the relationship between lighting and work returned to the laboratory, where trials replicating real-life tasks could be done under controlled conditions, due to the lack of control achievable in many outdoor situations. Of course, because the work is now being performed in a different situation, people may act differently as a result. Nonetheless, if the goal of the study is to identify the influence of varied lighting conditions on task performance via changes in task visibility, the increase in sensitivity gained by good experimental control is usually worth the loss in face validity.

A number of simulated task studies have been published in the literature. The influence of incandescent and fluorescent lighting on the inspection of plastic discs or buttons on a conveyor belt was investigated by Lion et al. (1968). All the discs having a broken rather than a complete loop marked on them, as well as all the buttons with off-centre holes, had to be removed. On the conveyor belt, both types of lighting supplied the same level of illumination (320 lx). When sorting discs with broken loops under an extended fluorescent light source, inspection performance was significantly better than when sorting discs with broken loops under an incandescent point light source, but there were no significant lighting effects when sorting buttonholes. The visual complexity of the two activities, and hence their relative sensitivity to lighting conditions, is most likely the cause of this variation. This study also highlights the difficulties of extrapolating from a single activity. Both of these activities could be classified as sorting tasks, but because the two problems demonstrate different lighting effects, the results cannot be extended to sorting tasks in general.

Stenzel and Sommer (1969) looked at sorting screws of various sizes and crocheting stoles; Smith (1976) looked at threading a needle; Bennett et al. (1977) looked at needle probing as well as micrometre reading, map reading, pencil note reading, drafting, vernier calliper measurement, cutting, and thread counting over a range of illuminances from 10 to 5000 lx; and McGuiness and Boyce (1984) looked at kitchen construction. Higher illuminances improved performance on most of these tasks, though the amount of benefit varied depending on the task. This is not surprising given that these studies are primarily focused on task performance rather than visual performance, therefore the tasks differ not just in terms of the stimuli they show to the visual system, but also in terms of their cognitive and motor components. This is especially clear in two Smith and Rea experiments (1978, 1982). A small number of individuals proofread manuscripts for misspelt words in Smith and Rea's (1978) study. At four different illuminances ranging from 10 to 4885 lx, measurements of the time it took to proofread a passage and the percentage of errors identified were taken. The consequence of raising illuminance, as shown in Figure 4.3a, is to reduce the time spent and raise the percentage of errors identified. The same apparatus, as well as the same range of illuminances, were used in the Smith and Rea (1982) study, but this time the subjects were instructed to read a text and then answer questions on their comprehension of the material. With increased illuminance, neither the speed nor the level of comprehension changed much (Figure 2). The cognitive component of reading for comprehension is substantially larger than that of proofreading. [4][6]

Simulated work studies are carried out when it is necessary to investigate the impact of illumination on a certain task. They do allow for more exact experimental control than is generally achievable in the field, but the results are unavoidably limited in that they are only applicable to the specific activity at hand and cannot be applied to other tasks. Simulated work assignments, to take an analogy, are a dead end on the way to a general understanding of the link between light and work. Unless you have business there, there is no incentive to travel there.

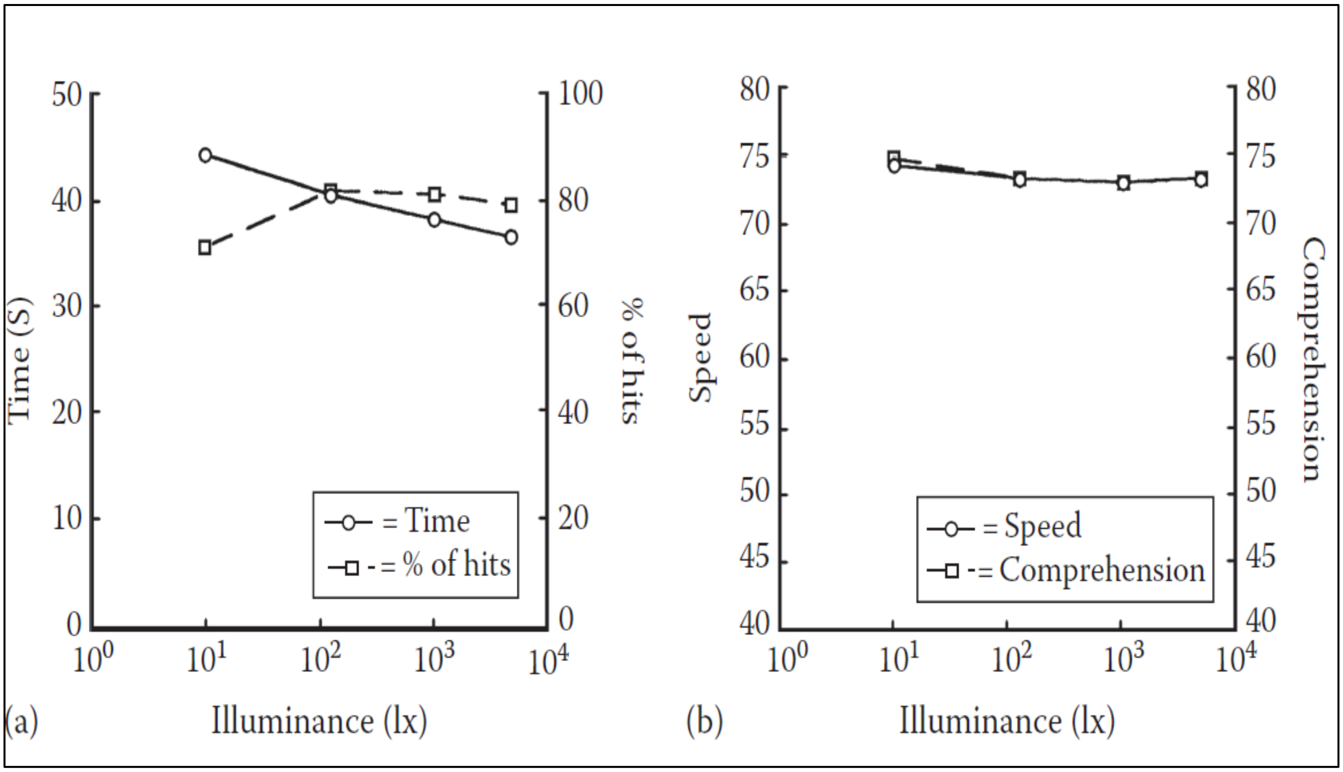


Figure (2)- *Performance on two types of reading tasks. For both tasks, the printing was of good quality on white paper: (a) time taken to proofread a passage and percentage of hits, that is, errors detected, plotted against illuminance; (b) speed and level of comprehension plotted against illuminance. (After Smith, S.W. and Rea, M.S., J. Illum. Eng. Soc., 8, 47, 1978; Smith, S.W. and Rea, M.S., J. Illum. Eng. Soc., 12, 29, 1982.)*

CHAPTER-3

3. EXPERIMENTATION

3.1 Background of Experiment

Human perception of colour is a fundamental aspect, and centuries of researchers have been interested in how colour influences cognition and behaviour tasks. Although a lot of studies have been done in this area, the psychological processes by which colour functions have not been well explored. As a result, the field has seen some contradictory outcomes. The majority of studies on this subject have contrasted the two fundamental colours—red and blue (or green). While some claim that red performs cognitive tasks better than blue or green, others have found the exact reverse. This experiment will analyse how the yellow and white colour spectrum might affect human task performance. This study describes the research done to explain the psychological processes through which colour influences how well people do cognitive tasks. Theoretically, it is possible to reconcile the contradiction mentioned above. It has been shown that the colour yellow and white elicit various motivations and, as a result, improve performance in many kinds of cognitive activities. This research only examines the colour spectrum's yellow and white portions, following most previous studies.

A previous study of sustained performance has shown a 13% difference in the amount of work done on a data-entry task, over an eight-hour day, for 6-point print vs 14-point print. Here An essentially identical lighting installation was used in each room. It consisted of four three-lamp, 18-cell, semi-specular parabolic-reflector luminaires, each cell being 7.6 cm deep. The lamps used in all the luminaires were seasoned 4 ft T8 fluorescents with a CIE General Color Rendering Index of 75 and a correlated colour temperature of 3500K.

Previous studying the office lighting simulation methodologies, a detailed evaluation of prior studies was undertaken. Scopus, Web of Science, and Google Scholar were used as database sources for the review. Lighting, simulation, CCT, illuminance, design, office, and virtual reality were utilized as search phrases. For the review, studies that were irrelevant to office lighting simulations were first excluded, and then methods for performing lighting simulations were divided into four categories, as shown in Table:3.1 field lighting simulation, photo-based lighting simulation, rendering-based lighting simulation, and IVE lighting simulations.

Beutell(1934) made the first attempt to create a broad model of the impact of lighting conditions on work. His approach was to first describe a standard job on which the effect of lighting was tested and the illuminance for every performance level was calculated. Weston (1935, 1945) used Beutell's theory and developed a method to investigate the effect of lighting on work. He completed a simple assignment involving identification and measuring. The Landolt ring chart was it. He instructed the participants to study the chart and circle all of the rings with a gap oriented in a specific way. Under various lighting conditions, the time taken and the number of errors made were recorded. The data was then merged to provide work speed and accuracy measurements.

Simulation type	Ref.	Lighting factor	Measurement	User response
Field lighting simulation	Boyce et al.	Illuminance	Questionnaire on participants' mood and lighting preference, alphanumeric verification task, lighting control behavior	Task performance, mood, visual perception (lighting preference)v
	Veitch et al.	Illuminance	Questionnaire on participants' lighting preferences and satisfaction, lighting control behavior	Visual perception (lighting preference, satisfaction)
	Chraibi et al.	Illuminance	Reading task, questionnaire on participants' lighting preference, lighting control behavior	Visual perception (lighting preference)
	Viola et al.	CCT	Questionnaire on participants' mood and health status, and task performance	Mood, task performance, health (eyestrain, headaches, sleep quality)
	Hoffmann et al.	CCT, illuminance	Sulfatoxymelatonin (aMT6-s) measure, questionnaire on participants' moodquestionnaire on participants' mood	Mood, health (circadian rhythm)
	Sun et al.	CCT, illuminance	Tear film crystallization measure, neurobehavioral test, questionnaire on participants' visual perception, task performance, and health status	Visual perception (comfort, pleasantness, satisfaction), task performance, health (stress, fatigue)
Photo-based lighting simulation	Newsham et al.	Illuminance	Questionnaire on participants' visual perception	Visual perception (pleasantness, comfort, uniformity, lighting preference, etc.)
	Céline et al.	CCT, illuminance	Questionnaire and interview on participants' visual perception	Visual perception (comfort, dimness, warmness, etc.)
	Moscoso et al.	Illuminance	Questionnaire on participants' visual perception	Visual perception (pleasantness, spaciousness, complexity, etc.)
Rendering-based lighting simulation	Newsham et al.	Illuminance	Questionnaire on participants' visual perception	Visual perception (comfort, uniformity, dimness, pleasantness, etc.)(comfort, uniformity, dimness, pleasantness, etc.)
	Villa et al.	Illuminance	Questionnaire on participants' visual perception	Visual perception (dimness)
	Murdoch et al.	CCT, illuminance	Questionnaire on participants' visual perception	Visual perception (pleasantness, uniformity, dimness, etc.)
IVE lighting simulation	Heydarian et al.	Illuminance	Questionnaire on the sense of presence and immersion, comprehension task, reading task, object identification task	Task performance
	Heydarian et al.	Illuminance	Lighting control behavior, questionnaire on participants' lighting preference, reading and comprehension task	Visual perception (lighting preference)
	Heydarian et al.	Illuminance	Lighting control behavior, questionnaire on participants' lighting preference, reading and comprehension task	Visual perception (lighting preference)
	Chokwitthaya et al.	Illuminance	Puzzle task, questionnaire on participants' visual perceptionquestionnaire on participants' visual perception	Task performance, visual perception (dimness, satisfaction, comfort, pleasantness)visual perception (dimness, satisfaction, comfort, pleasantness)

Table 3.1 *- Previous methods for lighting simulations*

The conclusions reached by Weston (1945) were repeatedly confirmed using a variety of visual tests (Khek and Krivohlavy, 1967; Boyce, 1973; Smith and Rea, 1978, 1982, 1987; Rea, 1981).

The significance of an analytical approach based on the concept of critical detail is demonstrated by the broad understanding of the relationship between lighting conditions and work. Boyce agreed with this observation (1974). Subjects in this study worked on a ring chart in two different forms, one difficult and one basic. The gap's visual size and brightness contrast were the same in both simple and complex rings, but the task's complexity, in terms of the number of alternative places for the crucial feature, is significantly greater in the complex ring. The results showed that searching with the complex ring chart took substantially longer than searching with the basic ring chart, but the performance change with illuminances was similar for both simple and complicated rings.

Rea (1987) compared Weston's 1935 and 1945 investigations and found that the trends in performance scores for Landolt rings of identical visual size and luminance contrast were not constant across the two studies. He objected to the fact that the number of accurate rejections or the number of Landolt rings evaluated and correctly rejected as not having a gap in the given direction, was not taken into account. The assessments of speed and accuracy must be imperfect if the number of correct rejections is not taken into account. While speed and accuracy are key parts of task performance, treating them as separate but related measures of performance rather than multiplying them together, as Weston's performance score metric does, is preferable. The optimal strategy would be to take into account the influence of illumination on the speed at a consistent level of precision or speed at a constant level of accuracy.

Although the term "human-centric lighting" is highly helpful in today's lighting design, it also begs the question of how to assess human performance in relation to whether or not human-centric lighting installations are acceptable. The most important criterion is the evaluation of a lighting arrangement from the perspective of human acceptance. Two methods can be used to determine whether human task performance is acceptable: (i) behavioural study and statistical analysis of the data; and (ii) a novel methodology that combines behavioural study and electroencephalography (EEG) data.

The ground-breaking approach suggested in this thesis combines electroencephalography (EEG)-based approach with behavioural research to determine the effectiveness of lighting installations from the perspective of human performance. The brain reactions to real-world stimuli can be identified with great accuracy by EEG-based studies. However, additional stimuli may also have an impact on the neuronal response. Therefore, this EEG-based study cannot be used as a beneficial approach on its own; rather, it will be carried out in conjunction with the behavioural study in order to be the most efficient and objective.

3.2 Experimental design

3.2.1 Experimental setup

In the experiment, the Landolt ring was used as a standard task to determine task performance under various lighting conditions. The Landolt ring chart was printed on white A4 paper. This was used as the object, and the subjects were asked to identify the Landolt Ring's right-hand side openings, left-hand side openings, upside openings, and downside openings at this moment, the total number of counts, response time, the number of misses, and false positives were calculated. A Landolt ring chart was provided for the experiment, as shown in (Figure 3.2.1.1). With two different CCTs: 2500K and 6500K, the landolt's ring chart is mentioned below in figures 3.1.2.2 & 3.1.2.3, respectively.

The purpose of this abstract research was to assess the impact of light source colour temperature on human work performance.

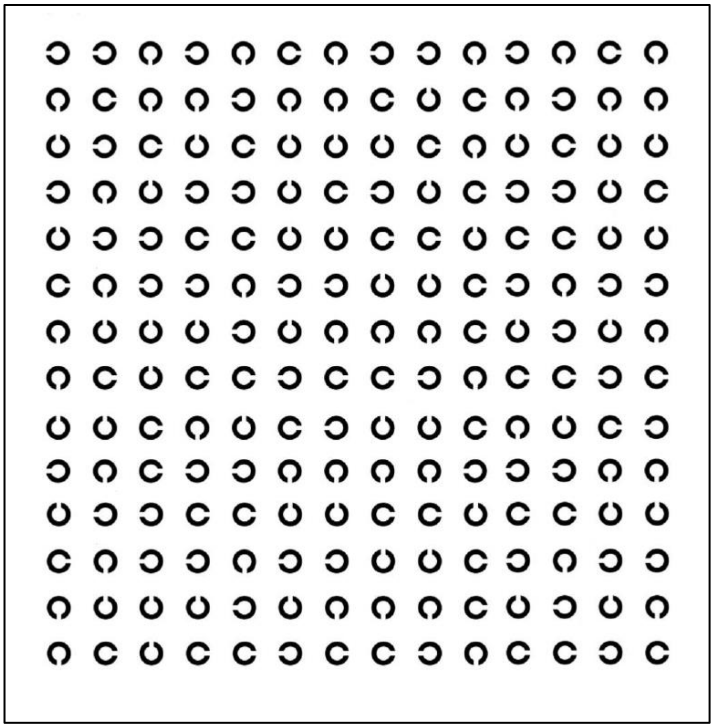


Figure (3.2.1.1)*: The Landolt Ring chart used in the experiment*

The setup took place in the Illumination Engineering Laboratory, Electrical Engineering Department, Jadavpur University, in a perfectly dark room measuring 5m x 5m x 4m. The fabric of the cloth is carefully selected to allow it to absorb the majority of outside light. Nearly no stray lights can enter the dark area and change the artificial lighting conditions inside. The cloth's 2.75 per cent reflectivity minimized indirect illumination and helped to concentrate the light on the job plane shown in (figure 3.2.1.2).

Figure 3.2.1.2: *Darkroom for the experiment*

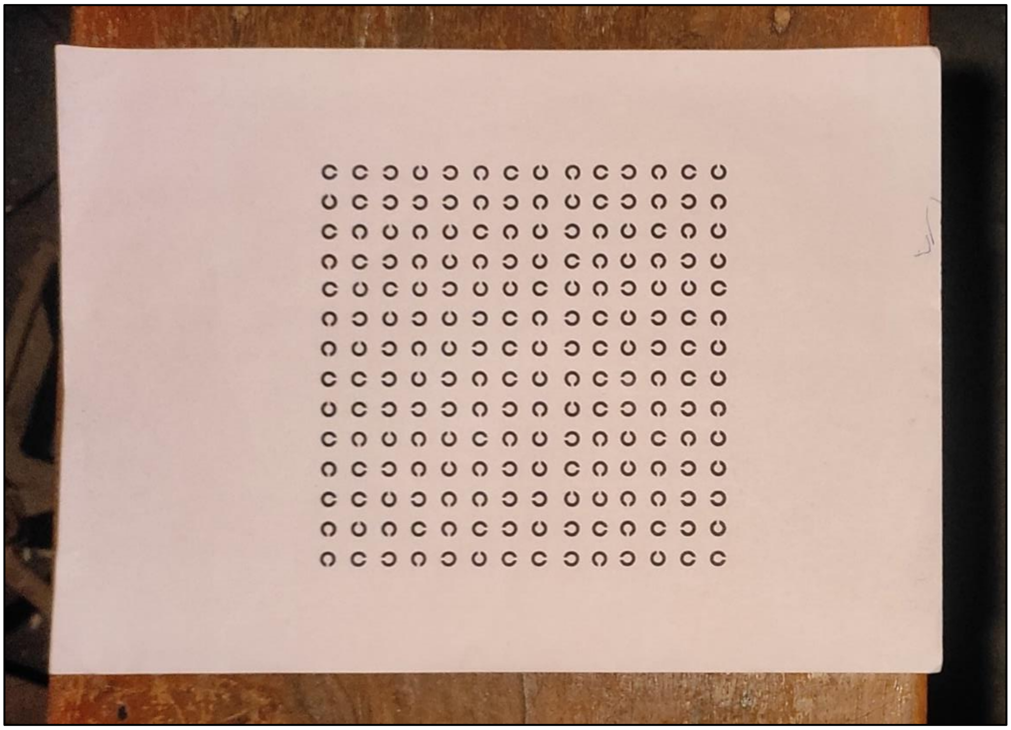


Figure (3.2.1.3)- *Landolt ring chart under CCT range as 2500K*

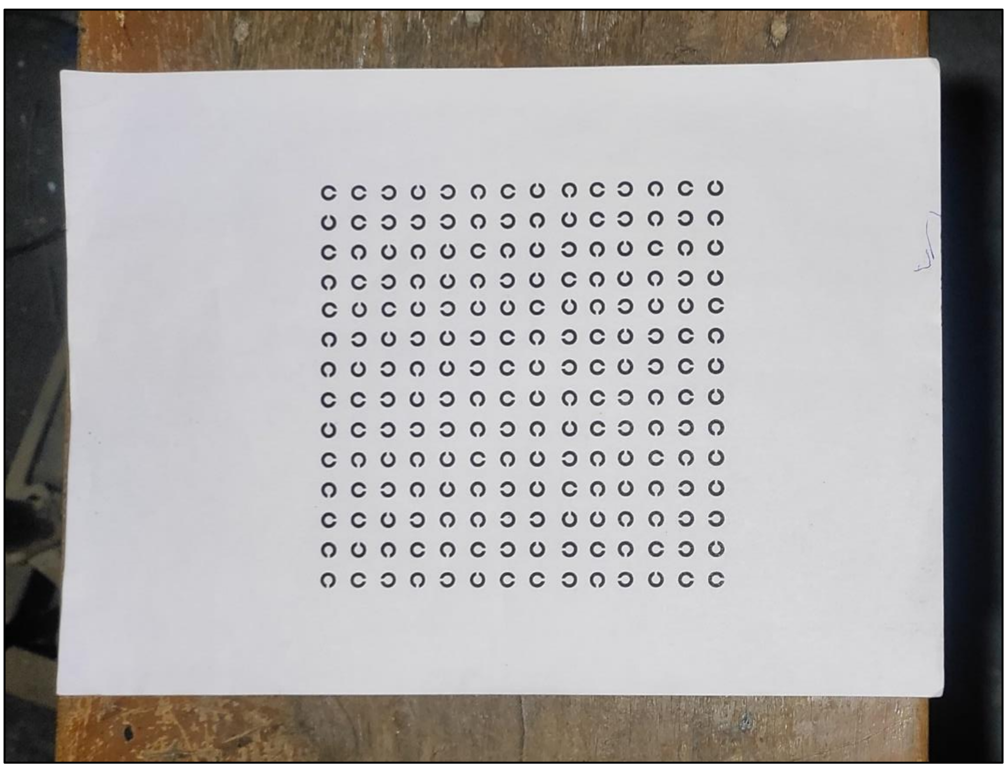


Figure 3.2.1.4- *Landolt ring chart under CCT range as 6500K*

3.2.2 Lighting

The whole experiment was carried out under 9 Watt WiFi Enabled B22 LED smart bulb known as Philips WiZ, which a mobile App WiZ wirelessly controls. The colour of this Philips WiZ light can be controlled at random, and several colour temperatures have been specified. The CCT (K) in the task plane and the average illuminance was measured using a calibrated CL 70F. The whole experiment was repeated for two CCT ranges, including 2500K and 6500K.

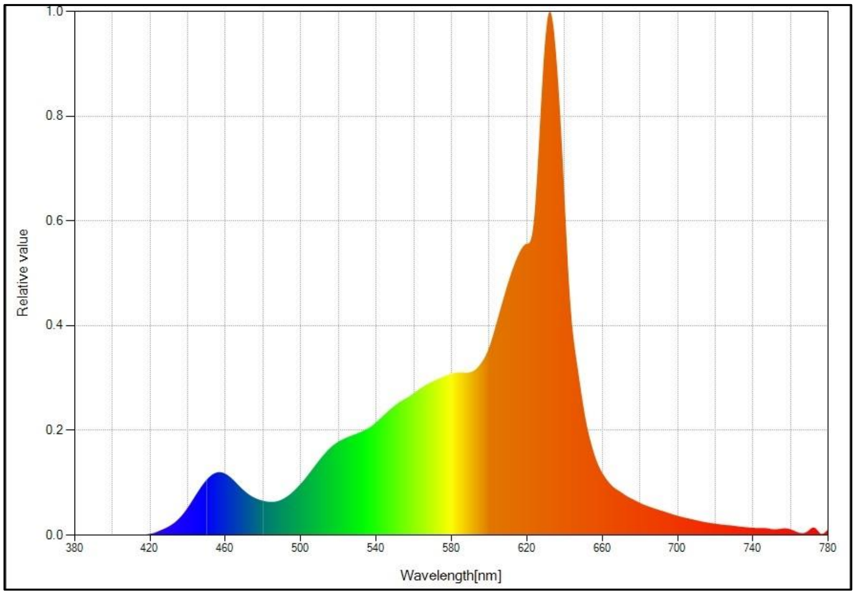


Figure 3.2.2.1: *Spectral Power Distribution at 2500K (CCT)*

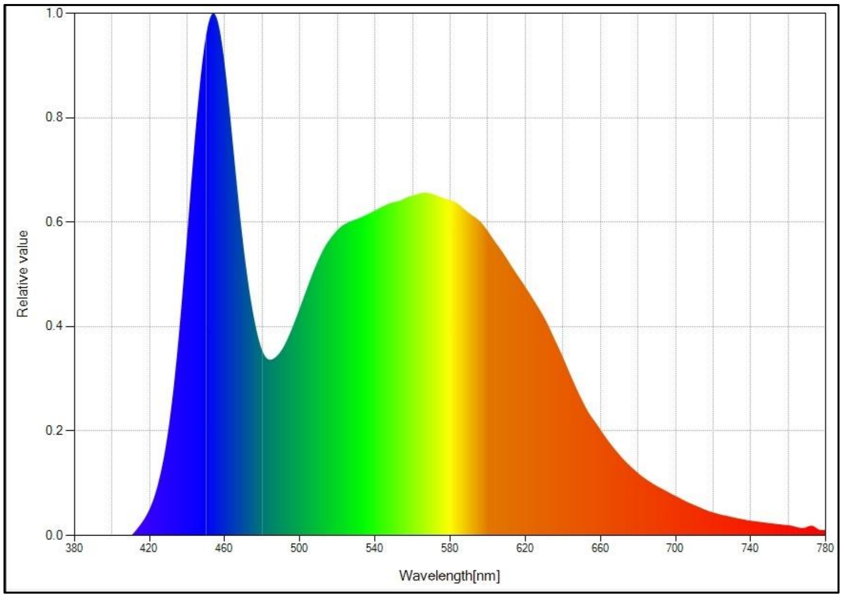


Figure 3.2.2.2: *Spectral Power Distribution at 6500K (CCT)*

3.2.3 Participants

A total of fifteen neurologically healthy students, five female and ten male, ages 18 to 25, participated in the experiment. The participants all claimed that their colour perception and visual acuity were in the normal range. Before the experiment started, they were given explanations about it and requested to sign a consent form.

	Name	Age	Gender
1	Subject 1	18	Female
2	Subject 2	20	Female
3	Subject 3	25	Female
4	Subject 4	24	Female
5	Subject 5	24	Female
6	Subject 6	25	Male
7	Subject 7	24	Male
8	Subject 8	22	Male
9	Subject 9	24	Male
10	Subject 10	21	Male
11	Subject 11	23	Male
12	Subject 12	23	Male
13	Subject 13	23	Male
14	Subject 14	25	Male
15	Subject 15	25	Male

Table 3.2.3: *Details of the Participants in the experiment*

3.3 Experimental Procedure and Data Recording

The electrical connection of the 9-Watt LED bulb WiZ made by Philips was completed first, and then mobile through WIFI was connected so that it could be controlled by WiZ application. The WiZ mobile application utilised for control modified two different CCTs that had already been picked to carry out the experiment. A calibrated Konica Minolta CL-70F CRI Illuminance meter was used to determine the corresponding CCT values. The CCTs were 2500K and 6500K. The lamp was positioned above the participants so that the task surface's average illumination was almost constant throughout the experiment.

A chair and table (height: 0.8 m) were positioned beneath the lamp. One by one, participants were instructed to enter the darkroom and took a seat on the chair. They were initially given roughly 3 minutes to get used to the specific CCT. After that, they received a sheet of instructions (Table 3.3.1) and were instructed on what to do.

After three minutes, students were given a Landolt's ring chart and told to quickly mark any rings with a particular side opening on the chart using a pen. Participants could not see anything in the darkroom except the Landolt’s ring chart and could complete their tasks without being interrupted. A stopwatch was used to time how long it took to complete this task in each of the various lighting scenarios. The number of the indicated rings was also recorded together with that specific opening direction each time. After that test, the subject was instructed to take a break outside the darkroom while another subject was called to do the same. They were told not to talk to any other participants about the test.

RULES

1. A chart will be given to you, where some rings are shown. Some are right opening rings, some are left openings, and some are upside and downside opening rings.

2. You have to count the rings with openings in the same direction as you are told.

3. You have to count that ring as fast as you can.

Table 3.3.1- *Instruction sheet given to participants*

Figure 3.3.1*: Performing task under 2500 K CCT*

Figure 3.3.2*: Performing task under 2500 K CCT*

CHAPTER-4

4 EXPERIMENTAL RESULTS

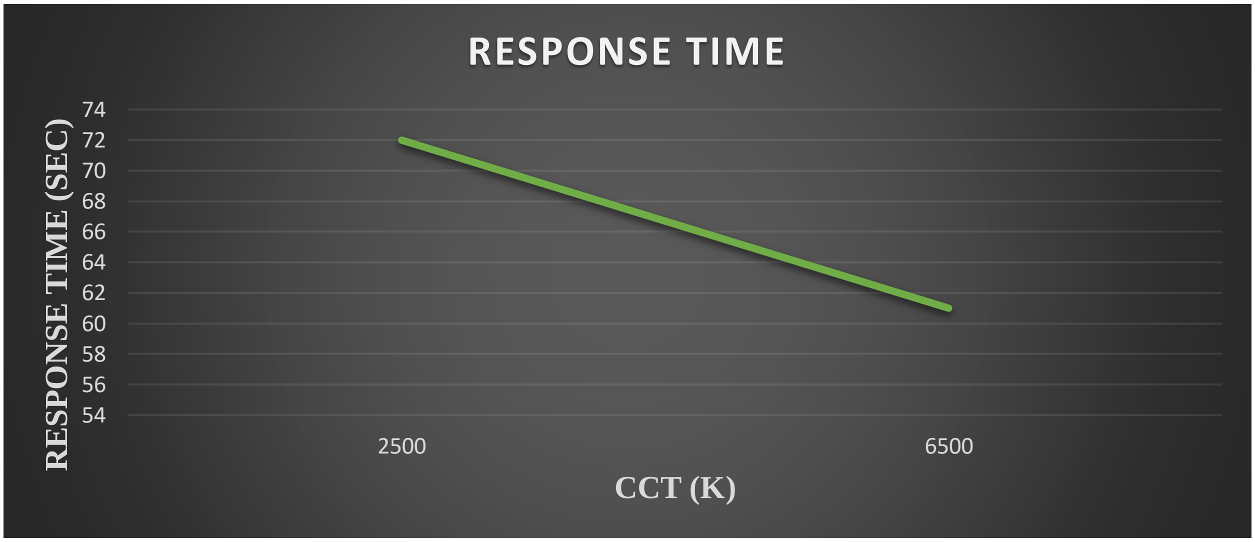
4.1 Experimental results

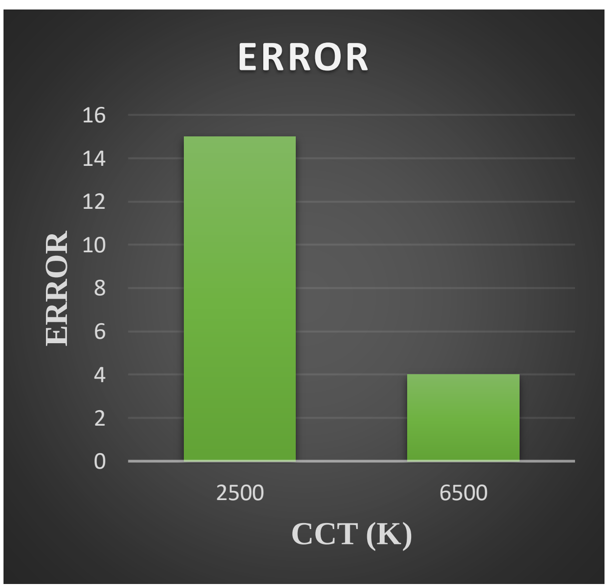
The results and analysis were done for two different sets. The first half focuses on calculating the total time required to complete the Landolt ring chart counting for a particular direction opening, while the second part determines the number of misses and false positives within the same time for the same task. The experiment was conducted with 15 subjects under the two distinct CCTs, 2500K and 6500K. A stopwatch was used to measure the response time of each subject and each task. Also, the number of rings counting was recorded. According to their tasks, the actual count for each direction of the opening in the rings for each Landolt's Ring chart is listed below in the tables as well as earlier counts. Below are subject-specific tabular and graphical data representations.

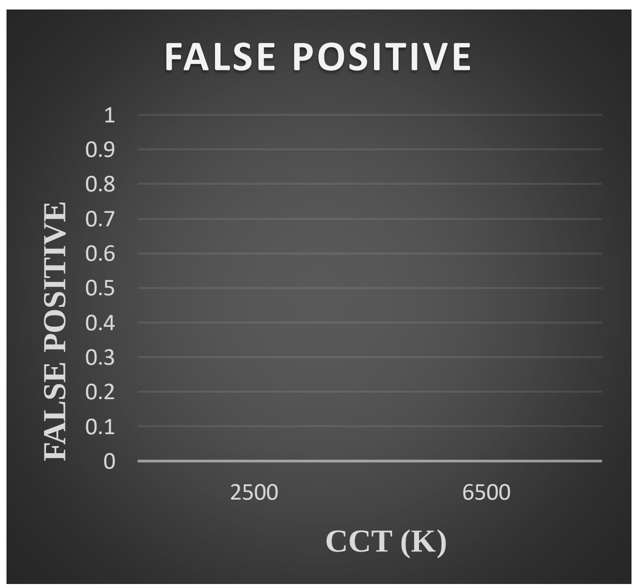
SUBJECTS	CCT (K)	DIRECTION	RESPONSE TIME (Sec)	COUNTS	CORRECT COUNT	ERROR	FALSE POSITIVE
1	2500	RIGHT	72	36	51	15	0
	6500	UP''	61	41	45	4	0
2	2500	LEFT''	62	45	51	6	0
	6500	RIGHT	52	47	51	4	0
3	2500	RIGHT	65	41	51	10	0
	6500	RIGHT	55	49	51	2	0
4	2500	RIGHT	63	50	51	1	0
	6500	RIGHT	56	48	51	3	0
5	2500	RIGHT''	108	46	51	5	0
	6500	RIGHT	76	49	51	2	0
6	2500	UP	87	48	49	1	0
	6500	RIGHT	70	50	51	1	0
7	2500	RIGHT''	73	47	51	4	0
	6500	UP	56	50	50	0	0
8	2500	LEFT''	96	51	51	0	0
	6500	LEFT''	74	50	51	1	0
9	2500	LEFT''	82	47	51	4	0
	6500	RIGHT''	55	51	51	0	0
10	2500	LEFT''	116	48	51	3	0
	6500	LEFT''	99	51	51	0	0
11	2500	LEFT''	102	46	51	5	0
	6500	UP''	80	45	45	0	0
12	2500	LEFT	75	46	51	5	0
	6500	DOWN''	55	47	49	2	0
13	2500	RIGHT''	79	51	51	0	0
	6500	RIGHT''	60	50	51	1	0
14	2500	RIGHT	58	38	51	13	0
	6500	RIGHT	56	47	51	4	0
15	2500	LEFT''	80	48	51	3	0
	6500	RIGHT''	55	51	51	0	0

SUBJECT-1

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500 K	RIGHT	72	36	51	15	00
6500 K	UP	61	41	45	04	00

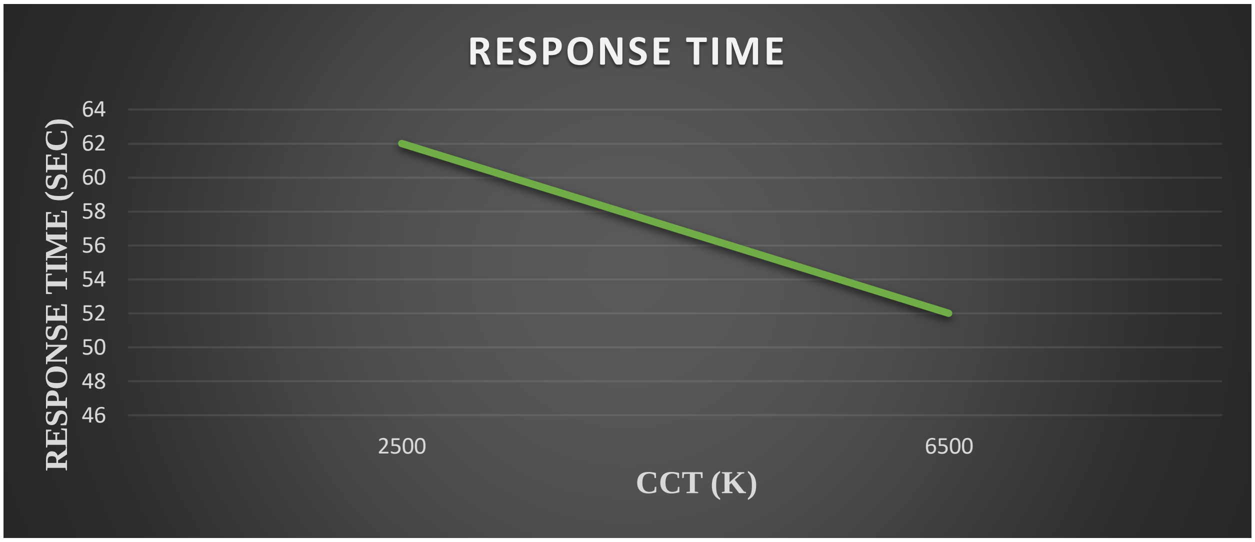


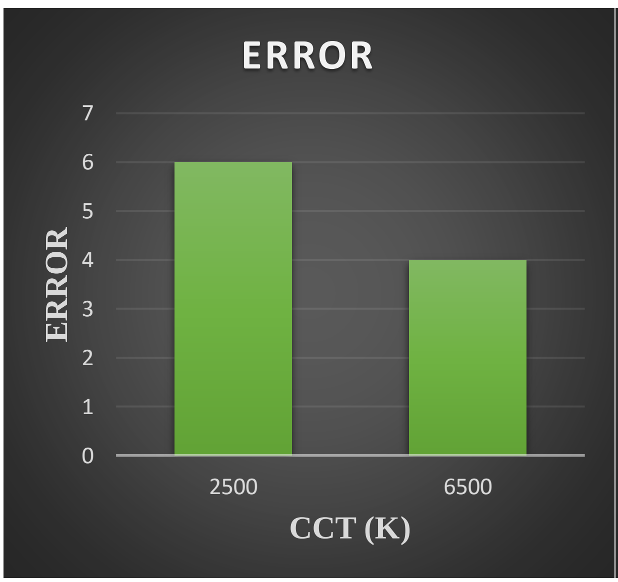


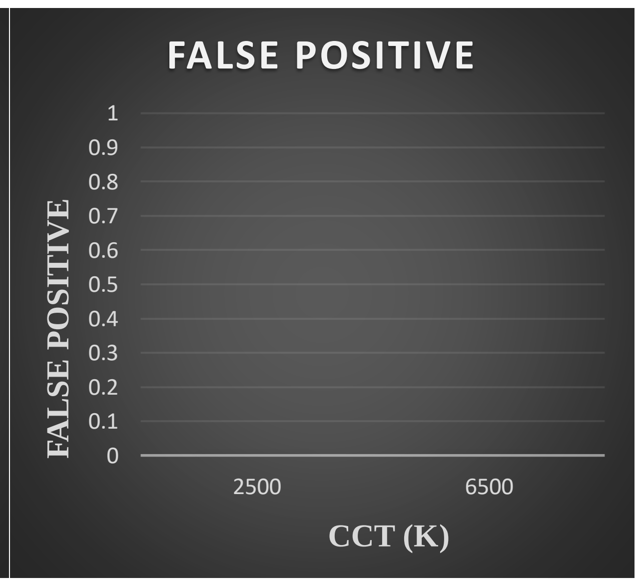


SUBJECT-2

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	62	45	51	06	00
6500	RIGHT	52	47	51	04	00

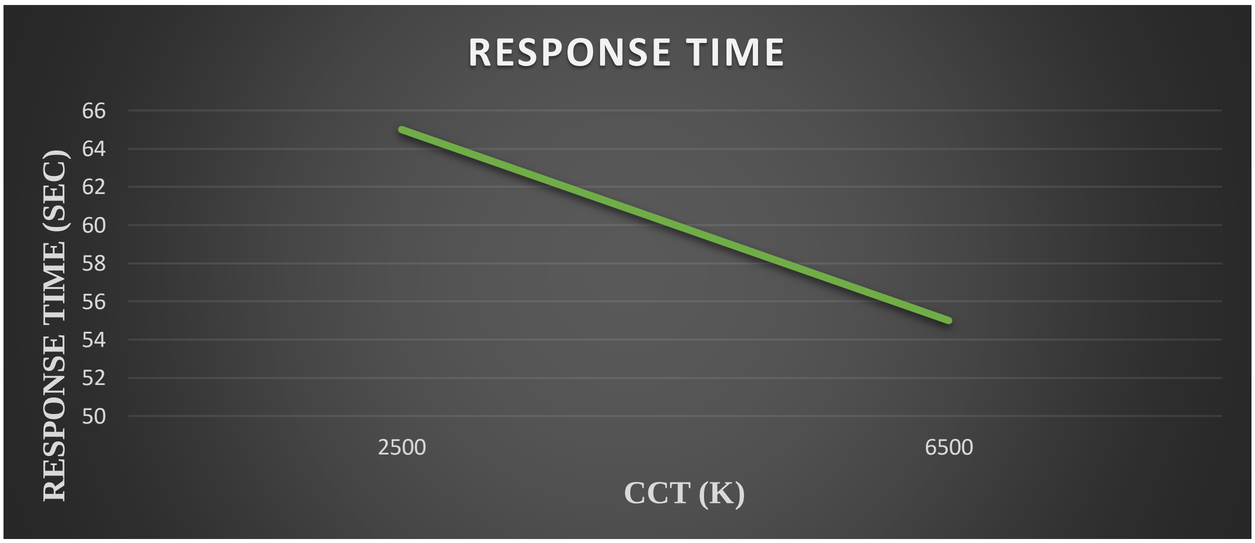


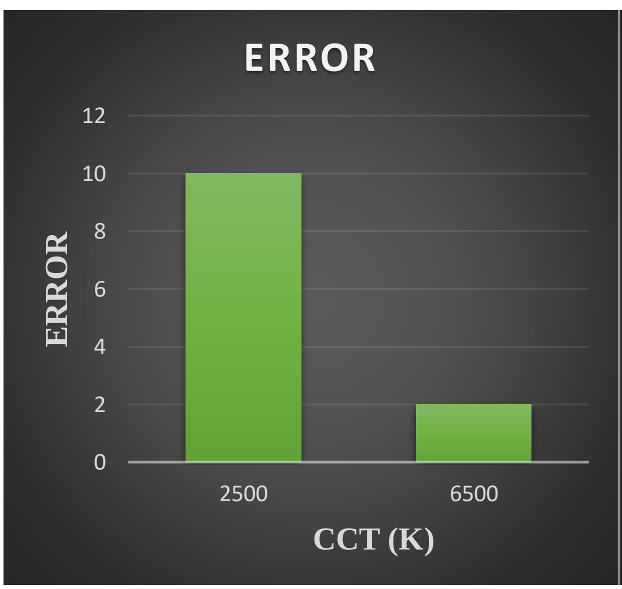


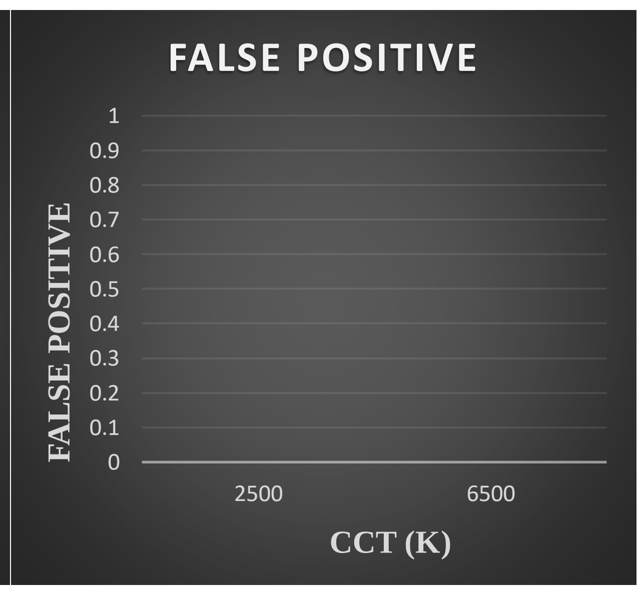


SUBJECT-3

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	RIGHT	65	41	51	10	0
6500	RIGHT	55	49	51	2	0

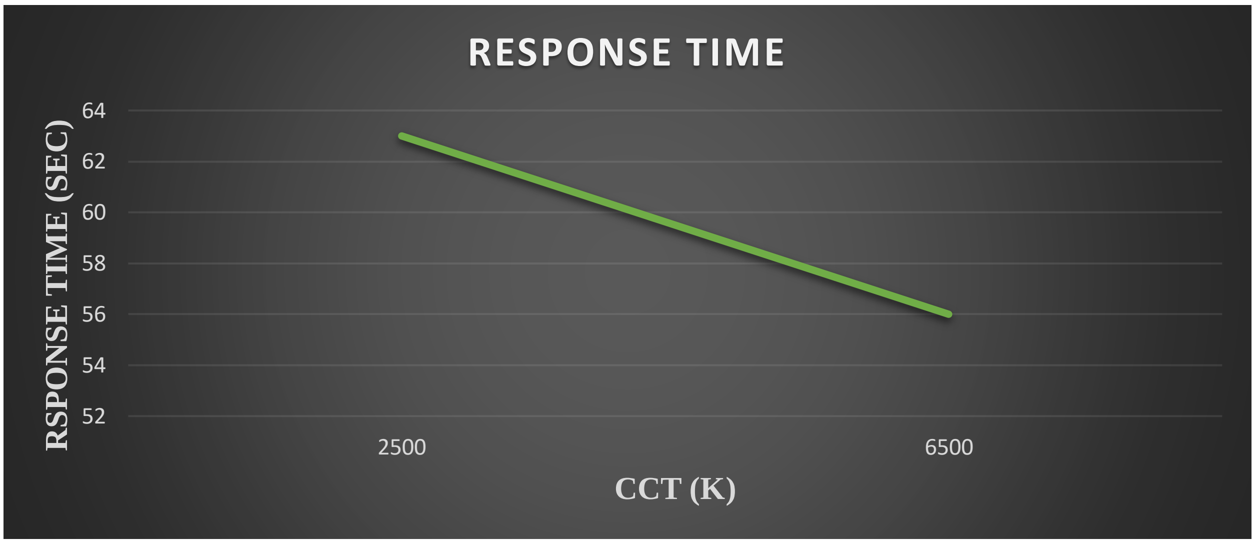


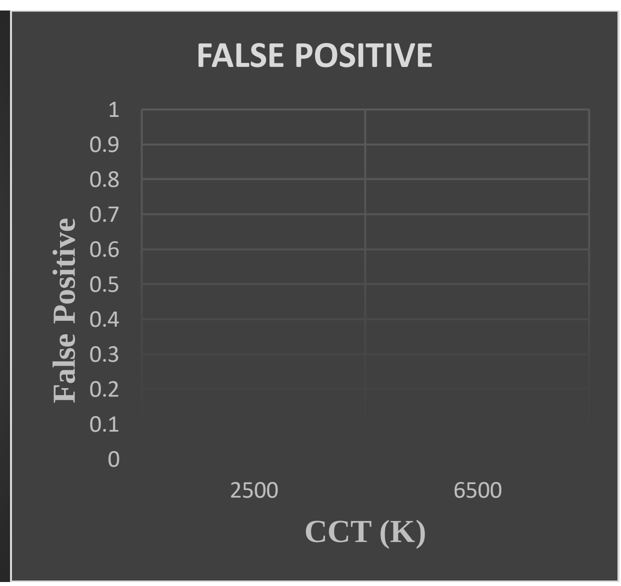




<u>**SUBJECT-4**</u>

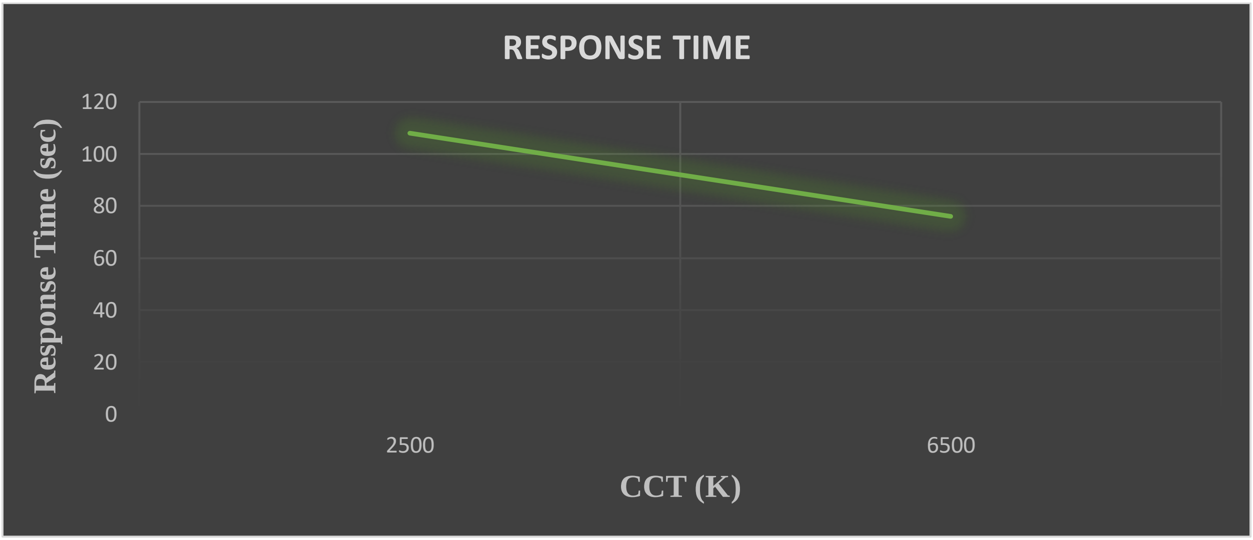
CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	RIGHT	63	50	51	1	0
6500	RIGHT	56	48	51	3	0

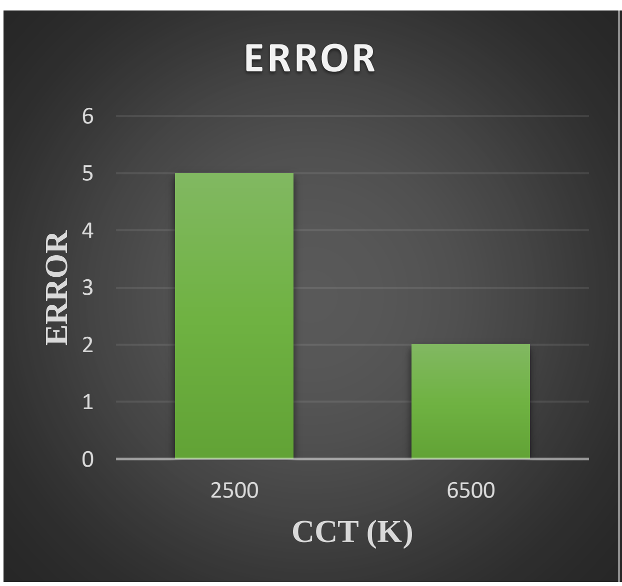


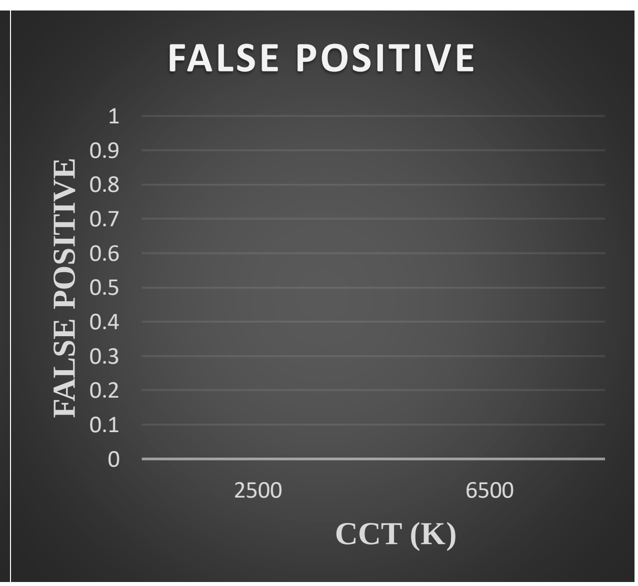


SUBJECT-5

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	RIGHT	108	46	51	5	0
6500	RIGHT	76	49	51	2	0

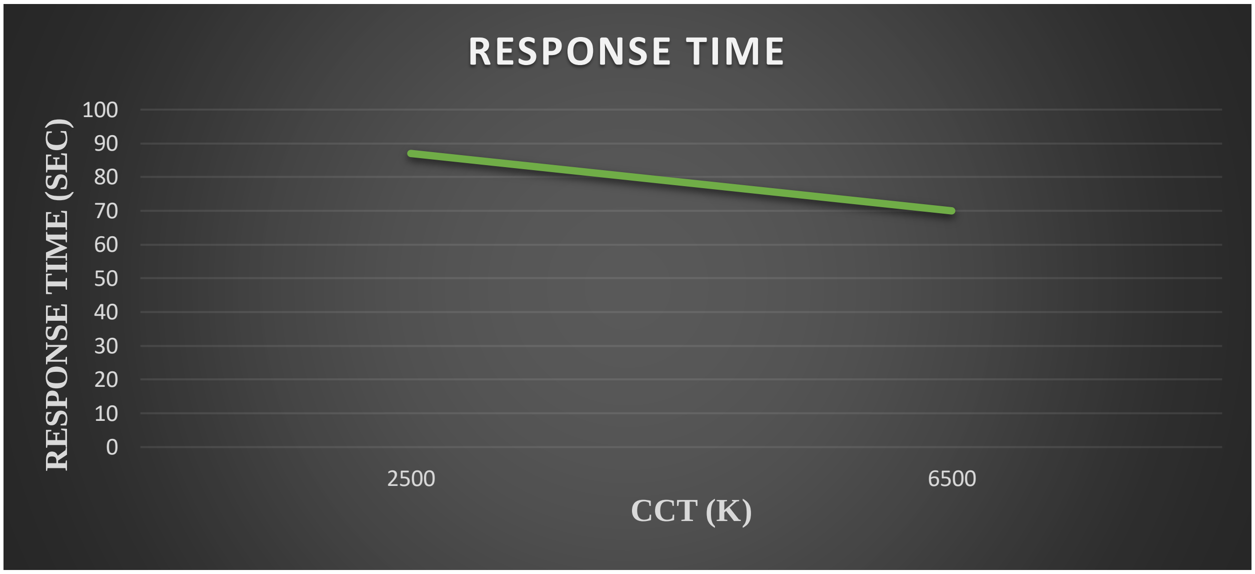


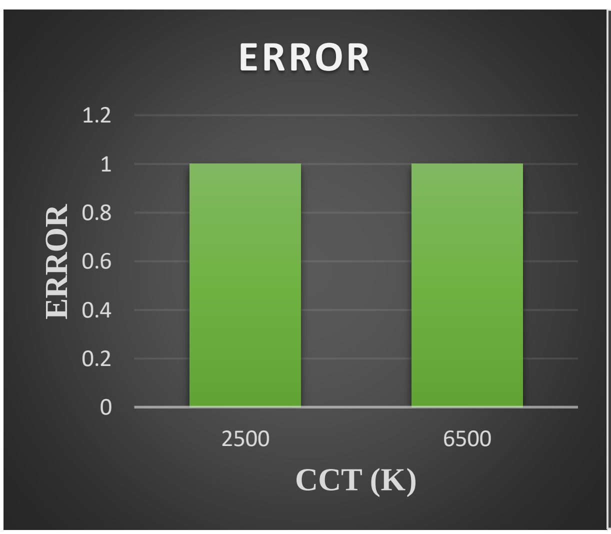


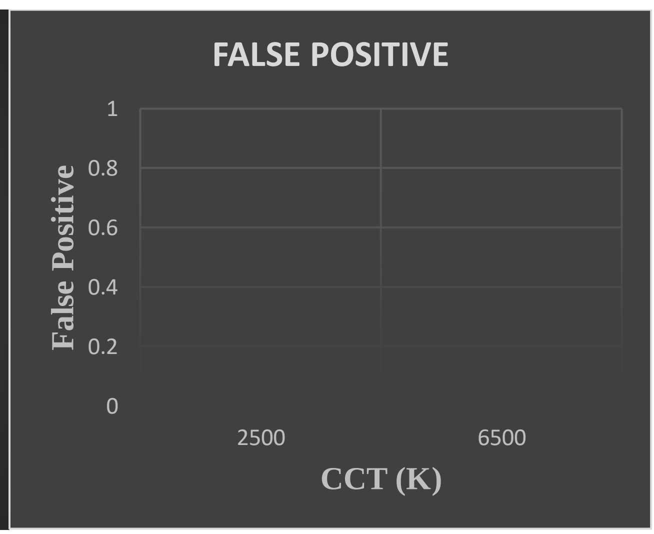


<u>**SUBJECT-6**</u>

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	UP	87	48	49	1	0
6500	RIGHT	70	50	51	1	0

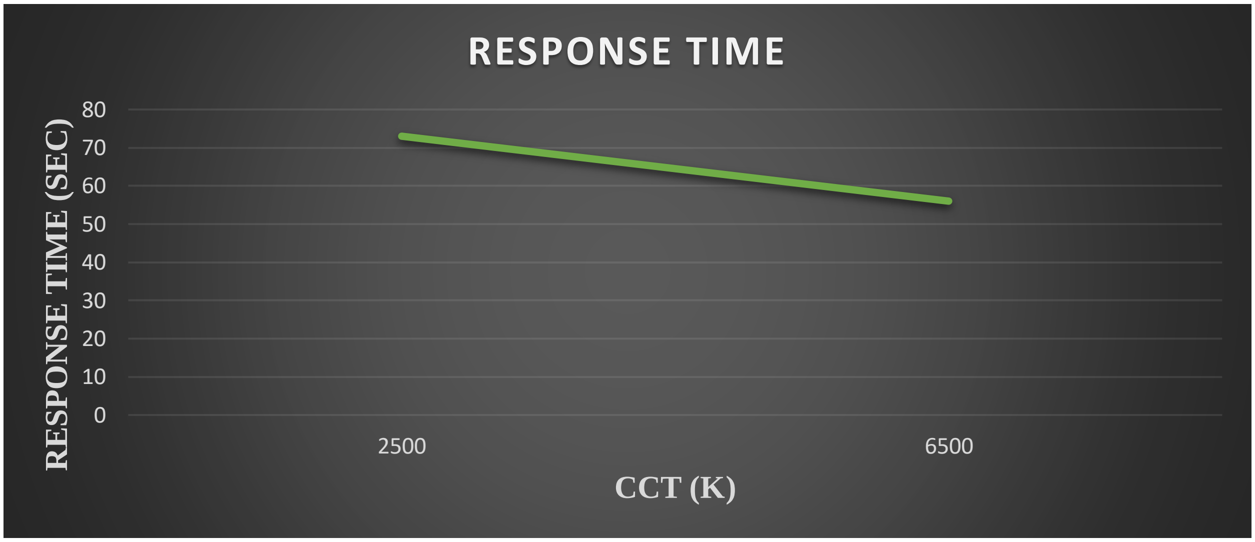


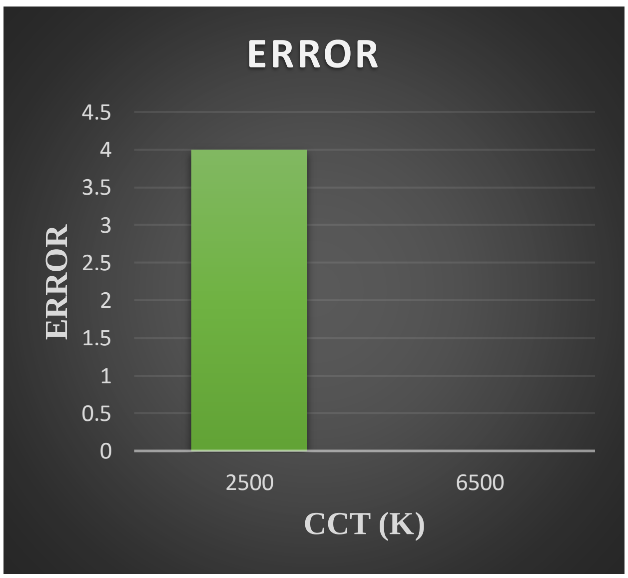


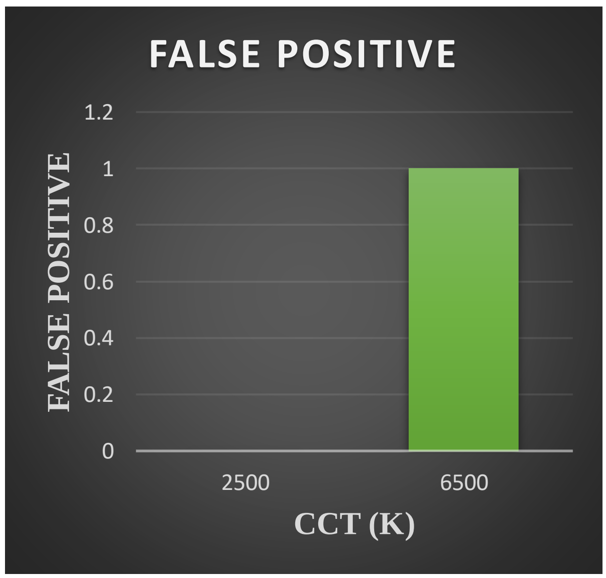


SUBJECT-7

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	RIGHT	73	47	51	4	0
6500	UP	56	50	49	0	0

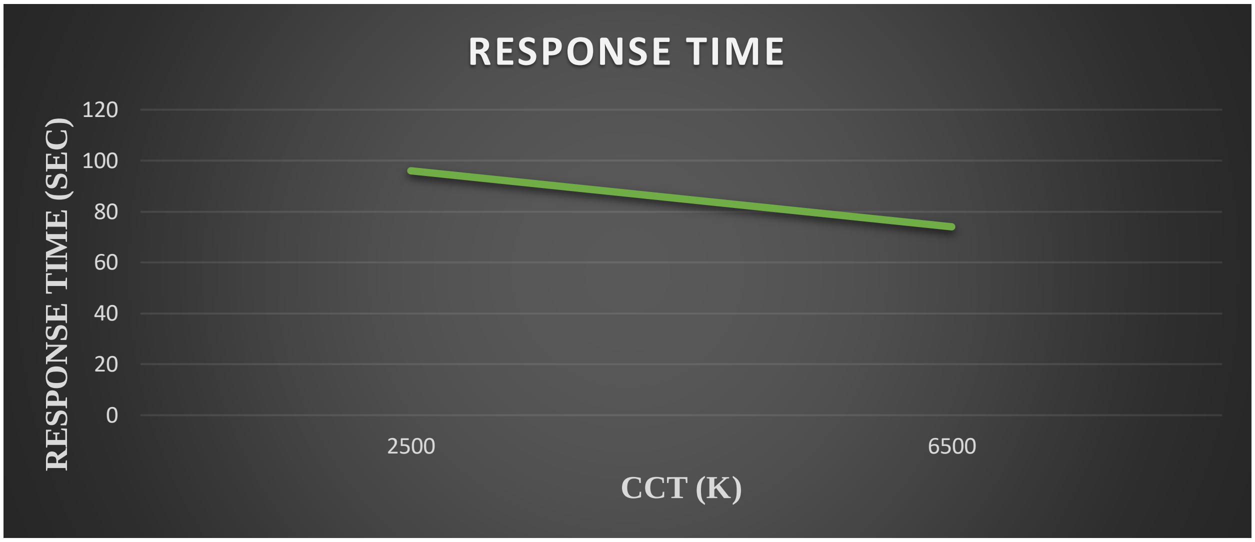


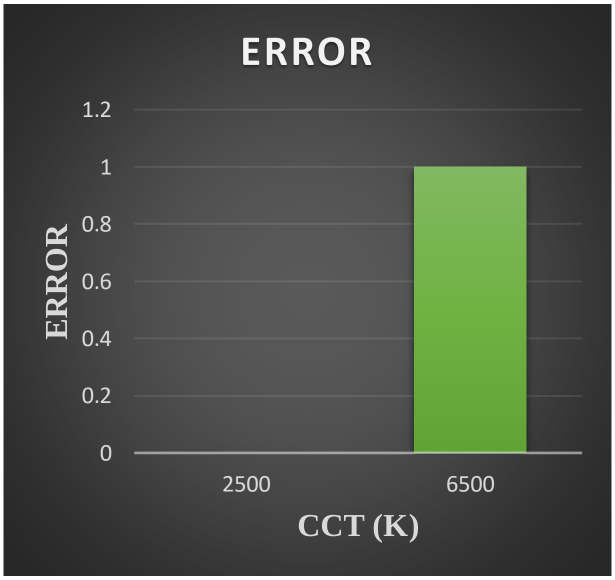


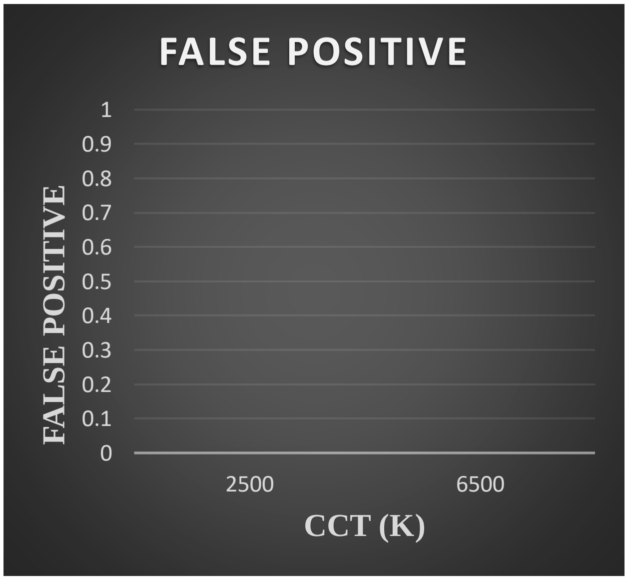


SUBJECT-8

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	96	51	51	0	0
6500	LEFT	74	50	51	1	0

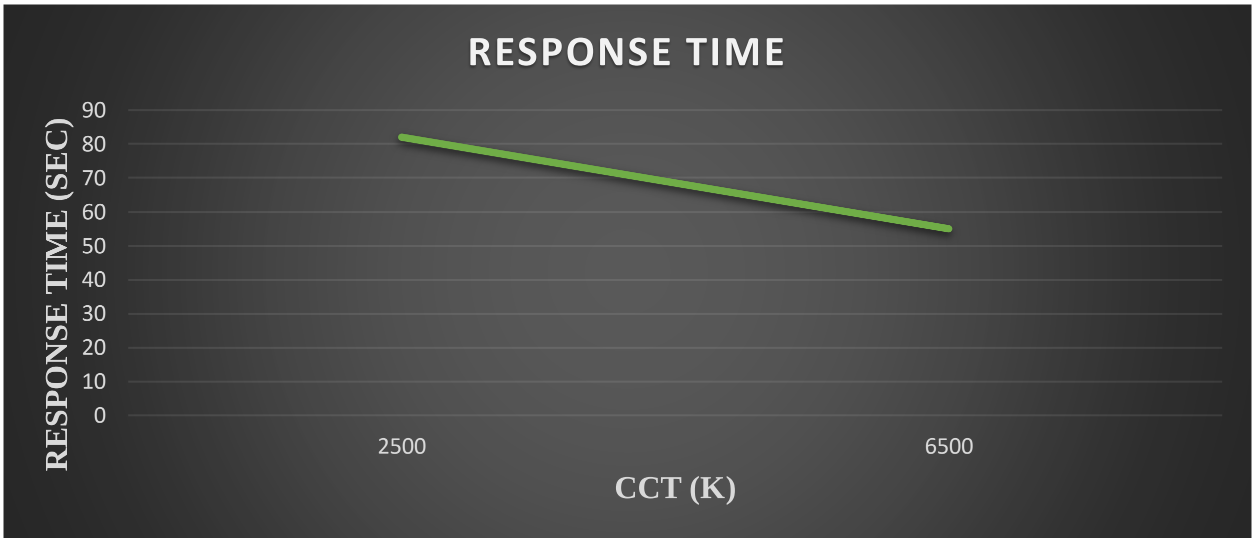


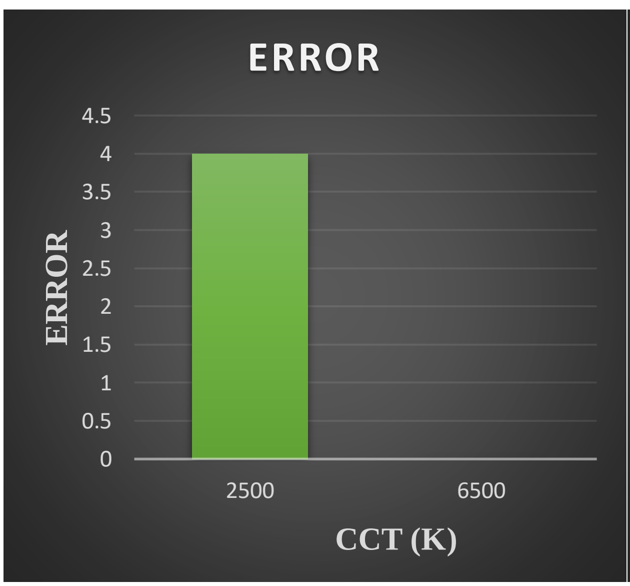


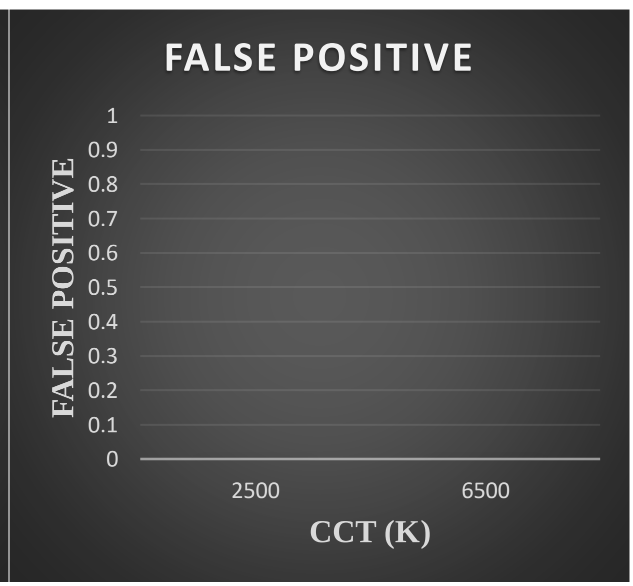


SUBJECT-9

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	82	47	51	4	0
6500	RIGHT	55	51	51	0	0

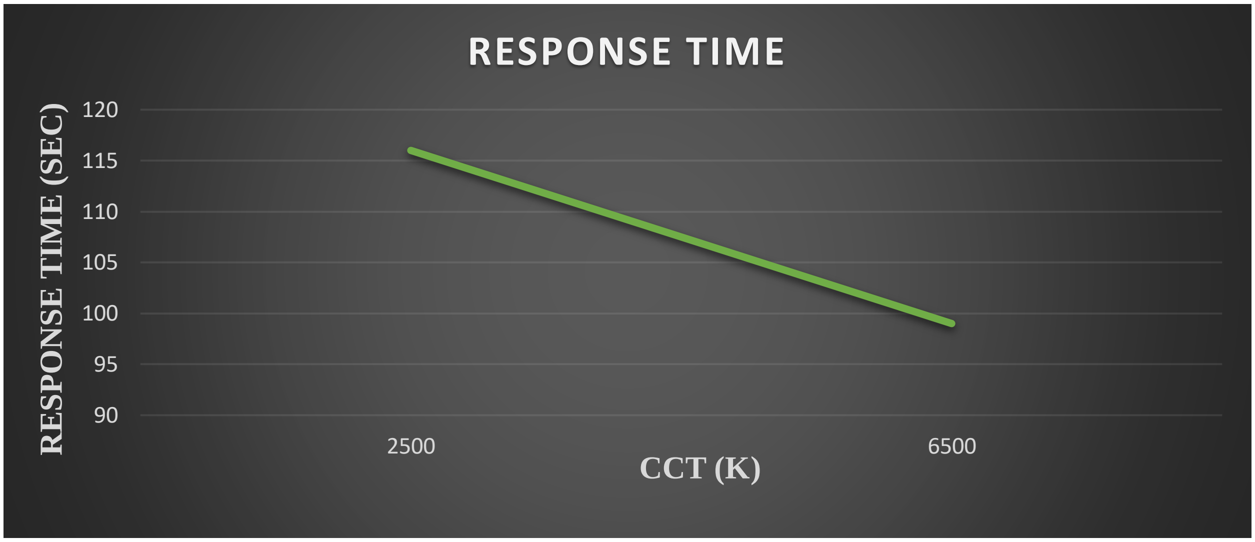


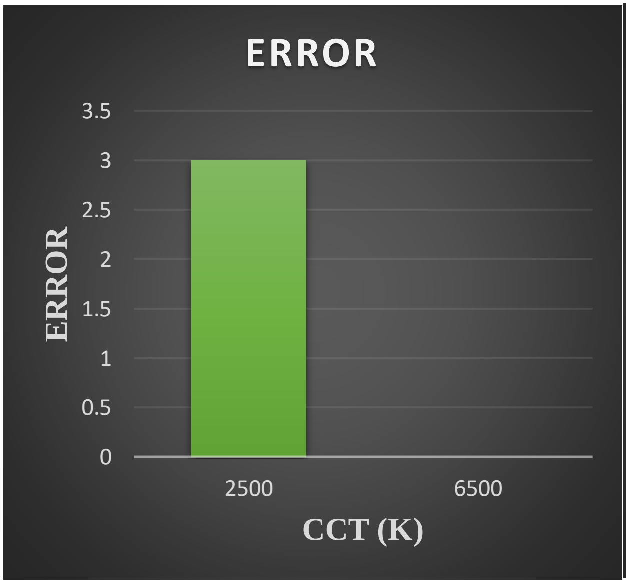


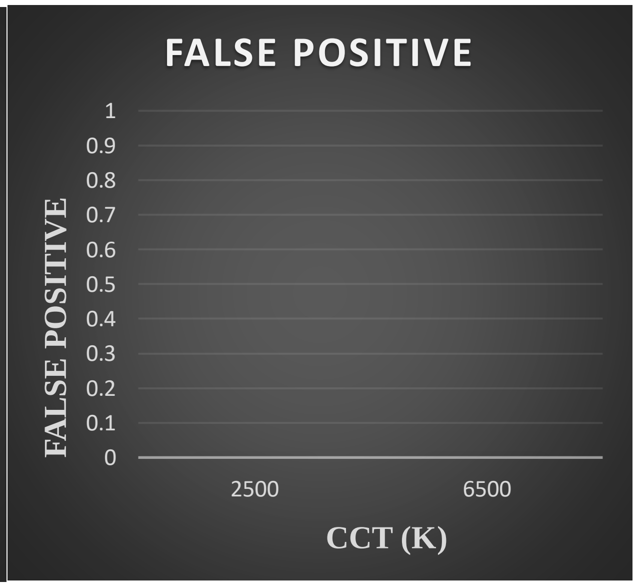


SUBJECT-10

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	116	48	51	3	0
6500	LEFT	99	52	51	0	0

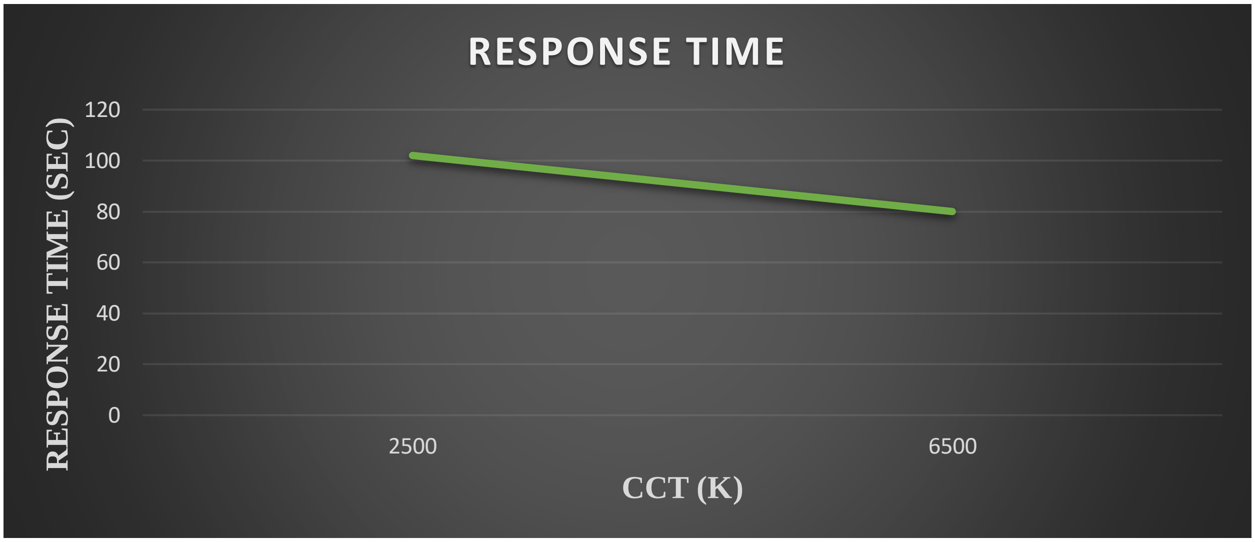


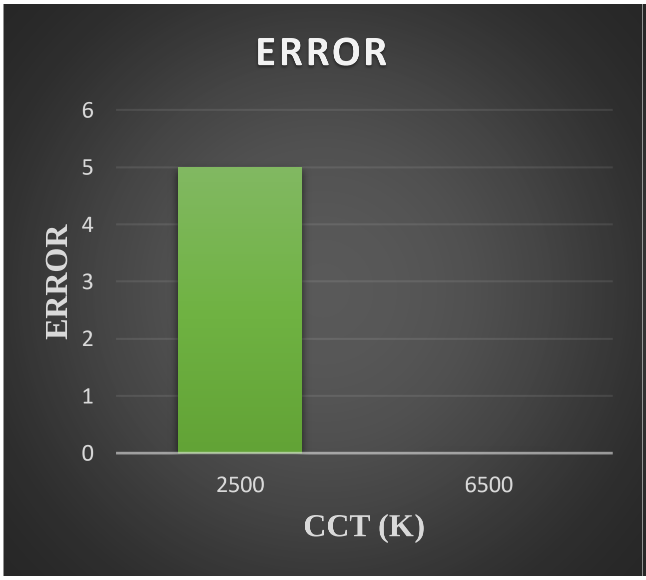


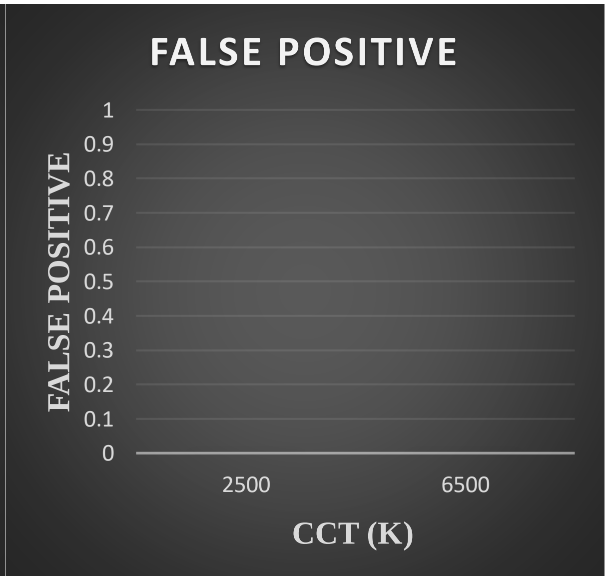


SUBJECT-11

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	102	46	51	5	0
6500	UP	80	45	45	0	0

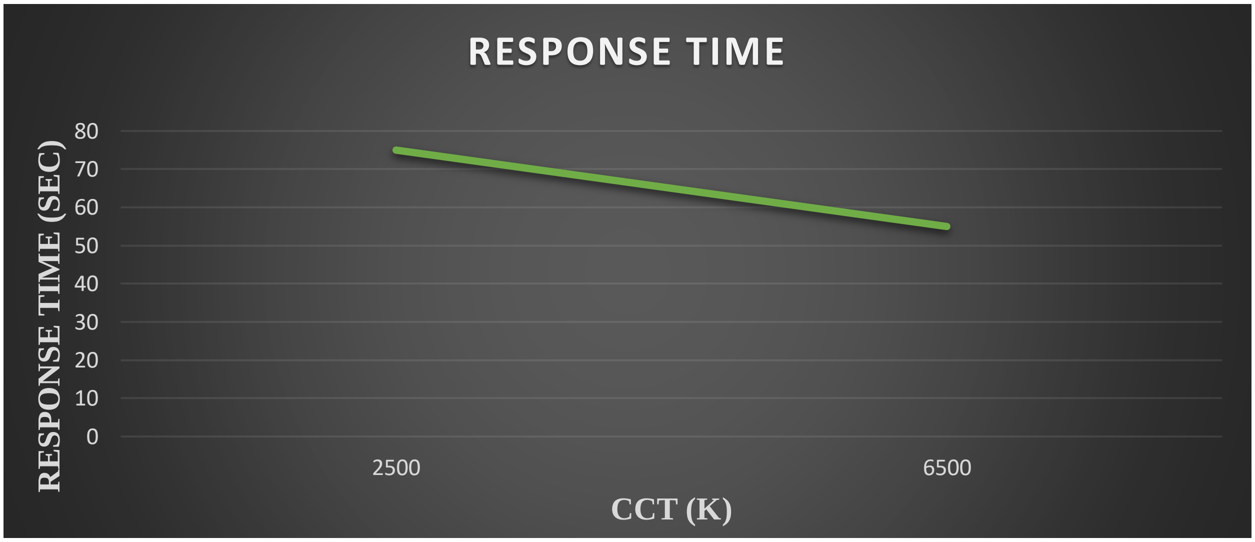


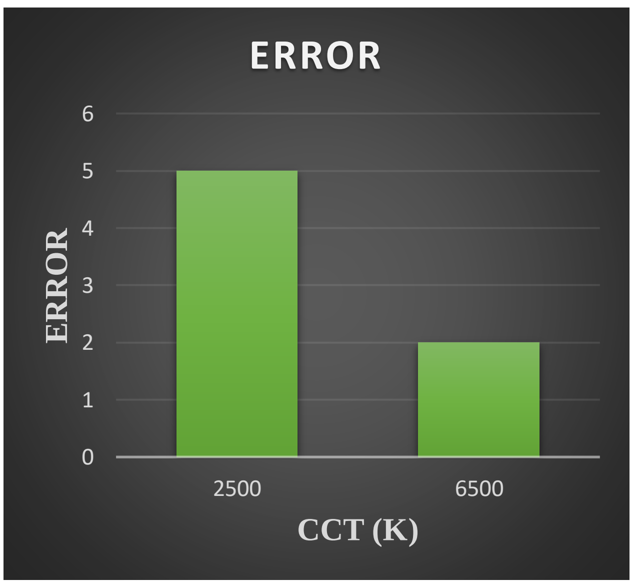


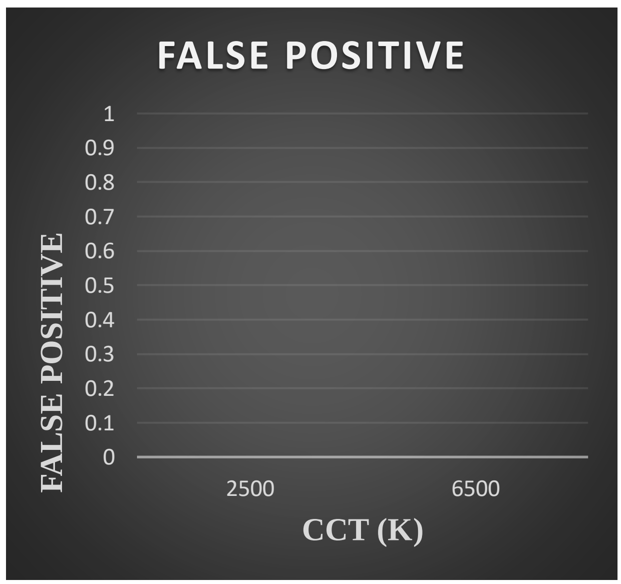


SUBJECT-12

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	75	46	51	5	0
6500	DOWN	55	47	49	2	0

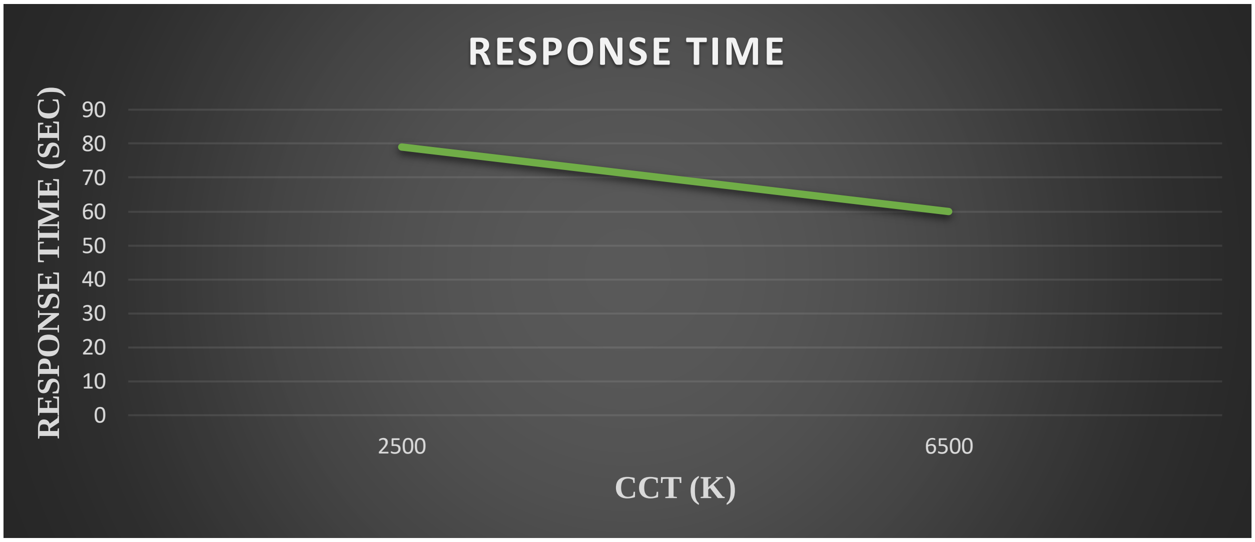


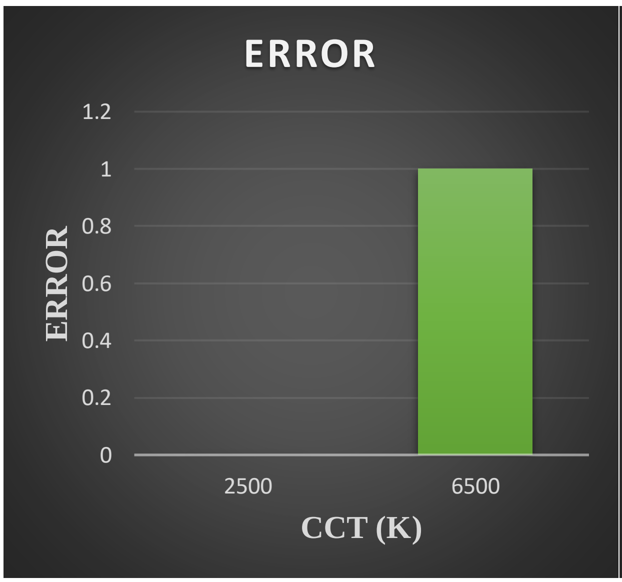


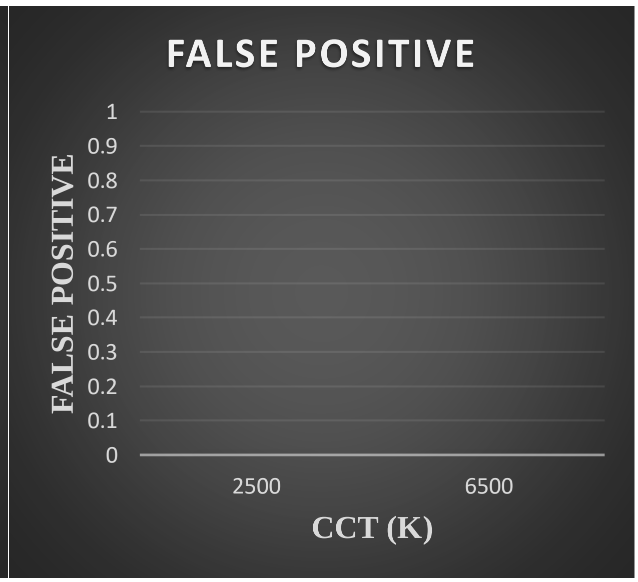


SUBJECT-13

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	RIGHT	79	51	51	0	0
6500	RIGHT	60	50	51	1	0

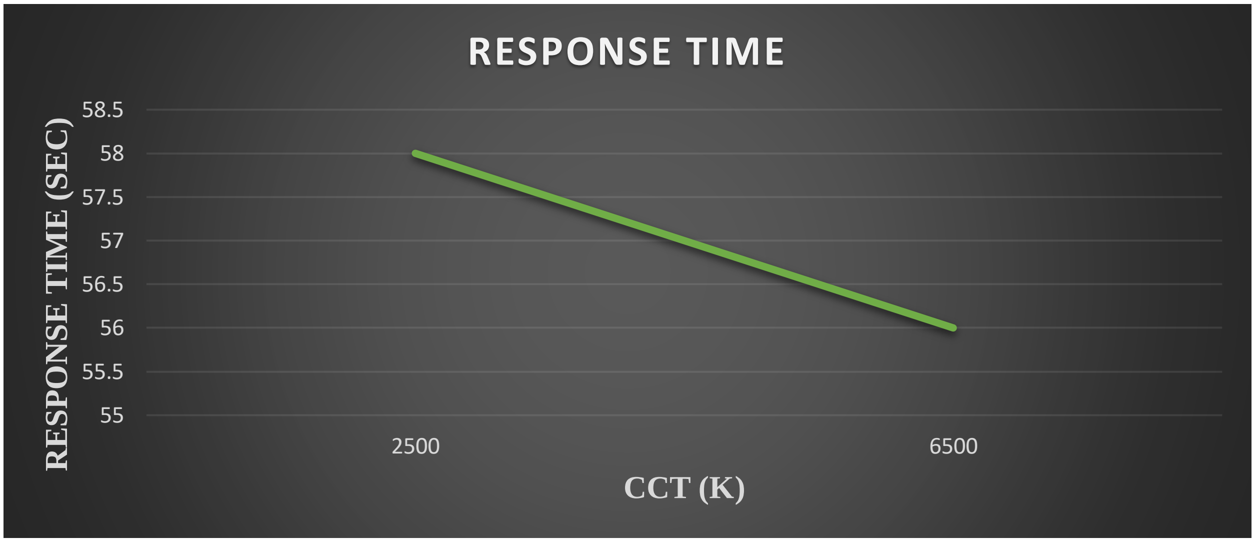


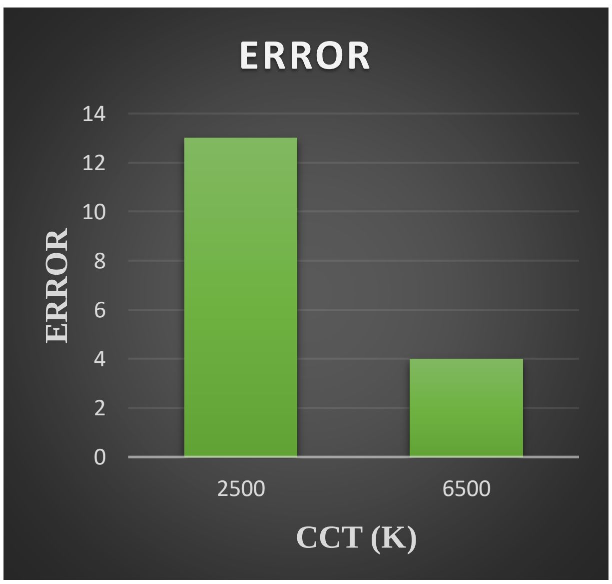


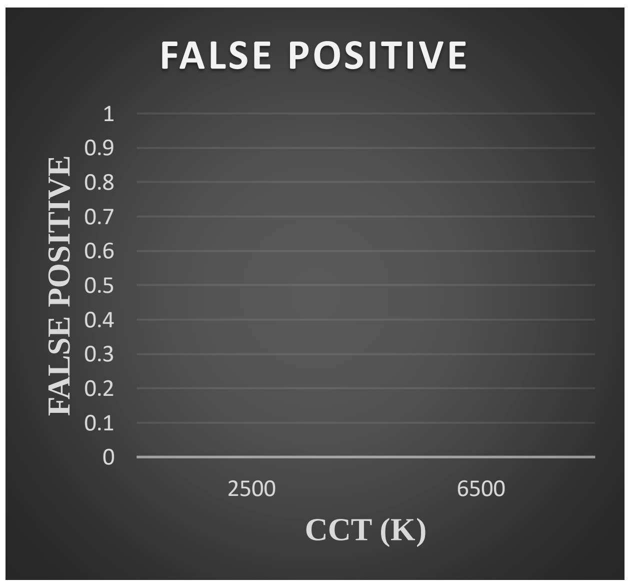


SUBJECT-14

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	RIGHT	58	38	51	13	0
6500	RIGHT	56	47	51	4	0

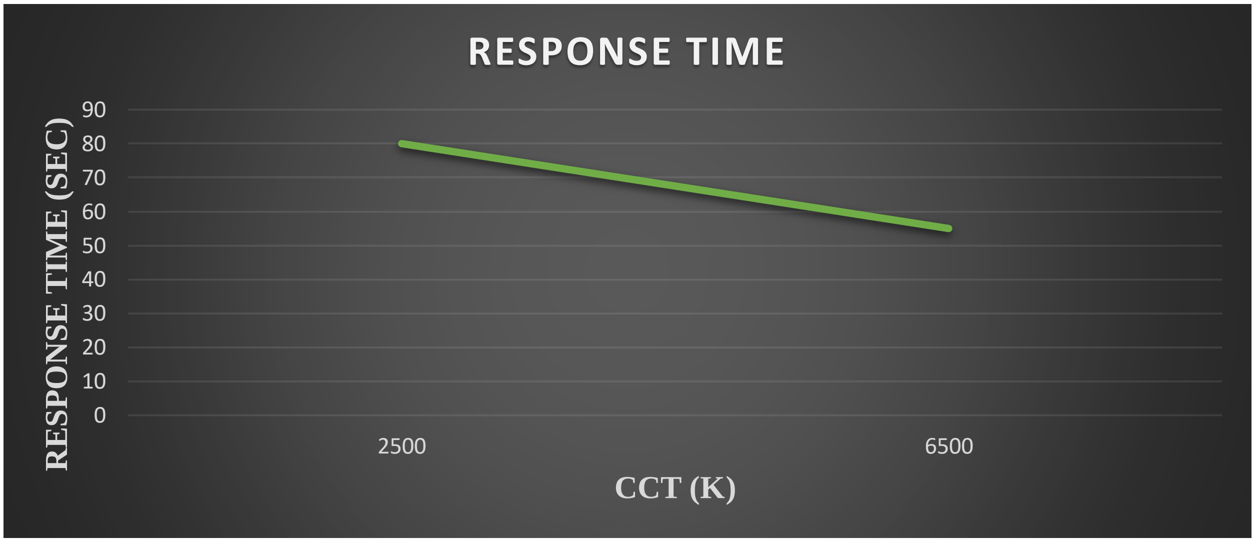


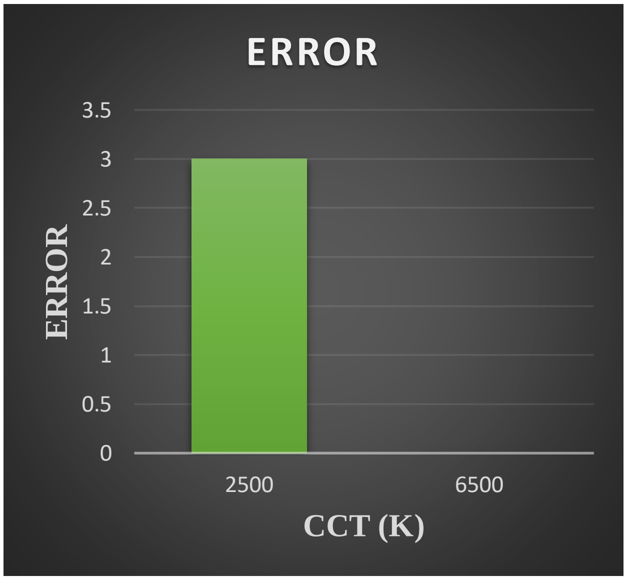


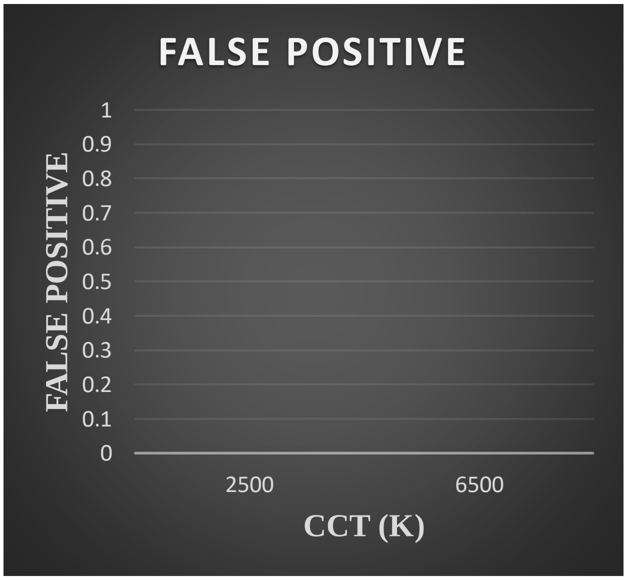


SUBJECT-15

CCT	DIRECTION of Opening Rings	RESPONSE TIME	ACTUAL COUNTS	CORRECT COUNT	ERROR	FALSE-POSITIVE
2500	LEFT	80	48	51	3	0
6500	RIGHT	55	51	51	0	0







4.2 EXPERIMENTAL ANALYSIS

4.2.1 Data Analysis by Single Factor ANOVA

A single factor analysis of variance (ANOVA) is a statistical technique that examines variance to see whether there is a statistically significant difference between the means of three or more groups of data. Ronald Fisher, a statistician, initially proposed it in 1918. [28] After the term was used in Fisher's book "Statistical Methods for Research Workers," it became widely used. This approach builds on the t-tests and z-tests that were used before the invention of ANOVA. [29] The drawback of these tools was that they could only be used to compare the means of two groups at a time. In order to comprehend the diversity within and between groups, it is therefore preferable to do an ANOVA on a large number of groups or populations.

ANOVA is essentially a hypothesis-testing technique that analyses a relatively small sample of a larger population in order to evaluate an educated hypothesis that was generated prior to the test. Similar to ANOVA, when comparing the means of three or more groups of data, the initial assumption is that there is no difference between the means of each group that is taken into account for an acceptable level of significance. The "Null Hypothesis (H_0)" refers to this. "Alternate Hypothesis (H_1)" is a different hypothesis. This hypothesis states that at least one mean differs significantly from the means of the other groups. The ratio of variability between groups to variability within groups, or the F value, is the test statistic for an ANOVA. The p-value can be used to confirm the test results' statistical significance. If the F-value is high and the p-value is less than the level of significance (α), it signifies that there is a high likelihood of having a significant difference between the means of the individual groups. This is because there is a chance of rejecting the null hypothesis even if it is true. The null hypothesis needs to be disproved in that situation.

$$H_0: \mu_1 = \mu_2 .... = \mu_k$$

H_1: All means are not equal

Where, k = number of groups

μ = Mean of each group

The sums of squares (SS), degrees of freedom (df), mean squares (MS), and F-value are typically included in an ANOVA table. Below, these terms and their meanings are briefly discussed:

<u>Sum of Squares (SS)</u>

Data variability is represented by the sum of squares. Sum of Square between Groups is the term used when the variation is compared between groups (SSB). It is calculated by adding together the squared differences between the grand mean ($\overline{X}$) and the individual group means ($\overline{X}_j$), then multiplying those differences by the number of groups' samples (n_j).

$$\boldsymbol{SSB = \sum n_j\,(\overline{X}_j - \overline{X})^2}$$

There is another term called Sum of Square within groups (SSW) which depicts the variations in the data within a single group. It is computed by summing squared differences between each sample (X) of the group and the group mean ($\overline{X}_j$).

$$\boldsymbol{SSW = \sum \left(\overline{X}_j - X\right)^2}$$

The total Sums of Squares (SST) is computed by adding the sum of square between groups (SSB) and sum of square within groups (SSW).

$$\boldsymbol{SST = SSB + SSW = \sum n_j \left(\overline{X}_j - \overline{X}\right)^2 + \sum \left(\overline{X}_j - X\right)^2}$$

Degree of Freedom (df)

The number of independent sample points used to calculate an approximation is referred to as the degree of freedom (df) of the estimate. The degree of freedom between groups or numerator degree of freedom (df_1) and the degree of freedom within groups or denominator degree of freedom (df_2) can be computed using the formulae given below –

degree of freedom between groups(df1) = k – 1
degree of freedom within groups(df2) = N – k

where,
k = Number of groups
N = Total number of sample points

Mean Squares (MS)

The Mean Square value is the ratio between the Sum of squares upon the degree of freedom. The average sum of the square between groups (MSB) is computed by dividing the sum of squares between groups (MSB) by the numerator degree of freedom (df_1) and the average sum of Square within groups (MSW) is calculated by dividing the sum of square within groups (SSW) by denominator degree of freedom (df_2).

$$MSB = \frac{SSB}{df_1} = \frac{\sum n_j (\overline{X}_j - \overline{X})^2}{k-1}$$

$$MSW = \frac{SSW}{df_2} = \frac{\sum (\overline{X}_j - X)^2}{N-k}$$

F-Value

The test statistic of ANOVA, which is also known as F-value is the ratio between the average variability between groups and the average variability within groups.

$$F - Value = \frac{MSB}{MSW}$$

$$F - Value = \frac{\frac{\sum n_j (\overline{X}_j - \overline{X})^2}{k-1}}{\frac{\sum (\overline{X}_j - X)^2}{N-k}}$$

If any group mean is found to be statistically significant from the other group means, the F-value should be compared to the F-statistic or the F-critical value and the p-value should be examined. The F-distribution curve, which depends on the degree of statistical significance (α), degree of freedom in the numerator df_1, and degree of freedom in the denominator (df_2), can be used to determine the F-critical value df_2. The findings of the test are noteworthy if the F-value is higher than the F-critical level. In that situation, the p-value, which must be smaller than the statistical significance level (α), should be used to reject the null hypothesis.

One-way and two-way ANOVAs are the two categories into which ANOVAs are divided based on the number of independent variables or components. A one-way ANOVA only takes into account one factor that influences the findings, but a two-way ANOVA takes into account two independent variables. One may think of two-way ANOVA as a progression from one-way ANOVA. Because a two-way ANOVA test comprises two independent factors, the individual effects of each independent factor on the dependent variable are first assessed, just as it is in the case of a one-way ANOVA. Additionally, the interplay between the elements is addressed by taking into account every aspect at once.

One of the main problems with ANOVA is that it can only confirm that the means of all the groups are different; it cannot say which group is statistically different. Post hoc tests are essential when three or more groups are being analyzed in order to identify the statistically significant group. The two-tail t-test is one method for performing post hoc analysis. It analyses the means of two groups simultaneously and does other comparisons based on the group size. However, when the number of comparisons increases, the experiment-wise error rate also dramatically increases. The statistical significance level (α) is the same as the experiment-wise error rate. The likelihood of false positive results or rejecting the null hypothesis when it is true increases with more tests being run. After a given number of groups have been analysed, getting a false positive is almost always clear. It is essential to control the error rate in order to ensure the accuracy of the results. The Bonferroni correction method is one of the easiest ways to lower the mistake rate. It advises calculating the p-value for each comparison test by dividing the statistical significance threshold (α) by the number of comparisons (n). If a group continually has a p-value for comparisons with other groups that is less than α/n, that group is regarded as statistically significant when compared to other groups.

One-way ANOVA has been used to analyse the response time of the task with the factor being correlated colour temperature. The significance level (α) was set at 0.05. Two separate tests were conducted - one for the response time of the task and another for counting error to check whether Correlated colour temperature has any significant effect on these parameters. The results has shown significant difference in response time (F = 9.192472, p-value < 0.001) in Table (4.2.1.1). The counting error were also statistically different (F = 7.692015, p-value < 0.001) in Table (4.2.1.2).

Source of Variations	Sum of Squares (SS)	Degrees of freedom (df)	Mean Squares (MS)	F	p-value	F-critical
Between Groups	2218.8	1	2218.8	9.192472	0.00519	4.195972
Within Groups	6758.4	28	241.3714			
Total	8977.2	29				

Table (4.2.1.1): *ANOVA table for the response time with factor CCT (K)*

Source of Variations	Sum of Squares (SS)	Degrees of freedom (df)	Mean Squares (MS)	F	p-value	F-critical
Between Groups	86.7	1	86.7	7.692015	0.009759	4.195972
Within Groups	315.6	28	11.27143			
Total	402.3	29				

Table (4.2.1.2): *ANOVA table for the error rate with factor CCT (K)*

CHAPTER-5

5. DISCUSSION

The experiment focuses on an abstract study that has two components. The first component seeks to determine the overall time required to complete the Landolt ring chart counting of a certain direction opening, and the second half is concerned with figuring out how many misses and false positives there were for the same task. Two CCTs, 2500K and 6500K, were selected, and both portions were completed for each CCT taken into consideration. Sections (5.1) and (5.2) display the responses and data visualisation for all subjects.

5.1 Average response Time detection under two different CCTs

Under two distinct CCTs, the experimental study was conducted on fifteen participants in all. 2500K and 6500K CCTs were used. The given table (5.1) displays the average response time for actual counting of Landolt's ring, and (figure 5.1) displays the average response time for all subjects as a graphical representation.

CCT (K)	Average time response for detection (in sec)
2500	81.87
6500	64

Table (5.1): *Average response time for detection of all the subjects*

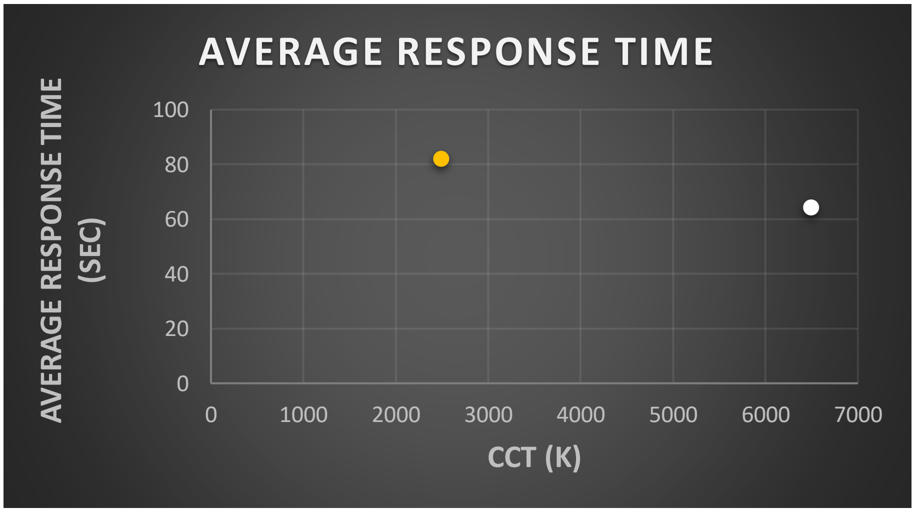


Figure (5.1): *Average response time for counting at different CCT (K)*

It is clearly visible that the average response time drastically drops from 81.2 sec to 64 sec at CCT 2500K to 6500K.

5.2 Number of errors and false positives under different CCTs

The average number of misses and false positives of all subjects obtained within the specified time are shown in the given table (5.2) and the graphical representation of the average number of misses of all the subjects is shown in (figure 5.2).

CCT (K)	Average error	Average false positive
2500	5	0.066666667
6500	1.6	0.066666667

Table (5.2): *Average no. of errors and false positives of all the subjects*

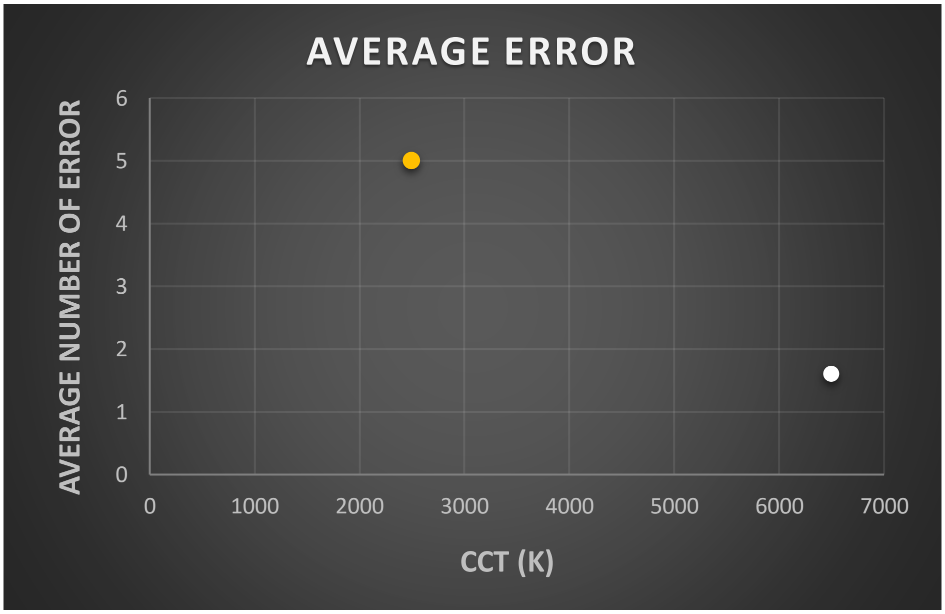


Figure (5.2): *Average number of misses*

The average number of misses in figure (5.2) is maximum at 2500K and minimum at 6500K. At CCT, the number of misses dropped from 1.6 to 5 between 2500K and 6500K.

It is obvious that in all the CCTs taken into consideration for all the subjects, the average number of false positives was zero.

Hence, this section can be concluded that at CCT level 6500 K, all the participants performed very comfortably and counted quickly Landolt's ring with minimum error.

CHAPTER-6

6 CONCLUSIONS

Lighting factors such as spectrum composition, illuminance value, correlated colour temperature, colour rendering, efficacy, etc. may be easily regulated with the introduction of the most recent illumination engineering technology. The identification of intrinsically photosensitive retinal ganglion cells (ipRGC) in the human eye led to the development of the conventional illumination engineering methodology. One can experience lighting's visual and non-visual impacts through lighting design and application. In the twenty-first century, numerous studies on the psychological and physiological impacts of lighting on human behaviour have been carried out. Thus, the term "human-centric lighting" has become entrenched.

This project study was completed using Human Centric approach and Led technology.In this work has been identified the effect of correlated colour temperature on human task as such counting Landolt’s ring. The participants were counted rings with two CCT lebels. In addition, this study was used EEG technology. The EEGLab toolbox may be used to quickly analyse the electrical signal data relating to brain activity.

To discuss office lighting or interior lighting design, which is important to implement for improved human performance and vision. Illuminance level as well as light CCT has effect on people both psychologically and physiologically.

Both survey based and EEG-based data were employed in this investigation. As a result, behavioural results can vary depending on the subject. EEG data can vary from person to person as well. Additionally, due to the disruptions, capturing the EEG data is quite difficult. As a result, there are many factors to take into account and the results may differ.

The participants concluded that the light source with a 6500K CCT was the most comfortable to perform at and preferred it over one with a 2500K CCT. Participants claimed that 6500K CCT lighting settings were more pleasant than 2500K CCT lighting conditions, and that they could imagine themselves performing tasks performance there without discomfort.

CHAPTER-7

7 EEG-BASED HUMAN TASK PERFORMANCE

7.1 Electroencephalography (EEG) Study

The control centre of the entire human body is the brain. It controls routine motor functions, moods and emotions, memory, appetite, touch, breathing, and other daily functions. The brain processes all the data received from the sense organs, and the body subsequently performs necessary functions in accordance with the brain's instructions. The human brain's billions of neurons control how information is received, translated, and distributed. The neurons use the electrical impulses they produce to communicate with one another. It causes the brain's voltage to fluctuate. Membrane transport proteins pump ions across their membranes to produce the ionic current. Similar charge polarity ions repel one another. A non-linear electrical signal wave is created when a neuron's ionic charges reject its neighbouring neurons, who in turn repel their neighbours. Volume conduction is the name of this mechanism. Electroencephalography is the process of gathering brainwaves in order to extract valuable information.

The first person to record human EEG waves was **Hans Berger**, a German scientist and psychiatrist after it became clear that rabbit and monkey brains had electrical activity. It is regarded as a seminal invention because it made it possible to study how the brain responds to varied stimuli. In addition to more conventional uses like the diagnosis of epilepsy and sleep disorders, EEG is frequently used for cognitive research, Brain-Computer Interface (BCI), work-space optimization, and neuromarketing.

The cerebral cortex, the brain's outermost layer, is the sole place where EEG equipment can record brain waves. The resulting electric field may push or pull the valence electrons from the metal electrodes when millions of neurons collaborate to produce the ionic current. It is possible to record the potential difference between any two electrodes being pushed or pulled. Raw EEG data are the voltage variations that were recorded throughout time, as illustrated in (figure 7.1).

Normally, the neurons' electrical pulses range in frequency from 0.5 Hz to 100 Hz. Depending on our actions or experiences on a physical and mental level, the frequency of brain wave oscillations changes. It has been discovered that the frequency of these signals and the level of neuronal activity are related. While the high frequency and low amplitude waves are linked to a noticeably more active state of mind, low-frequency waves with bigger amplitude are related to a peaceful and sleepy state of mind. Although there is no linear relationship between brainwave frequency and the function of the brain, depending on the activity of the brain, brainwaves are classified into five frequency sub-bands, namely delta (0.5 – 3 Hz) band, theta (4 – 7 Hz) band, alpha (8 – 13 Hz) band, beta (14 – 30 Hz) band, and gamma (31 – 100 Hz) band.

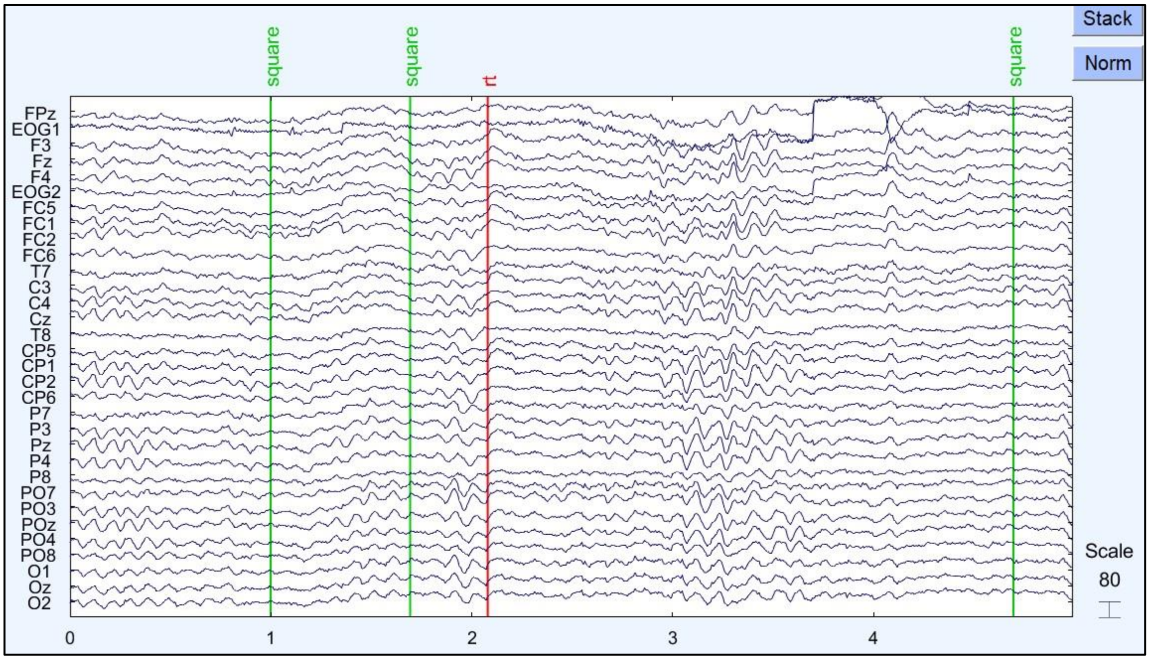


Figure (7.1): *Raw EEG data*

7.2 EEG Data Recording Procedure

Participants were made to feel at ease and ready for continuous EEG data collection when they arrived. Sintered saline-based electrodes mounted on Quickcaps (placement 10/20 system) were used to record EEG from 32 scalp locations with reference to the left and right mastoid (Compumedics Neuroscan, USA).

Blink and lateral movement patterns were captured by four additional electrodes positioned medially below and above the eye. In accordance with the conventional BESA coordinate system, which is defined by the nasion, inion, and two peri-auricular points, standard electrode positions for Quickcaps (as provided by the manufacturers) were modified to participants. By abrading the skin, inter-electrode impedances were kept low (20 KΩ). EEG recordings were first digitalized at 1024 Hz after being bandpass filtered with cutoffs at 0.05 and 250 Hz (analogue filter).

The EEG equipment was simultaneously recording the participant's EEG data while they were counting Landolt's ring chart as mention direction under the 4500 CCT condition. In this investigation, "EMOTIV EPOC FLEX" with saline sensors was used. One of the main factors in choosing this gadget was its portability, which was necessary to guarantee the performers' freedom of movement. 32 electrodes (Cz, Fz, Fp1, F7, F3, FC1, C3, FC5, FT9, T7, CP5, CP1, P3, P7, PO9, O1, Pz, Oz, O2, PO10, P8, P4, CP2, CP6, T8, FC6, C4, FC2, F4, F8, Fp2) and two reference electrodes, Common Mode Sense (CMS) and Driven Right Leg, are included (DRL). DRL must be positioned over the right mastoid, and CMS must be positioned over the left mastoid.

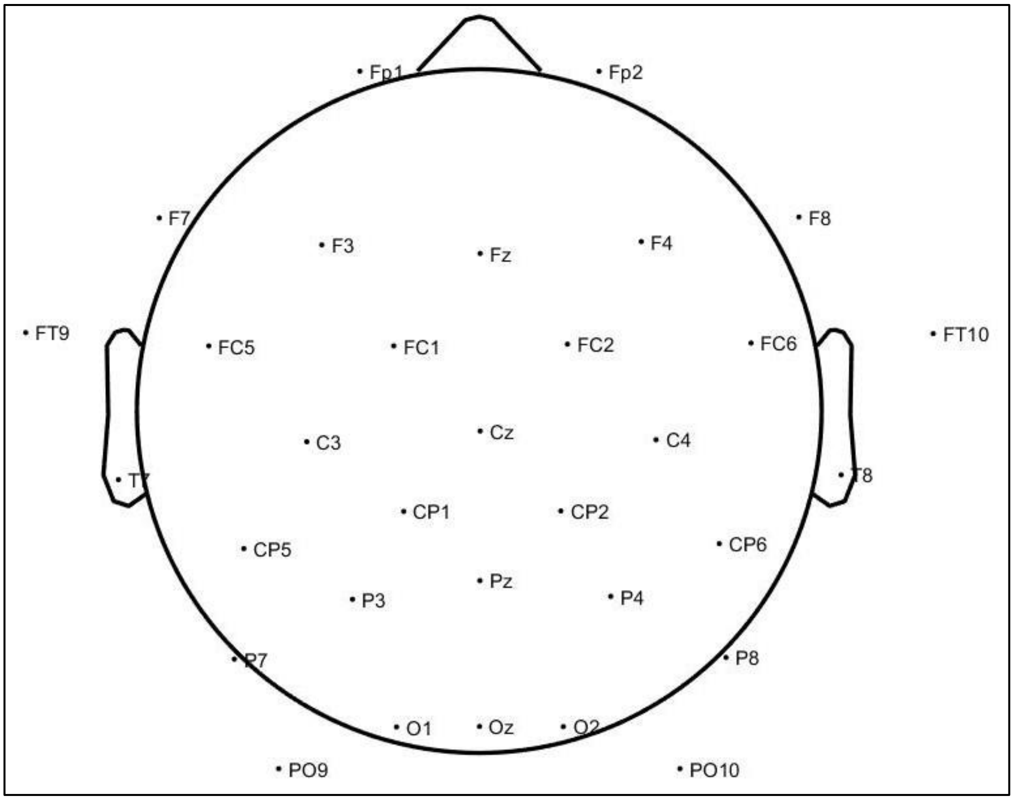


Figure (7.2.1): *EEG channel locations*

According to the International 10-20 system, all of the sensors are enclosed in caps at the predetermined locations. 17 sensors (16 sensors + 1 reference) are coloured blue and should be placed on the left side of the scalp. The remaining sensors are coloured red and should be placed on the right side. Each sensor has a hollow aperture to fit the felt pads, which must be submerged in saline solution before utilising the EEG machine. The outputs of the sensors must be connected to a wireless controller after the electrodes have been set up and placed appropriately. Each electrode's raw EEG data is captured at a sampling rate of 128 SPS and wirelessly transmitted to a computer using a generic USB receiver. The "EMOTIV Pro" programme allows for the visualisation of real-time data.

(Figure 7.1) displays the subject raw EEG data taken in 4500 K CCT illumination conditions. Although the electrodes were placed to only record brain signals, some noise signals were also recorded because of the electrodes' high sensitivity. In order to remove the artefacts from the raw EEG signals, the data must first be cleaned. Fast Fourier Transform (FFT) analysis was used to retrieve meaningful information from the preprocessed signals later on. Plots were made using the Power Spectral Density (PSD) of various brain waves and topographic scalp maps for each Epoch seconds. In section 6.3, the pretreatment stages and analytic method are covered in great detail.

Figure (7.2.2): *EPOC FLEX saline sensor kit*

7.3 EEG Data Analysis

MATLAB R2019a has been used to preprocess and analyse the acquired EEG data. After each session, the recordings were downloaded in European Data Format (.edf) and stored on a laptop. After the data collection process was complete and the participant's EEG recordings under 4500 CCT lighting conditions were accessible, the data analysis method started. It was necessary to download the "EEGLAB" MATLAB toolbox, which features an interactive graphical user interface and a number of extensions for EEG signal processing. This made the process simpler. Prior to starting the data analysis, the connection between MATLAB and EEGLAB was established. The figure illustrates the procedures taken for EEG data analysis (figure 7.3).

With the use of the EEGLAB toolkit [30] and unique Matlab (Mathworks Inc.) scripts, the EEG data were preprocessed and analysed.

Preprocessing aimed to minimise extremely large movement artefacts and non-brain signals. Epochs were retrieved after the raw data had been bandpass filtered (FIRS filter, cutoffs of 0.5 and 45 Hz), resampled at 512 Hz, and referred to CMS- DRL. Rejecting tests that were tainted by motions, non-repetitive artefacts, and electrode pops. Using a 75 µV threshold, extremely large implausible values were manually recognised and eliminated.

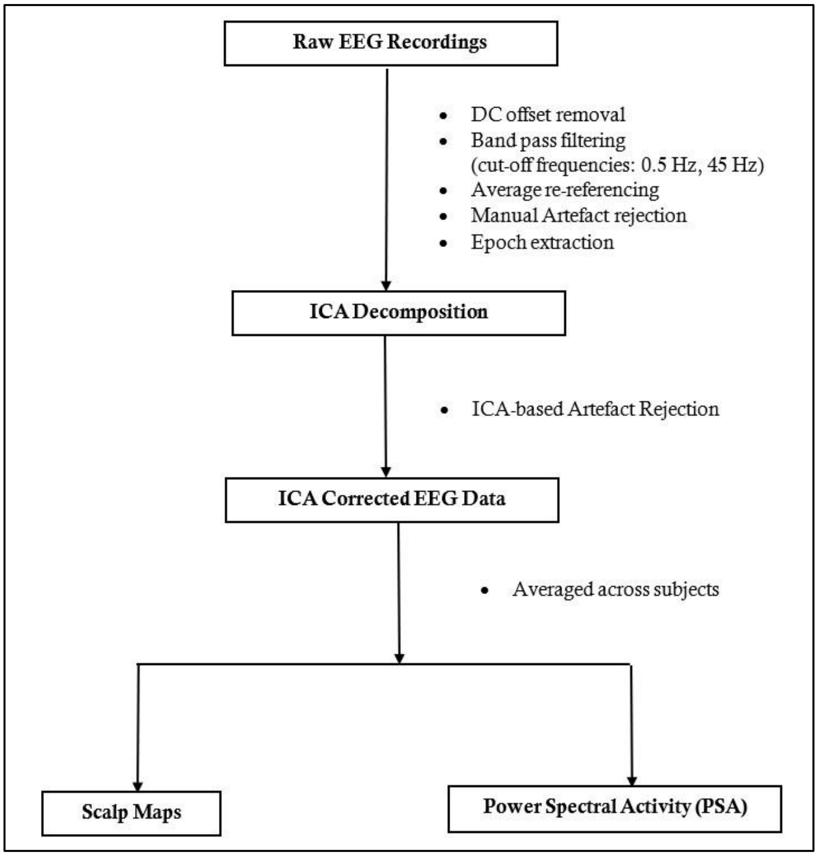


Figure (7.3): *The step-wise EEG data analysis*

Blinks, lateral eye movements, and electromyogenic activity, which are repetitive artefacts in single trials, were kept in the dataset and rectified using independent component analysis (ICA). For the separation of neuronal and artifactual activity, the visually trimmed datasets were sent to extended Informax ICA[31]. The programme divided the datasets into 64 components that were maximally time independent and spatially fixed (ICs). The resultant ICs stand in for the many spatially filtered sets of scalp EEG activities that linearly add up to produce the recorded data. Using established standards, brain ICs and non-brain ICs were distinguished. [31][32][33][34] Far frontal medial maxima on ICs including blinks were used to identify them, while significantly dipolar bulbs on the lateral portions of the topography and irregular occurrence/timing across trials were used to identify lateral eye movements. The juxtaposed dipoles, flat activity spectra, non-dipolar scalp maps, and irregular occurrence were used to identify the myogenic artefacts. Based on spectral studies at 25 Hz, 20 Hz, and 40–80 Hz, respectively, frontalis and temporalis muscle activity was also discovered. These ICs were individually eliminated, and pruned datasets with decreased artefacts were then used for further research. After averaging the ICA-corrected datasets across circumstances, scalp maps were produced at appropriate time intervals.

7.4 EEG-Based Result

Event Related Potential data related to object detection were computed for each channel in order to assess the human real-time performance. In order to perform Landolt's ring counting, the ERP for all 32 channels was then combined and plotted as scalp contours in a temporal frame between the moment the stimulus is presented and the moment the subject responds (epoch). (figure 30) displays the subject's topographical scalp maps and activity power spectrum while counting the Landolt's ring at 4500 K CCT.

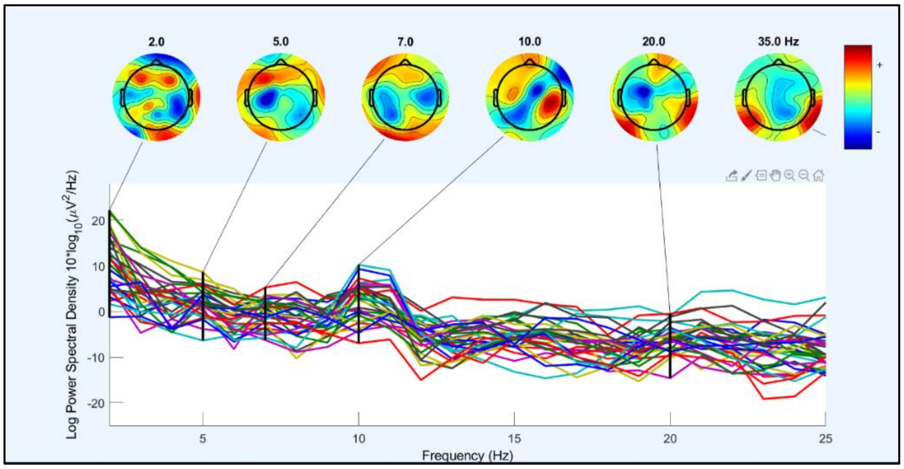


Figure (7.4.1): *The topographical scalp maps as well as the activity power spectrum of a subject counting the Landolt's Ring chart in the presence of 4500 K CCT of lighting condition.*

The various colours in (figure 30) depict the degree of activity in the various brain areas related to the task. While other colours imply engagement on a scale, red denotes maximal engagement.

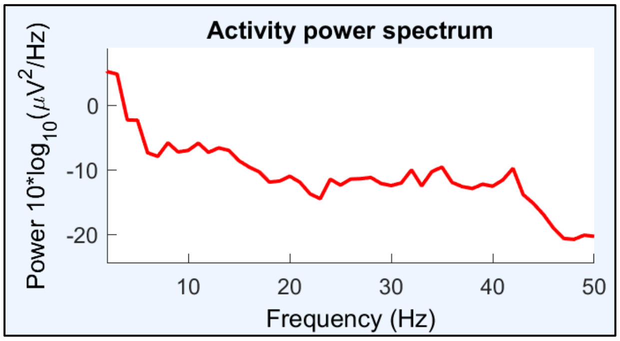


Figure (7.4.2): *Activity power spectrum for counting the Landolt's Ring chart under 4500 K CCT conditions.*

According to (figure 31), the type of brain waves produced in the subject's brain under 4500 K CCT lighting circumstances is more prevalent. The different frequencies produced can be used to make observations about the degree of brain activity during low-light situations. More beta and gamma waves are seen in the power spectrum activity, which indicates how alert the patient is. The graph's high peak in the beta range suggests that the individual is more engaged.

CHAPTER-8

8 FUTURES SCOPE OF WORK

The current study has demonstrated the impact of colour temperature on how well people accomplish Landolt's ring tasks. The respondents were instructed to count the number of rings in a specific direction.

The work can be further analyzed when the effects of the measured peripheral glare source on on-axis vision during a simple task are taken into consideration.

With the age group factor, it can be extended even further. The experiment would involve varying age groups, such as those under 15 and those over 30 or 50, and it is possible to study how the outcome would differ.

There were only 15 participants included in the ongoing study. By adding more participants, it may be prolonged even further. As a result, the statistical analysis, namely the ANOVA results, may be more significantly incorporated in this study.

This study employed correlated colour temperature as its stimulus. Also, this experiment can be run with different light spectrum compositions, illumination levels, and background luminance levels.

Additionally, their reaction times were measured using an electroencephalography (EEG) machine to capture the brain's first response after spotting a ring in Landolt's ring for 4500 K CCT.

By reducing the computing error, future EEG analysis processes could be improved. This improvement can be implemented using Python or Matlab programming.

It is advisable to do additional study and build a bigger database for future uses because the outcomes of any human-related studies, particularly those based on EEG, vary widely in general.

CHAPTER-9

9 REFERENCES

[1] I. E. S. of North America, Lighting Handbook: Reference& application. Illuminating Engineering Society of North America, 2000.

[2] Marberry, S. O., & Zagon, L. (1995). The power of color: Creating healthy interior spaces. John Wiley & Sons.

[2] G. Optik, basic of light measurement. Gigahertz Optik, 2018.

[3] V. Gligor, "Luminous environment and productivity at workplaces," Helsinki University of Technology.

[4] P. R. Boyce, "Lighting research for interiors: the beginning of the end or the end of the beginning," Lighting Research & Technology, vol. 36, no. 4, pp. 283–293, 2004.

[5] K. W. Houser, "Human-centric lighting and semantic drift," 2018.

[6] P. R. Boyce, Human factors in lighting. CRC Press, 2003.

[7] G. C. Brainard, J. P. Hanifin, J. M. Greeson, B. Byrne, G. Glickman, E. Gerner, and M. D. Rollag, "Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor," Journal of Neuroscience, vol. 21, no. 16, pp. 6405–6412, 2001.

[8] C. Cajochen, M. Munch, S. Kobialka, K. Krauchi, R. Steiner, P. Oelhafen, S. Orgul, and A. Wirz-Justice, "High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light," The journal of clinical endocrinology & metabolism, vol. 90, no. 3, pp. 1311–1316, 2005.

[9] D. M. Berson, F. A. Dunn, and M. Takao, "Phototransduction by retinal ganglion cells that set the circadian clock," Science, vol. 295, no. 5557, pp. 1070–1073, 2002.

[10] D. M. Dacey, H.-W. Liao, B. B. Peterson, F. R. Robinson, V. C. Smith, J. Pokorny, K.-W. Yau, and P. D. Gamlin, "Melanopsin-expressing ganglion cells in primate retina signal colour and irradiance and project to the lgn," Nature, vol. 433, no. 7027, pp. 749–754, 2005.

[11] J. F. Duffy and K. P. Wright Jr, "Entrainment of the human circadian system by light," Journal of biological rhythms, vol. 20, no. 4, pp. 326–338, 2005.

[12] S. Whiteley, Y. Sauv´e, M. Avil´es-Trigueros, M. Vidal-Sanz, and R. Lund, "Extent and duration of recovered pupillary light reflex following retinal ganglion cell axon regeneration through peripheral nerve grafts directed to the pretectum in adult rats," Experimental neurology, vol. 154, no. 2, pp. 560–572, 1998.

[13] G. C. Brainard and J. P. Hanifin, "Photons, clocks, and consciousness," Journal of biological rhythms, vol. 20, no. 4, pp. 314–325, 2005.

[14] H. R. Wright, L. C. Lack, and K. J. Partridge, "Light emitting diodes can be used to phase delay the melatonin rhythm," Journal of pineal research, vol. 31, no. 4, pp. 350–355, 2001.
[15] K. Thapan, J. Arendt, and D. J. Skene, "An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans," The Journal of physiology, vol. 535, no. 1, pp. 261–267, 2001.
[16] J. J. Gooley, J. Lu, D. Fischer, and C. B. Saper, "A broad role for melanopsin in nonvisual photoreception," Journal of Neuroscience, vol. 23, no. 18, pp. 7093–7106, 2003.
[17] S. Lehrl, K. Gerstmeyer, J. Jacob, H. Frieling, A. Henkel, R. Meyrer, J. Wiltfang, J. Kornhuber, and S. Bleich, "Blue light improves cognitive performance," Journal of neural transmission, vol. 114, no. 4, pp. 457–460, 2007.
[18] P. R. Mills, S. C. Tomkins, and L. J. Schlangen, "The effect of high correlated colour temperature office lighting on employee wellbeing and work performance," Journal of circadian rhythms, vol. 5, no. 1, pp. 1–9, 2007.
[19] E. Rautkyl¨a, M. Puolakka, E. Tetri, and L. Halonen, "Effects of correlated colour temperature and timing of light exposure on daytime alertness in lecture environments," Journal of Light & Visual Environment, vol. 34, no. 2, pp. 59–68, 2010.
[20] F. H. Zaidi, J. T. Hull, S. N. Peirson, K. Wulff, D. Aeschbach, J. J. Gooley, G. C. Brainard, K. Gregory-Evans, J. F. Rizzo III, C. A. Czeisler, et al., "Short-wavelength light sensitivity of circadian, pupillary, and visual awareness in humans lacking an outer retina," Current biology, vol. 17, no. 24, pp. 2122–2128, 2007.
[21] T. A. WEHR, "The durations of human melatonin secretion and sleep respond to changes in daylength (photoperiod)," The Journal of Clinical Endocrinology & Metabolism, vol. 73, no. 6, pp. 1276–1280, 1991.
[22] C. Cajochen, M. Freyburger, T. Basishvili, C. Garbazza, F. Rudzik, C. Renz, K. Kobayashi, Y. Shirakawa, O. Stefani, and J. Weibel, "Effect of daylight led on visual comfort, melatonin, mood, waking performance and sleep," Lighting Research & Technology, vol. 51, no. 7, pp. 1044–1062, 2019.
[23] P. Raynham and P. Boyce, "The sll lighting handbook," The Society of Light and Lighting, Lon-don, UK, 2012.
[24] Y. Ohno, "Cie fundamentals for color measurements," in NIP & Digital Fabrication Conference, vol. 2000, pp. 540–545, Society for Imaging Science and Technology, 2000.
[25] G. Wyszecki and W. S. Stiles, Color science, vol. 8. Wiley New York, 1982.

[26] J. Schanda, Colorimetry: understanding the CIE system. John Wiley & Sons, 2007.

[27] A. R. Robertson, "The cie 1976 color-difference formulae," Color Research & Application, vol. 2, no. 1, pp. 7–11, 1977.

[28] R. A. Fisher, "Xv. —the correlation between relatives on the supposition of mendelian inheritance.," Transactions of the Royal Society of Edinburgh, vol. 52, no. 2, p. 399–433, 1919.

[29] R. A. Fisher et al., "Statistical methods for research workers.," Statistical methods for research workers., no. 10th. ed., 1946.

[30] Bullough JD, Rea MS. Simulated driving performance and peripheral detection at mesopic and low photopic light levels. Lighting Res. Technol. 2000; 32: 194–98.

[31] Yukio Akashi, MS Rea and JD Bullough, Driver decision making in response to peripheral moving targets under mesopic light levels, Lighting Res. Technol. 39,1 (2007) pp. 53–67

[32] P. Raynham, "An examination of the fundamentals of road lighting for pedestrians and drivers," Lighting Res. Technol. vol. 36, pp. 307-316, 2004.

[33] Adrian, W., Visibility of Targets: Model for Calculations, Lighting Research and Technology, 21, pp. 181-188, 1989

[34] CIE, "Calculation and measurement of luminance and illuminance in road lighting," Technical report No. 30, 1976.

[34] "eye, human."Encyclopaedia Britannica. 2008. Encyclopaedia Britannica 2006 Ultimate Reference Suite DVD

[35] Danilova MV, Bondarko VM (2007). "Foveal contour interactions and crowding effects at the resolution limit of the visual system". J Vis. 7 (2): 25.1–18. doi:10.1167/7.2.25. PMC 2652120. PMID 18217840.

[36] The visual resolution of Landolt-C optotypes in human subjects depends on their orientation: the 'gap-down'effect Michael Schraufa, Claudia Sternb Neuroscience Letters 2001

[37] The Effects of Optical Defocus on the Legibility of the Tumbling-E and Landolt-C REICH, LEWIS N. OD, PhD, FAAO; EKABUTR, MICHELE Optometry & Vision Science: June 2002

CHAPTER-10

10 ANNEXURES

10.1 Instruments used in the experiment

10.1.1 KONICA MINOLTA CL-70F CRI Illuminance Meter

The CL-70F Illuminance Meter is a low-cost spectrometer-based illuminance meter that measures electrical flash using an accumulation-type sensor. It has a very high colour measurement precision and the high-resolution CMOS sensor makes it an ideal choice for measuring Spectral Power Distribution (SPD), Spectral compositions, Illuminance, Correlated Colour Temperature (CCT), Colour Rendering Index (CRI) of a variety of light sources.

This instrument had been used to check for the consistency of the lamp's colours throughout the tenure of the experiment. The spectral composition and the chromaticity of the light output of each lamp were measured every day before starting the experiment.

10.1.1.1 Features

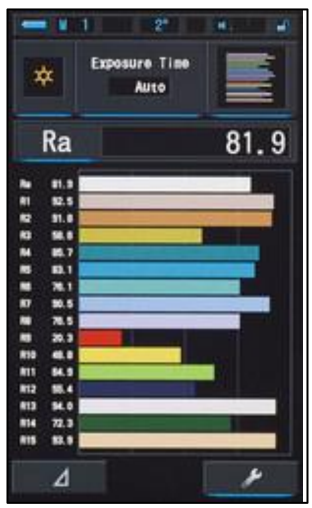
- Easy to use & easy-to-read display
- 180 rotating receptor head
- Dark calibration can be performed without needing a cap
- Measurement of flashlights
- Measurement data of chromaticity, dominant wavelength & excitation purity

- Wide measuring range
- Conforms to JIS A Class and DIN Class C
- Includes utility software CL-SU1w

Lighting design and continuous maintenance are only two of the usual lighting jobs that the lightweight CL-70F body is made for. The CL-70F gives entry-level access to cutting-edge light measurement features by measuring CRI and providing spectral data. The CL-70F is a potent tool for professional image and entertainment sectors when used in conjunction with a flash sync connection, which permits spectral measurements of the flashlight.

10.1.1.2 Colour Rendering Index measurement:

Access to measurement information for the Colour Rendering Index (CRI) is made simple by the CL-70F. The display presents a simple bar graph of the Ra value together with each individual index (R1 to R15).



(Colour rendering Index)

10.1.1.3 Measurement of correlated color temperature (Tcp) :

The variables that are often used to characterise the colour of light sources, correlated colour temperature and the difference from the blackbody locus Δuv, may be measured using the CL-70F. The absolute temperature (in Kelvin) at which a blackbody would produce a specific hue of light is known as the colour temperature of light. The "blackbody locus" is a curve that allows the colours of light emitted by a blackbody at various temperatures to be plotted. Since many light sources' outputs does not coincide with the blackbody locus exactly, "correlated colour temperature" which are referred to as (CCT). Normally, the difference from the blackbody locus Δuv is provided in addition to the associated colour temperature when characterising a colour using correlated colour temperature.

10.1.1.4 Spectral Power Distribution:

The CL-70F provides easy access to Colour Rendering Index (CRI) measurement data. The display shows the SPD value over the wavelength. The Y scale is normalised to 1.

Chromaticity Diagram (for CCT Calculation), Spectral composition and others important information

10.1.1.5 Rotating Receptor Head:

The rotating receptor head improves screen visibility and comfortable use of the instrument.

(Rotating Receptor Head)

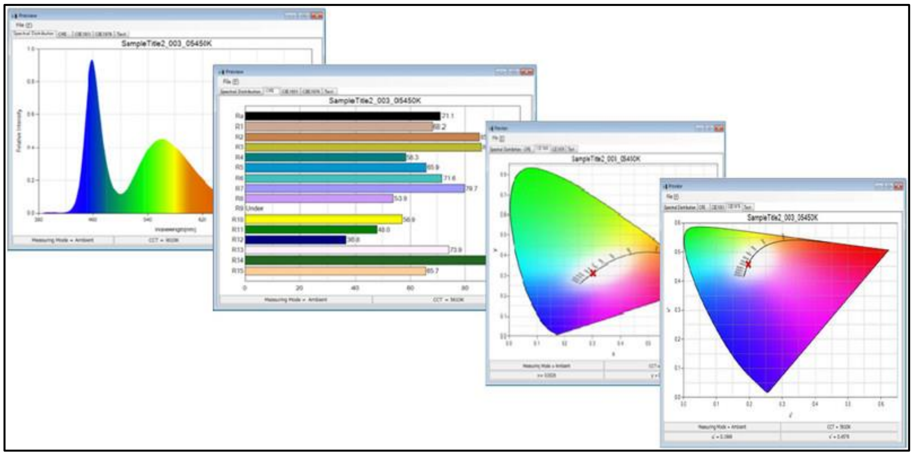
10.1.1.6 Zero Adjustment:

Without a receptor cap, it is simple to modify this device’s zero setting. To calibrate the dark, turn the diffusor’s ring counter-clockwise.

(Zero Adjustment Without Receptor Cap)

10.1.1.7 Additional Features:

It provides including Utility software CL-SU1w with the software CL-SU1w which is included as a standard accessory, one can modify instrument settings, store & group data and make further analyses of the measured data.



(Stored Data in CL-SU1w Software)

10.1.1.8 Specifications

Illuminance Meter Class	Conforms to requirements for Class A of JIS C1609-1： 2006 "Illuminance meters Part1: General measuring instruments; Conforms to DIN 5032 Part 7 Class C
Sensor	CMOS linear image sensor
Spectral wavelength range	380 nm ～ 780 nm
Output wavelength pitch	1 nm

Measuring range	Constant light: 1 to 200,000 lx; 1,563 to 100,000 K (Chromaticity display requires 5 lx or more) Flash light: 20 to 20,500 lx*s; 2,500 to 100,000 K
Accuracy (Standard Illuminant A)	EV: ±5%+1digit of the displayed value
	xy: 0.003 (at 800 lx)
Repeatability (2σ) (Standard Illuminant A)	EV: 30 to 200,000 lx: 1%+1digit; 1 to 30 lx: 5%+1digit
	xy: 500 to 200,000 lx: 0.001 xy: 100 to 500 lx: 0.002 xy: 30 to 100 lx: 0.004 xy: 5 to 30 lx: 0.008
Visible-region relative spectral response characteristics (f1')	Within 9%
Cosine response (f2)	Within 6%
Temperature drift (fT)	EV: ±5% ; xy: ±0.006
Humidity drift (fH)	EV: ±3%; XY: ±0.006
Power	2 AA-size batteries (Alkaline batteries or manganese dry cells); USB bus power
Response time	Constant light (Maximum): 15 sec Constant light (Minimum): 0.5 sec Flash light: 1 ～ 1/500 sec (in 1-step intervals)
Colour indication modes	Correlated colour temperature Tcp, Difference from blackbody Δuv, XYZ, xy, u'v', Dominant wavelength λd, Excitation purity Pe, Spectral irradiance, EV, CRI (Ra, Ri), Peak wavelength λp, exposure value
Other functions	Data memory: 999 data; Preset function; Auto power off function
Display languages	English, Japanese, Chinese (Simplified)
Interface	USB 2.0 Mini B
Operating temperature and humidity range	-10 to 40℃, relative humidity of 85％ or less (at 35℃) with no condensation

Storage temperature/humidity range	-10 to 45°C, relative humidity of 85％ or less (at 35°C) with no condensation
Size	73 (W)× 183 (H) × 27 (D) mm (Not including projecting buttons)
Weight	230 g

10.1.2 Philips Wiz Wi-Fi Enabled B22 9-Watt LED Smart Bulb

Wi-Fi Smart LED from Philips Smart bulbs that are simple to use, practical, and reasonably priced provide total control over the illumination.

Simply link them to an established Wi-Fi network to make high-quality Philips lights smarter. Smart Color and White Light: Color your life! Dynamic light options allow filling any space with favourite colour. Utilize the WiZ lighting app or a voice assistant that is compatible to control the lights. For the device to work wirelessly, a WiFi connection is necessary. The Philips Smart Wi-Fi LED smart lamp works with WiZ products and applications in addition to Alexa, Google Assistant, and Siri Shortcuts.

Additional Features

Install in 3 Easy Steps

1. Plug in the Bulb
2. Download the Free Wiz App
3. Follow Steps to Complete Setup

10.1.2.1 Product Description

Bulb	**Characteristics**
Intended use	Indoor
Lamp shape	A19
Socket	B22
Technology	LED
Type of glass	Frosted
Dimmable	Wireless Dim
Bulb	**Dimensions**
Height	11.8 cm
Weight	0.07 kg
Width	06 cm
Durability	
Average life (at 2.7 hrs/day)	25-year (s)
Lumen maintenance factor	0.7
Nominal lifetime	25,000 hour(s)
Number of switch cycles	50,000
Light	**Characteristics**
Beam angle	120 degree(s)
Colour rendering index (CRI)	90
Colour temperature	2700-6500 K

Light Color Category	Color & Tunable White
Nominal luminous flux	825 lumen
Starting time	< 1s
Warm-up time to 60% light	Instant full light
Colour Code	927-965, CCT of 2700K-6500K
Other	**Characteristics**
Lamp current	100 mA
Efficacy	90.1 lm/W
Packaging	**Information**
Product family	LED
EAN	8718699732561
EOC	871869973256100
Product Title	Philips Smart WiFi LED Full-colour 9w Led Bulb B22
Power	**Consumption**
Power factor	0.9
Voltage	220-240 V
Wattage	9 W
Wattage equivalent	60 W

Product Dimensions	& weights
Length	6 cm Rated values
Rated beam angle	120 degree(s)
Rated lifetime	25,000 hour(s)
Rated luminous flux	825 lumens
Rated power	9 W
Packaging dimensions	**And weight**
EAN/UPC - product	8718699732561
Net weight	0.060 kg
Gross weight	0.112 kg
Height	14.500 cm
Length	9.900 cm
Width	7.200 cm
Material number (12NC)	929002317513

10.1.3 Stop-Watch

To measure the response time, a stopwatch was used. This is an analog stopwatch and recorded time in sec.

Stop Watch

10.1.3.1 Product Specifications

Brand	Eisco
Item Dimensions L x W x H	16 x 50 x 70 Millimeters
Human Interface Input	Dial

10.1.4 EMOTIV EPOC Flex

EMOTIV EPOC Flex is a portable wireless EEG device which had been employed in this experiment to capture the brain signals from the participants while they were enacting the script. The device had to be connected with the "EMOTIV Pro" software to check the contact quality and EEG quality of the electrodes and record the EEG data. The software has a cloud storage facility where all the recordings are stored. The latest version of the software - EMOTIV Pro V3.3 had been used in this experiment.

10.1.4.1 Product Specifications

Device	EPOC Flex
No. of Channels	32 (plus CMS/DRL references)
Channel names	Configurable on standard 72 channel international 10-20 locations.
Sampling method	Sequential sampling. Single ADC
Sampling rate	128 SPS (1024 Hz internal)

EEG Resolution	14 bits 1 LSB = 0.51μV (16 bit ADC, 2 bits instrumental noise floor discarded)
Max Slew Rate	32.64uV/sample (Compression required for BLE data transmission)
Bandwidth	0.2 - 45Hz, high attenuation at 50Hz and 60Hz
Filtering	Built in digital 5th order Sinc filter
Dynamic range (input referred)	+/- 4.12 mV
Coupling mode	AC coupled
Connectivity	Proprietary 2.4GHz wireless, BLE (coming soon)
Battery Capacity.	LiPo battery 595mAh
Battery life (typical)	6-9 hours
Impedance Measurement	Real-time contact quality using patented system
IMU Part	ICM-20948 3-axis Accelerometer, 3-axis Gyroscope, 3-axis Magnetometer. Data Output 10 channels Quaternions, (Q0, Q1, Q2, Q3), Acceleration (X,Y,Z) and Magnetometer (X,Y,Z)
Motion Sampling	16 Hz
Motion Resolution	8-bit Output
Sensor Material	Electroplated Ag/AgCl (EPOC Flex Saline models) with replaceable polyester felt pads that can be sterilised and re-used.

10.1.5 Laptop

Asus Vivobook 14/15 laptop has been used in this experiment for running the Emotiv Pro software and analysing the EEG and SAM data received from the participants.

Laptop

10.1.5.1 Product Specifications

Model Name	ASUS Vivobook 14
Processor type	AMD Ryzen 5 4500U
Processor core count	6
Processor thread count	12
Processor speed	2.3 GHz with Turbo Boost Upto 4 GHz
Processor cache	11 MB
Integrated graphics	AMD Radeon Graphics
Operating System	Windows 11 Home, 64-bit
Memory type	DDR4
Memory speed	3200 MHz
Storage	512 GB SSD