STUDIES ON ENERGY EFFICIENT OFFICE LIGHTING DESIGN

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

Master of Technology

in

Illumination Technology & Design

Submitted by

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "Studies on Energy Efficient Office Lighting Design", is a Bonafide work carried out by **Dip Narayan Sarkar (Exam roll no: M6ILT24001B, and Registration no: 160405 of 2021-22)** under my supervision and guidance for partial fulfilment of the requirement of MTech. (Illumination Technology and Design) in School of Illumination Science, Engineering and Design, during the academic session 2023 -2024.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented by **Dip Narayan Sarkar (Exam roll no.- M6ILT24001B and Registration no: 160405 of 2021-22)** in a manner satisfactorily to warranty its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn there in but approve the thesis only for purpose for which it has been submitted.

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his MTech. (Illumination Technology and Design) studies during academic session 2023-2024.

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

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Abstract

This research explores the role of lighting design in office spaces, focusing on how intentional lighting planning can enhance functionality, aesthetics, and employee well-being. By examining the relationship between lighting design, mood, and productivity, this study investigates how elements such as color temperature, light intensity, distribution, and dynamic lighting affect psychological well-being and workplace performance. It also considers the distinct impacts of natural versus artificial light on circadian rhythms, sleep quality, and overall satisfaction in office settings. Taking into account personal preferences, job requirements, and environmental factors, this research offers insights into optimizing lighting for diverse workplace environments. Through surveys, observations, and experimental approaches, it uncovers the nuanced effects of lighting on cognitive function and behaviour. Ultimately, the study provides actionable recommendations for architects, designers, and employers to create lighting environments that support positive mood and productivity, fostering healthier, more engaging office spaces.

Keywords: *Optimization, Photometric parameters, DIALux , Lighting calculation, Cost calculation*.

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CHAPTER 1

INTRODUCTION

Introduction:

1.1 Motivation:

A well-lit environment should provide visual comfort that enables individuals to perform various tasks effectively. Lighting impacts human behaviour and emotions, making it essential to create a balanced, well-lit setting that promotes productivity, well-being, safety, and health. Additionally, spaces must be thoughtfully designed with attention to energy-efficient lighting use. This entails a comprehensive approach to lighting design, utilizing each element purposefully. Lighting systems should be designed, operated, and specified to make efficient use of daylight. Achieving satisfactory and efficient work environments requires innovative research to optimize these aspects. On the other hand, excessive illumination wastes energy and increases the overall costs of lighting systems. For indoor applications, over-illumination, particularly with high levels of blue light, can have harmful biological effects on humans by disrupting the circadian cycle that regulates daily sleep and wake patterns.

Office lighting should enhance visual performance for employees engaged in various tasks, including desk-based activities. It should also create a comfortable, pleasant, and natural environment that aligns with workers' natural sleep-wake cycles. At the same time, minimizing maintenance costs and energy consumption is essential. To address these requirements, international standards outline specific criteria for indoor lighting in workplaces. Office lighting design is particularly complex, given the high demands for sensitivity and performance from employees, making it a challenging task to create an effective lighting scheme. Standards for indoor lighting are well-documented by organizations such as the International Commission on Illumination (CIE), the Illuminating Engineering Society of North America (IESNA), the National Lighting Code (NLC) 2010, and various Indian Standards.

This study aims to provide appropriate lighting for Hi-Tech Systems & Services Ltd., an office in Kolkata, in accordance with national and international standards.

Significant efforts are underway to achieve optimal electrical energy savings in lighting. Various strategies are being employed to this end, with the most common techniques including: (i) Replacing outdated conventional light sources with energy-efficient lighting, and (ii) Implementing lighting controls and sensors.

1.2 Literature Review:

1.2.1 "Smart Office Lighting Control Using Occupancy Sensors" by Xin Wang, Tjalling Tjalkens, Jean-Paul Linnartz [1]

Objective of the Paper: The paper aims to utilize the information derived from the estimated occupancy probability to determine the optimal dimming strategy based on the detected presence probability. The goal is to optimize the illuminance level in the office to reduce energy consumption.

Findings of the Work: The results show that when the occupancy probability is low, it is best to turn off the lights completely. As the probability of presence exceeds a certain threshold (based on user characteristics), the optimal illuminance level gradually increases. The strategy was compared to the commonly used hard decision-making approach, with the results indicating that the proposed strategy consistently reduces energy consumption. Additionally, when daylight is considered, the optimum level of artificial light supplementation follows a similar pattern.

1.2.2 A Case Study on Energy Saving Through Lighting System for Building: An Internal Energy Review by M. F. Lee[1] & N. Q. Zulkafli [2]

Objective of the Paper: The paper aims to investigate the characteristics of the lighting system and lamp types used in the FPTV building. It seeks to evaluate the selection of lamp types for optimal energy consumption based on the selected area, and to analyze the return on investment (ROI) for the chosen lamp type. The study is focused on: 1. Choosing appropriate lighting, 2. Determining the number and arrangement of lights, and 3. Assessing energy efficiency in buildings.

Findings of the Work: The case study focuses on the use of energy-efficient, environmentally friendly LED lamps, which offer energy savings of approximately 30%–80% compared to conventional bulbs. The total energy consumption could be reduced by 281,566.032 kWh per year, with an estimated cost of RM 102,771.602 for replacing existing lamps with LED lamps. LED lamps are highly recommended due to their ability to save electricity and reduce greenhouse gas emissions, which are significant contributors to global warming. The study highlights several benefits of implementing

energy management, including: 1. Energy cost savings, 2. Reduced greenhouse gas emissions and carbon footprint, 3. Increased energy awareness among staff, 4. Improved knowledge of equipment efficiency, and 5. Enhanced decision-making processes from system design to operation.

1.2.3 An Energy-Saving Office Lighting Control System Linked to employee's Entry/Exit

by Yosuke Kaneko, Masahito Matsushita, Shinji Kitagami. **[3]**

Objective of the Paper: The paper aims to propose an energy-saving lighting control system that detects employees' positions on an office floor using information from the access control system. The system adjusts the lighting to provide the necessary brightness for employees by controlling dimming rates, and it also tracks entry and exit information, such as the number of people on a floor.

Findings of the Work: The experimental evaluation conducted over a month confirmed that the proposed system reduced lighting power consumption by approximately 25% compared to traditional wall light switch operation. In the wall light switch setup, one block (consisting of eight light sources) is illuminated at full brightness (100% dimming rate) near a detected person. By precisely controlling the lights around present individuals, the proposed system achieved higher energy savings than the wall switch method. Lighting power consumption accounted for about 30% of the total energy use on the floor, including air conditioning and electrical outlets. As a result, the developed system reduced overall office power consumption by about 7.5%. While the system relies solely on access control information to detect employee presence, leading to some energy waste when employees are in meeting or rest rooms, significant energy savings were still achieved.

1.2.4: 'Design and Implementation of an Energy-Saving Lighting Control System Considering User Satisfaction

by Jinsung Byun, and Taiwan Shin, **[4]**

Objective of the Paper: The paper aims to improve energy efficiency and occupant satisfaction by controlling lighting parameters based on the characteristics of a space and occupant behavior patterns. It seeks to meet users' illuminance requirements according to their activities and profiles, control blind angles to maximize daylight usage, and automatically detect room light intensity to adjust lighting accordingly.

Findings of the Work: The energy-saving performance of the proposed ESLiCoS system was evaluated by measuring energy consumption in offices, corridors, and stairs, where 58W fluorescent lights were installed, over a 20-day period. The fluorescent lights were then replaced with ESLiCoS (LED, 42W), and energy consumption was measured under the same conditions for another 20 days. The results showed a 43% reduction in energy consumption due to the replacement of the existing lights. The energy savings were attributed to: 1) the reduction from replacing the 58W fluorescent light with a 42W LED (27.6%), 2) adjusting maximum luminance based on light brightness simulation (6%), and 3) autonomously controlling the lights according to occupant movement (9.4%).

1.3 Problem definition:

To create a lighting system for an old office building that uses energy-efficient, modern lighting components.

1.4 Objective of the Project

The objectives of this thesis are as follows:

• To analyze and design an energy-efficient lighting system for an existing office building, tailored to meet the specific needs of its users.

• To ensure the lighting system delivers the desired illuminance level and uniformity according to recommended standards, supporting visual performance for office employees and visitors. A well-designed lighting system in an office environment can improve task performance, reduce errors, and alleviate discomfort, anxiety, and stress for users.

1.5 **Thesis Outline:**

This thesis is divided into eight chapters.

Chapter 1: The first chapter covers an introduction to the project, including the motivation behind undertaking this work, a review of relevant literature, a clear definition of the problem, and detailed information about the project itself.

Chapter 2: This section provides a brief overview of the basic theory and terminology related to energy-efficient light sources. It also covers various parameters of office lighting design, the use of Light Emitting Diodes (LEDs), applicable codes and standards for office lighting, the role of sensors and controllers, and the application of software tools for lighting design.

Chapter 3: This section provides detailed information about the application area, specifically the Hi-Tech Systems premises, including its layout, configuration, and lighting requirements.

Chapter 4: This section provides the designing the office building is equipped with energy-efficient lighting components.

Chapter 5: In this section, the results are summarized.

Chapter 6: This section describes the Pay back calculation and return on investment for this lighting design.

Chapter 7: The conclusion of the project is presented, along with a discussion of potential future developments and areas for further research.

Chapter 2

LIGHTING DESIGN FOR ENERGY EFFICIENCY

2.1 Introduction

The role of lighting in indoor environments extends beyond mere illumination; it significantly impacts productivity and well-being. As energy costs rise and sustainability becomes increasingly important, the demand for energy-efficient lighting solutions is at an all-time high. By adopting advanced technologies such as LED lighting and smart control systems, organizations can drastically reduce their energy consumption while enhancing the quality of light in their spaces. Additionally, proper lighting design considers factors like colour temperature, glare reduction, and uniformity, which contribute to a more comfortable and productive work environment. Emphasizing energy-efficient practices not only helps in lowering operational costs but also supports a commitment to environmental stewardship. According to the international agencies lighting accounts for 19 percent of the global electricity of the total power depending on the type of usage [5].

India is undergoing urbanization at a rate that exceeds previous expectations. Failures to adhere to building codes and the prevalence of inefficient lighting designs have turned the building sector into a significant consumer of energy. In 2015, energy consumption in buildings accounted for approximately 14% of India's total delivered energy consumption [6]. While the U.S. Energy Information Administration projects that the growth rate of commercial energy use in India will surpass that of residential energy, the residential sector continues to be the largest energy consumer in buildings, making up over 70% of total building energy consumption throughout the forecast period. A substantial portion of this energy is utilized for artificial lighting, as well as for cooling and ventilation through fans.

Lighting is not only a critical aspect of office design but also represents a high-return, low-risk investment that can lead to significant long-term savings. By implementing modern lighting technologies, offices can dramatically decrease their electricity consumption and the associated energy costs related to lighting, creating a more sustainable operational environment. Adequate lighting is essential for ensuring visibility in dark or poorly lit spaces, which can enhance safety and improve overall functionality. Efficiency in lighting refers to the effectiveness with which light is produced for a given amount of input power, making it a key factor in energy conservation. Recently developed energy-efficient lighting solutions, such as Light Emitting Diodes (LEDs), have transformed the landscape of office lighting by offering a remarkable reduction in operational costs—ranging from 30% to 60%—while simultaneously improving the quality of illumination

[18]. These advancements not only help minimize energy consumption and reduce carbon footprints but also contribute positively to employee health, well-being, and overall work productivity. By creating a well-lit and comfortable working environment, organizations can foster greater employee satisfaction and performance, ultimately leading to a more efficient and productive workplace.

2.2. Objectives & Criteria for Office Lighting Design

2.2.1: Objectives of Lighting Design:

The primary objectives of lighting design in office environments are multifaceted, aimed at enhancing both functionality and aesthetic appeal. Key objectives include:

1. **Visibility and Clarity**: Ensuring adequate visibility for all tasks performed within the office is paramount. Proper lighting reduces glare and shadows, allowing employees to see clearly, which is essential for productivity, accuracy, and safety.
2. **Energy Efficiency**: A crucial objective is to minimize energy consumption through the use of energy-efficient lighting technologies. By incorporating solutions such as LED lighting and smart control systems, offices can significantly reduce their electricity usage and lower operational costs while maintaining high-quality illumination.
3. **Employee Comfort and Well-Being**: The lighting design should contribute to the overall comfort of employees. This includes selecting appropriate color temperatures and intensities that reduce eye strain and fatigue, thus promoting a more pleasant working environment.
4. **Flexibility and Adaptability**: Office lighting should be designed with flexibility in mind, allowing adjustments for different tasks and activities. This can include the ability to modify lighting levels based on the time of day or specific requirements of various workspaces.
5. **Aesthetic Appeal**: The design of lighting should complement the overall aesthetics of the office environment. A well-thought-out lighting scheme can enhance the architectural features of the space and contribute to a positive organizational image.
6. **Supporting Productivity and Creativity**: Effective lighting design can influence mood and energy levels, impacting employee productivity and creativity. A well-lit environment can foster innovation and focus by creating a vibrant and inspiring workplace.
7. **Compliance with Standards**: Lighting design must adhere to relevant regulations and standards, including building codes and safety requirements. This ensures that the office space is not only functional but also safe for all occupants.

8. **Enhancing Collaboration**: Lighting design should facilitate collaboration by creating well-lit communal areas where teams can gather. Proper lighting in meeting rooms and collaborative spaces can encourage communication and teamwork.
9. **Supporting Technology Integration**: As offices increasingly adopt advanced technology, lighting systems must be compatible with various tools and devices. Smart lighting solutions that integrate with automated systems can enhance the overall functionality of the workspace.
10. **Promoting Sustainability**: Beyond energy efficiency, the lighting design should consider the use of sustainable materials and practices. This includes selecting fixtures made from recyclable materials and implementing designs that maximize natural light, reducing reliance on artificial lighting.
11. **Creating Zones for Different Activities**: Different areas of an office serve varied purposes, from quiet workspaces to dynamic meeting zones. The lighting design should create distinct zones tailored to the specific activities taking place in each area, ensuring that lighting supports the intended function.
12. **Reducing Light Pollution**: Consideration should be given to minimizing light pollution, both within the office and externally. This involves strategic placement of lighting fixtures to direct light where it is needed, thus reducing unnecessary spillover and enhancing the surrounding environment.

By focusing on these comprehensive objectives, office lighting design can create a harmonious balance between functionality, energy efficiency, and aesthetic quality, ultimately leading to improved employee satisfaction and enhanced organizational performance.

2.2.2 Criteria for Lighting Design

To achieve effective lighting design in office environments, several critical criteria must be considered. These criteria ensure that the lighting is functional, energy-efficient, and conducive to a positive work environment. Below are the key criteria along with relevant equations and considerations:

1. **Illuminance Levels**:
    - **Definition**: Illuminance is the measure of how much luminous flux is spread over a given area. It is measured in lux (lx).
    - **Equation**: $E=\Phi/A$

      where:
        - E = illuminance in lux (lx)
        - Φ = luminous flux in lumens (lm)
        - A = area in square meters (m^2)

Average illuminance (E) given by the Lumen Method is given by : $E = (\phi * n * N * UF * MF) / A$,

Where,

- ϕ = Initial bare lamp luminous flux (lumens)
- n = Number of lamps per luminaire
- N = Number of luminaires
- UF = Utilisation factor
- MF = Maintenance factor
- A = Area of the surface (m^2)

- **Consideration**: Different tasks have varying illuminance requirements. For example, general office work may require about 300-500 lx, while detailed tasks may require 1000 lx or more.

2. **Uniformity**:
   - **Definition**: Uniformity refers to the even distribution of light across a workspace.
   - **Equation**: $U=E_{min}/E_{avg}$

     where:
     - U= uniformity ratio
     - E_{min}= minimum illuminance in the area
     - E_{avg} = average illuminance in the area
   - **Consideration**: A uniformity ratio of at least 0.7 is often recommended for office spaces to ensure visual comfort.
3. **Colour Temperature**:
   - **Definition**: Colour temperature, measured in Kelvin (K), describes the appearance of the light source. It affects mood and productivity.
   - **Consideration**: For task-oriented areas, a colour temperature of 4000K to 5000K is generally suitable, while warmer lighting (2700K to 3000K) is better for relaxation areas.

4. **Colour Rendering Index (CRI)**:
   - **Definition**: CRI measures the ability of a light source to accurately render colours in comparison to natural light, with values ranging from 0 to 100.
   - **Consideration**: A CRI of 80 or above is recommended for office lighting, particularly in areas where colour accuracy is important, such as design studios.

[Table 1 – Corelated Colour Temperature & Colour Rendering Index]

Type of lamp	CCT (K)	CRI
General Lighting Service lamp	2500 – 2700	100
Tungsten Halogen Lamp	2700 – 3200	100
Florescent Tube Light	3000 – 6500	60 - 90
Compact Fluorescent Lamp	2700 – 6500	> 80
High Pressure Mercury Vapour Lamp	3200 – 3900	40 - 50
Quartz tube Metal Halide Lamp	3000 – 5000	60 -90
Ceramic tube Metal Halide Lamp	3000 – 4400	78 - 93
SOX (Low Pressure sodium vapour lamp)	2100	19
SON (High Pressure sodium vapour lamp)	1900 – 2500	40
Induction Lamp	2500 – 4000	80
Light Emitting Diode	2700 – 6500	> 70

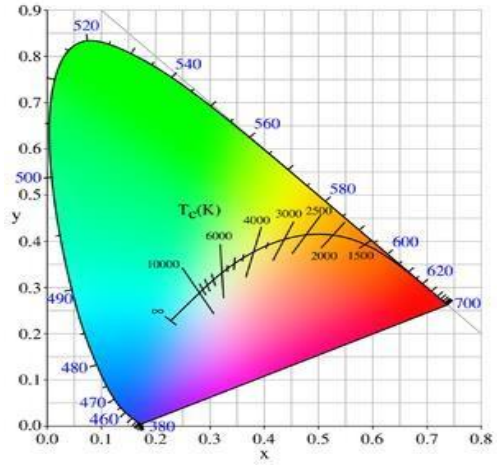

Fig 1: CCT for LED

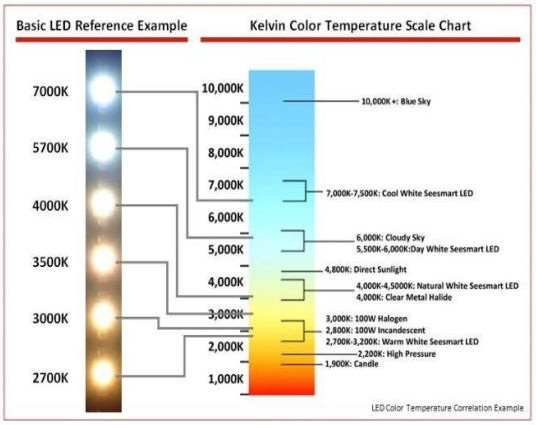

Fig 2: CIE 1931 x, y Chromaticity Space

5. **Energy Efficiency**:
    - **Definition**: This refers to the ratio of light output (in lumens) to energy consumption (in watts).
    - **Equation**: $E_{eff}=\Phi/PE$

      where:
        - E_{eff} = efficacy in lumens per watt (lm/W)
        - Φ = luminous flux in lumens (lm)
        - P = power consumption in watts (W)
    - **Consideration**: Energy-efficient lighting solutions such as LEDs can provide an efficacy of 80-100 lm/W or higher compared to traditional incandescent bulbs, which typically provide 10-17 lm/W.

6. **Control Systems**:
    - **Definition**: Control systems allow for the customization of lighting levels based on occupancy and time of day.
    - **Consideration**: Implementing dimmers, occupancy sensors, and daylight-responsive controls can help optimize energy use and improve user comfort.
7. **Daylight Integration**:
    - **Definition**: The practice of using natural light to supplement artificial lighting.
    - **Consideration**: Daylight factor (DF) can be calculated to determine how much daylight reaches a workspace:
    - **Equation**: $DF=(E_{inside}/E_{outside})\times 100$

      where:
        - E_{inside} = illuminance inside the building (lx)
        - $E_{outside}$ = illuminance available outside (lx)
    - **Recommendation**: A daylight factor of 2% to 5% is ideal for maintaining a balance between natural and artificial lighting.
8. **Glare Control**:
    - **Definition**: Glare occurs when there is excessive brightness in the field of view, which can cause discomfort and reduced visibility.
    - **Consideration**: The Unified Glare Rating (UGR) can be used to assess glare in a space:
    - **Equation**: $UGR=8\log_{10}(L_{ref}/L_b)$

      where:
        - L_b= luminance of the glare source (cd/m^2)

        - LrefL= reference luminance (cd/m²)
    - **Recommendation**: A UGR of less than 19 is recommended for office settings to minimize discomfort.
9. **Maintenance and Durability**:
    - **Definition**: Consideration of the lifespan and ease of maintenance of lighting fixtures.
    - **Consideration**: Selecting fixtures with longer lifespans (e.g., LEDs typically last 25,000-50,000 hours) can reduce maintenance costs and interruptions.
10. **Acoustic Considerations**:
    - **Definition**: The integration of lighting with acoustic treatments to enhance sound quality in the workspace.
    - **Consideration**: Lighting fixtures that incorporate sound-absorbing materials can help reduce noise levels, contributing to a more pleasant working atmosphere.
11. **Safety and Compliance**:
    - **Definition**: Adherence to safety standards and regulations regarding lighting in workspaces.
    - **Consideration**: Emergency lighting systems must be implemented in accordance with local regulations to ensure safety during power outages.
12. **Aesthetic Integration**:
    - **Definition**: The alignment of lighting design with the overall interior design and branding of the office.
    - **Consideration**: A cohesive aesthetic can enhance the visual appeal of the workspace and contribute positively to the organization's identity.

By following these criteria, office lighting design can effectively enhance the workspace, promoting productivity, comfort, and well-being while ensuring energy efficiency and sustainability.

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2.3 LIGHT SOURCE:

FLUORESCENT LAMP

Fluorescent lamp is an electric discharge light source in which light is produced by the fluorescence of phosphors activated by Ultra Violet energy from a low-pressure mercury arc. The efficiency of fluorescence lamp varies between 30 -100 Lumen /watt (excluding approximately 20% power loss at the Ballast which is required for starting and running of the lamp) Energy efficient fluorescent lamps are now available.

The limitations of energy efficient reduced wattage lamps are as follows:

1)Ambient temperature should not be below 15ºC (see more details later).

2) Should be used only on high power factor ballasts

3) Not to be used where drafts of cool air ducts will exit.

Principle of operation:

The fundamental means for conversion of electrical energy into radiant energy in a fluorescent lamp relies on inelastic scattering of electrons. An incident electron collides with an atom in the gas. If the free electron has enough kinetic energy, it transfers energy to the atom's outer electron, causing that electron to temporarily jump up to a higher energy level. The collision is 'inelastic' because a loss of energy occurs.

This higher energy state is unstable, and the atom will emit an ultraviolet photon as the atom's electron reverts to a lower, more stable, energy level. Most of the photons that are released from the mercury atoms have wavelengths in the ultraviolet (UV) region of the spectrum predominantly at wavelengths of 253.7 nm and 185 nm. These are not visible to the human eye, so they must be converted into visible light. This is done by making use of fluorescence. Ultraviolet photons are absorbed by electrons in the atoms of the lamp's interior fluorescent coating, causing a similar energy jump, then drop, with emission of a further photon. The photon that is emitted from this second interaction has a lower energy than the one that caused it. The chemicals that make up the phosphor are chosen so that these emitted photons are at wavelengths visible to the human eye. The difference in energy between the absorbed ultra-violet photon and the emitted visible light photon goes toward heating up the phosphor coating.

When the light is turned on, the electric power heats up the cathode enough for it to emit electrons. These electrons collide with and ionize noble gas atoms inside the bulb surrounding the filament to form

a plasma by a process of impact ionization. As a result of avalanche ionization, the conductivity of the ionized gas rapidly rises, allowing higher currents to flow through the lamp.

The followings are few energy-efficient fluorescence lamps which are commonly used today.

T_{12}Lamp :40WT_{12} Lamp with Magnetic starter is of common use.

T_8Lamp :34W T_8 Lamp is available for replacement of 40W T_{12} Lamp. It is cheap but it causes the following performances:

(a) Higher lumen depreciation
(b) More sensitive to low temperature
(c) Not appropriate for dimming
(d) Has a potential Lamp-Ballast compatibility problem.

Using 32W T_8Lamp, utilizing rare earth phosphors: Europium and Terbium both efficacy and good Colour Rendering can be achieved. This lamp is found compatible for both Magnetic and Electronic Ballast (See later) and discharges its maximum light output at 25°C. It has been standard for new construction specially most popular for retrofit replacement of 40W T_{12}Lamp.

T_5Lamp: T_5 Lamp with suitable ballast will be very popular in near future for its high efficacy and slick diameter. However, the problem with T_5 Lamp is its poor efficacy at 25°C than 35°C.Till time this is the point why T_5 Lamp has been unsuccessful in Cold countries. It accepts only Electronics Ballast while T_8 Lamp can be operated on existing Electromagnetic as well as new Electronic Ballast (s).

COMPACT FLUORESCENT LAMP

Similar in operation of Conventional Fluorescent lamp. It is a unique replacement of GLS lamp. The ballast and lamp are connected together using a socket and bare design that ensures compatibility of Lamps and Ballasts.

- Rated life is about 10,000H.
- CRI 80
- Colour Temperature: 2700°K, 4000°K and 6500°K, is available

CFL should be matched to a specific ballast type from a particular manufacturer, otherwise it will not property start / operate. The CFL are of Integral and non-integral Ballast type.

Comparison with incandescent lamps

Lifespan

The average rated life of a CFL is between 8 and 15 times that of incandescent. CFLs typically have a rated lifespan of between 6,000 and 15,000 hours, whereas incandescent lamps are usually manufactured to have a lifespan of 750 hours or 1,000 hours.

Energy efficiency

Electrical power equivalents for differing lamps,

[Table 2: Energy Efficiency table]

Electrical Watts (W)	Power consumption	Minimum light output lumens (lm)
Compact fluorescent	Incandescent	
8–9	40	450
9–15	60	800
15–20	75	1,100
20–25	100	1,600
25–45	150	2,600

Heating and cooling

If a building's indoor incandescent lamps are replaced by CFLs, the heat produced due to lighting is significantly reduced. In warm climates or in office or industrial buildings where air conditioning is often required, CFLs would reduce the load on the cooling system when compared to the use of incandescent lamps, resulting in savings in electricity, in addition to the energy efficiency savings of using CFLs instead of incandescent lamps.

Efficacy: The typical luminous efficacy of CFL lamps is 60 to 72 lumens per watt, and that of normal domestic incandescent lamps is 5 to 15 lm/W.

LED (Light Emitting Diodes)

A **light-emitting-diode lamp** is a solid-state lamp free from Mercury, with instant switching capability, fully dimmable lamp is the upcoming source of lamp. LEDs providing over 200 lm/W (have been demonstrated in laboratory tests) , although average efficacy is still about 20-60 lm/W and expected lifetimes of around 50,000 hours are typical.

Diodes use here are driven by direct current (DC) electrical power, so LED lamps must also include internal circuits to operate from standard AC voltage. LEDs are damaged by being run at higher temperatures, so LED lamps typically include **heat management** elements such as heat sinks and cooling fins. LED lamps offer long service life and high energy efficiency, but till time initial costs are much higher than those of fluorescent lamps.

The colour is characteristic of the energy bandgap of the semiconductor material used to make the LED. To emit white light from LEDs requires either mixing light from red, green, and blue LEDs, or using a phosphor to convert some of the light to other colours.

The first method (RGB-LEDs) uses multiple LED chips each emitting a different wavelength in close proximity, to form the broad white light spectrum.

The second method, phosphor converted LEDs (pcLEDs) uses one short wavelength LED (usually blue or ultraviolet) in combination with a phosphor, which absorbs a portion of the blue light and emits a broader spectrum of white light. (The mechanism is similar to the way a fluorescent lamp emits white light from a UV-illuminated phosphor.) The major advantage here is the low production cost, and high CRI, while the disadvantage is the inability to dynamically change the character of the light and the fact that phosphor conversion reduces the efficiency of the device. The recent trend of low cost and adequate performance makes it the most widely used technology for general lighting today.

Advantages: LED lamps are used for both general and special-purpose lighting. Where coloured light is needed, LEDs come in multiple colours, which are emitted with no need for filters. This improves the energy efficiency over a white light source that generates all colours of light then discards some of the visible energy in a filter.

White-light light-emitting diode lamps have the traits of **long-life expectancy** and relatively **low energy use**. The LED sources are compact, which gives **flexibility in designing** lighting fixtures. LED lamps

have **no glass tubes to break**, and their internal parts are rigidly supported, making them resistant to vibration and impact. With proper driver electronics design, an LED lamp can be made dimmable over a wide range; there is no minimum current needed to sustain lamp operation.

Problems:

- The production process of white LEDs is complex and many aspects have room for improvement.
- Price of volume products is still relatively high compared to traditional light sources.
- Efficiency falls with temperature rises.
- Poor quality of Driver circuit (similar to Electronic Ballast) leads to lamp failure.

Applications: In recent passed usage confined to Indicator, Signal lighting, Decorative lighting etc., but in near future expected to replace FL and CFL Lamps in commercial use.

A light-emitting-diode (LED) is a semiconductor diode that emits light when an electric current is applied in the forward direction of the device, as in the simple LED circuit. The effect is a form of electroluminescence where incoherent and narrow-spectrum light is emitted from the p-n junction in a solid-state material.

LEDs are widely used as indicator lights on electronic devices and increasingly in higher power applications such as flashlights and area lighting.

An LED is usually a small area (less than 1 mm^2) light source, often with optics added directly on top of the chip to shape its radiation pattern and assist in reflection. The color of the emitted light depends on the composition and condition of the semi conducting material used, and can be infrared, visible, or ultraviolet.

Besides lighting, interesting applications include using UV-LEDs for sterilization of water and disinfection of devices, and as a grow light to enhance photosynthesis in plants.

VARIOUS TECHNOLOGIES OF LED

Fig 10: Various types of LED

LED Chips comes now in different form depending on the use and technology used by the LED manufacturer. The most common LED is used for indicator lights (conventional **DIP-Dual in-line package** structure) which have very low lumens per watt. The development of **SMD-Surface Mounted Device** Structure LEDs paves the way for a better or higher lumens per watt that reaches 50 to 80Lm/W and having a lifespan of 20,000 to 50,000 burning hours however the only problem is, it has a high manufacturing cost. Another development in LED light chips is the **COB or Chips on board**, a new technology in LED packaging. Multiple LED chips are package as one lighting module that also increased the heat dissipation to 70%. The latest LED development is the **S-COB** LED (**Stereoscopic** Chips on Board). S-COB LED have a simple structure (LED Chips are directly embedded on the heat sink) that made lower manufacturing cost but giving a better quality by having a faster heat dissipation of up to 97% and higher lumens that can reach 90Lm to more than 140Lm per watt. S-COB LED have a burning hour of 40,000 to 100,000 hours. Faster heat dissipation prolongs the life of internal electrical components, because of lower heat operation and lower energy consumption while giving a superb lighting, S-COB LED lights change the way how we see lights. LED Lights have no Toxic materials, longer life span and lower energy consumption but is brighter 3 times than a CFL and more than 10 times that an incandescent light. Because of the many advantages of LED's and having a lower energy

consumption that can drastically lower down carbon emission of our planet that in turn help solve global warming problem.

SMD LED

SMDs (Surface Mounted Device) are the new generation of LED lighting, the majority of our bulbs contain SMD chips allowing our bulbs to be much brighter than older generations of LED. The LED is soldered directly onto the PCB therefore requiring less space and improves the thermal connection. The competent design of an SMD LED has resulted in better heat dispersion with high lumen output. The SMDs have single-handedly abled the manufacturers to mechanism LED production along with improved quality control.

SMDs are easier to maintain in comparison with other LEDs and have a longer life.

SMD LED Basics

Surface mounted device light emitting diodes (SMD LEDs) are the most common type of LED lights right now - these consist of a LED chip that is permanently fused to a printed circuit board, resulting in solid units that can be connected in a simple circuit to create various lighting configurations (including light bulbs and strip LED lights).

Up to 3 diodes can be fused onto a single SMD chip - this gives SMD LEDs the ability to output a huge range of colors when a chip is built using red, green and blue diodes (while the old-style DIP LEDs are mono-colored).

SMD LEDs are available in a range of dimensions - tuners might be familiar with the two most common sizes, SMD 3528 and SMD 5050; those are the two most common sizes used for 12V LED light strips.

COB LED

Chip on Board (COB) is the most recent development in LED technology using chips with multiple diodes (typically 9, or more). There is no casing with COB technology which enables a much denser LED array of light compared to SMD. A consistent and controlled light beam is given off, without any visible individual light points, thus offering great optics. COB offers a greatly improved lumen per watt ratio compared with other LED technologies such as DIP and SMD. COB technology gives the best

conditions for optimal cooling, which in turn will increase efficiency and lengthen the overall life of the lamp.

Chip-on-Board or COB LEDs, as opposed to SMDs are segmented into **numerous tiny pieces of semi-conductor crystals and are directly placed over a substrate.** COBs are popular for their heat efficient behaviors. They ensure minimum heat production and emit homogeneous light. The behavior is enhanced with the addition of a ceramic substrate which induces a cooling effect in addition to the homogeneous light production. COBs' assembling is relatively cheap and the LEDs have a longer life span.

LED lighting technology is also growing rapidly; there are now three major types of LED lights available; DIPs (a.k.a. old-school LEDs), SMDs and COBs. Here's a brief rundown on the two most common types of LED lights currently in use today - COB LEDs and SMD LEDs.

COB LED Basics

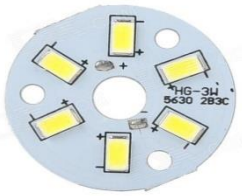
Chip on board light emitting diodes, **aka COB** LEDs, are the newest type of LED lights to hit the market. Like SMD LEDs, COB LEDs consist of multiple diodes that are soldered directly onto a microchip, however, unlike SMDs, COBs typically use 9 or more diodes per chip - this produces a light that looks like a glowing panel (rather than a bunch of tiny little lights as with SMDs).

COB LEDs are extremely 'heat efficient'; they produce very little heat, thanks in part to their cooling ceramic substrate. Unlike SMD LEDs, COB LEDs do not have the ability to emit different light colors, however, the light temperature (such as warm or cool) can be controlled.

COB LEDs can produce a higher lumen-per-watt ratio in comparison to both SMD and DIP LEDs. COB (wide angle beam) LEDs use a single circuit and just two contacts, regardless of how many diodes are on each chip.

Because they are relatively cheap to manufacture, consumers can look forward to lower prices on COB LEDs as production of this latest generation of LED lights ramps up.

[Table 3: Difference of LED Light Chips]

	SMD (Surface Mounted Diode) LED	COB (Chip On Board) LED
1		
3	Low light intensity/ lumen efficacy (50-60 lm per watt)	High light intensity/ lumen efficacy (up to 120 lm per watt) **Nearly twice than SMD's**
4	Are difficult to install & indulge high amount of labour & skilled man power in manufacturing luminaries.	Are easy to install & hassle free in nature, thus require less labour & man power in manufacturing luminaries.
5	require high amount of maintenance	are almost maintenance free
6	they can't bear high junction temperature	they can bear high junction temperature
7	The slightest of power fluctuations can blow up the SMD's	COBs don't fuse easily & can survive major power fluctuations
8	They get damaged easily & stop working	They work effectively even after rough handling
9	SMD's radiate **more heat** as compared to COB's	COBs radiate **less heat** as compared to SMD's
10	SMD's are a very expensive source of lighting. Due to high amount of investment in labor &skilled manpower indulgence in manufacturing cost.	Compared to the **SMD** LED lights **COB** LED Lights are economic in nature. As they are easily manufactured, hence decrease manufacturing cost greatly. **(approximately 15-20% cheaper than SMD LED's)**
11	Are usually laid down in circuit, even a single fault in line diffuses all the following LEDs in the fixture.	COB technology does not require a circuit. Thus, it is unaffected & totally safe from this defect unlike the SMD's.
12	Are **not very much reliable,** the damaged SMD's **leave a spot or dead point** in the	**Good reliability**, the whole COB panel enlightens on receiving power thus **no dead bulb and no spot caused** unlike the SMD's.

	whole layout fixture. Making it very awful to look.	
13	SMD LED is fixed on small base PCB. Thus, radiates more heat which could not dissipate further easily increasing the junction temperature dangerously. Thus reducing the luminous efficacy and life span of LED fixture.	COB LED Lights use flat base aluminium COB packing technology: COB **LED** is fixed on aluminium layer of aluminium base PCB. The heat from chip is spread out through aluminium layer rapidly. Thus, enabling to reduce LED Lights junction temperature, thus increasing the luminous efficiency and extend life.
14	SMD's emit **unidirectional light** in a single direction (in form of a straight beam) which makes them **in-efficient for general lighting purposes as in flood lighting & street lights.**	**COB LED Lights emit out multi-directional light (i.e:** uniform light in all directions) unlike the unidirectional lighting of **SMD LED's. Which make them more efficient than the SMD lighting fixtures**, .
15	Thermal resistances occurring in SMD's	Proper thermal management in COB's
16	In SMD LEDs without optimal thermos management, the following situations may occur- Exceeding the permissible junction temperature Decrease in optical performance Shifting of wavelength Changes in brightness and color Destruction of an LED	Whereas, in COB LEDs without optimal thermal management, the following situations as occurring in SMD's are suppressed.
17	Straight & Strong irradiancy (not safe)	Equable and soft irradiancy (safe)
18	Hard glaring and no eye Protection. SMD LED Lights proved that LED light source is too stimulating to the eye.	No glaring and proper eye Protection. COB LED Lights effectively solved the problem that LED light source is not too stimulating to the eye, paving the road area to large-scale application for road lighting.

19	Can’t handle jarring & bumping	Can handle jarring & bumping
20	Highly affected by rain & storm	Not affected by rain & storm
21	Generally, IP 57 protection grading provided	Always above IP 65 protection grading provided
22	Not successful on Indian grounds.	Successful on Indian Grounds.

What's Better - COB or SMDs?

That all depends on your application. If you're looking for color-changeable interior and/or exterior accent lighting, you'll need to go with SMD LEDs; if you want the maximum lumens per Watt for a mono-colored light (such as a fog light, headlight or dome light) you might want to check out what's available in COB LEDs.

Where SMDs demand a low maintenance cost, COBs have a low production cost. However, both being energy efficient, COBs produce better results with respect to heat emission. Where SMDs alleviate heat dispersion, COBs minimize the heat output altogether. Both the types of LED lights have a long life span and generally speaking both can prove to be of advantage in differing circumstances.

However, where both SMDs and COBs fail is in terms of shape and design. Till now they have been unable to imitate the exterior design of a conventional incandescent bulb. But with the advancement in LED technology, there now is available the LED filament bulb. The LED filament bulb successfully structures itself around the conventional shape of a regular bulb while being energy efficient and having longer life span.

Failure of SMD LED lights in some projects across India-

- 1100 SMD LED Street Lights were installed in Kanpur (U.P), out of which the KMC states that nearly 72% are non-functional.

- Various SMD LED lighting installations were made in Bangalore (Karnataka). The authorities complain that nearly 45% are having problems, while minimum 10% have to be replaced annually.

- Guwahati (Assam) got LEDs equipped in perspective departments, but they are not pretty pleased with their performance as due to moisture herald & other climatic conditions some of the SMD LEDs in the lighting units turned faulty. Thus, making the lighting unit look awkward & low on performance.
- The demo project at Kalka (Haryana) was a disaster, as the SMD LED's lighting units blew up due to high junction temperature caused as the lighting was left on for 1 whole day.

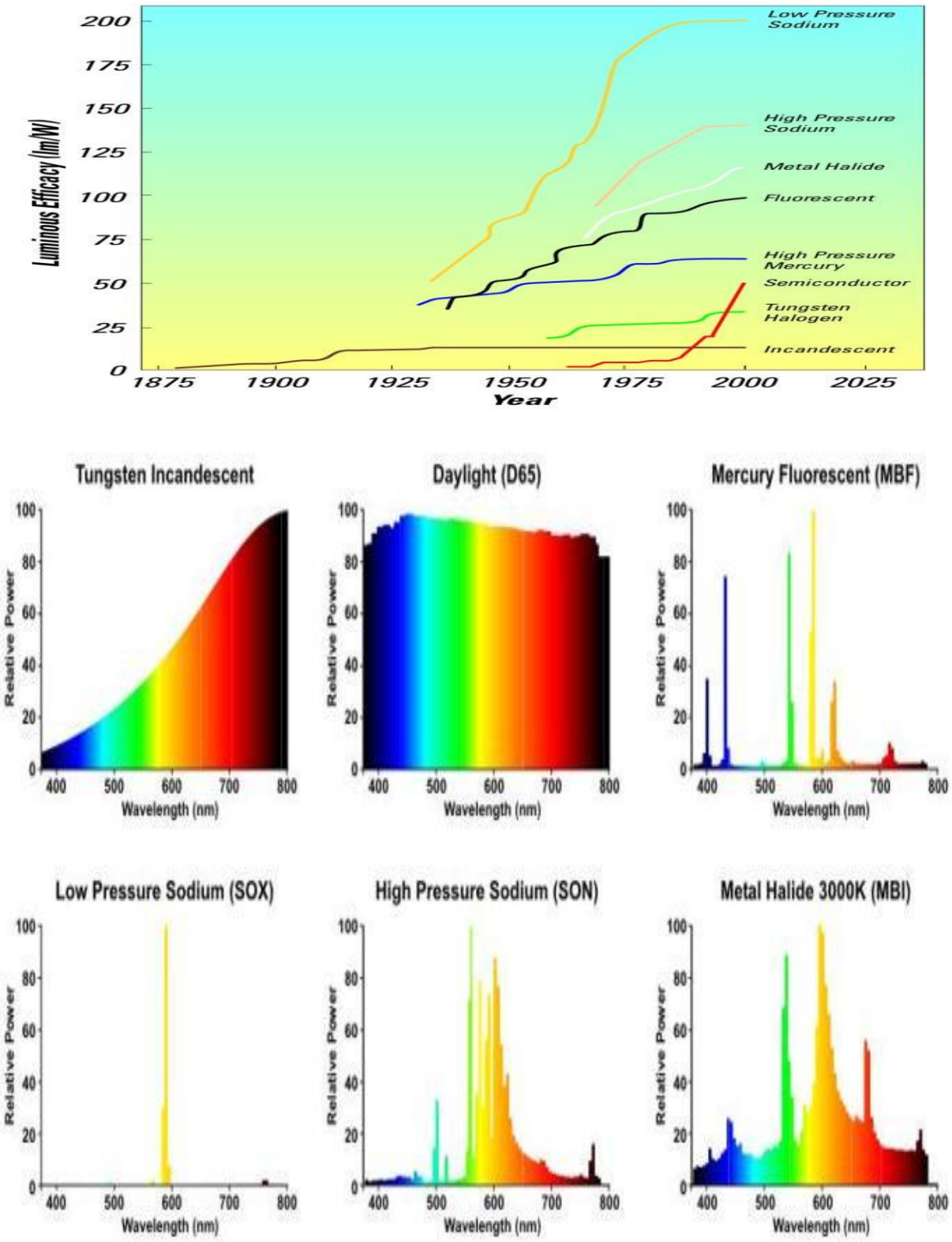


Fig 11: SMD Light

[Table 4: Properties of Misc. Light Sources and their applications]

Type of Lamp	Luminous Efficacy (Lumen/ Watt)	Life (Burning Hour)	Approx CRI	Remarks
Incandescent (GLS)	5 -15	1,000	100	Restricted use
Halogen	22	2,000	90-100	Projectors, motor car headlamps
Fluorescent	100	6,000	80 - 85	Popular indoor
CFL	100	3,000	80 - 85	Do
HPMV	58	6,000	70	Indoor high bay
Metal Halide	90	10,000	70 -90	Flood light
SON	145	4,000	20-25	Street, Area
SOX	180 – 200	12,000	0 ,< 20	Security (Area)
CDM	95	6-12,000	80	Hanger, Assembly Shop, Exhibition / Conference Halls, Sports, Street lighting, etc.
LED	20-60	50,000		Tailor made

[Table 5: Ratings of various lamps usually available in market]

Type of Lamp	Ratings (W)
Incandescent (GLS)	15,40,60,100,200
Halogen	15,20, 35, 50, 75,100
Fluorescent	**T_{12}**: 20, 40; **T_8**: 18,30,36,50,58, T_5:14, 21, 24,28,35, 39,54
CFL	**Integrated (in built Ballast):** 8,11,14,13,15,20, **Non-Integrated:**5,7,9,10,11,13,16,18,26,28,38,40,55,80
HPMV	250, 400 ,1000,2000
Metal Halide	70, 150, 250, 400 ,1000,2000
SON	50, 70, 100,150, 250 ,400 ,600, 1000
SOX	70, 125,250 ,400 ,1000,2000
CDM	22,35,38,70,100,150,245,380
LED	

LAMP PARAMETER COMPARISON & SELECTION PROCESS

LAMP SELECTION PARAMETERS

There are different types of parameters which distinguish the lamps. By this parameter we also differentiate various types of lamps according to their applicability in right place. The different parameters are

- Lamp wattage
- Lumen efficacy
- Life of the lamp and lumen depreciation.
- Lumen maintenance and maintainability of lamp
- Starting and restriking time
- Colour rendering index
- Correlated colour temperature and colour of the lamp.
- Heat dissipation
- Dimming capability
- Cost of the lamp
- Optical control
- Special requirements.

LUMEN MAINTENANCE AND MAINTAINABILITY OF LAMP

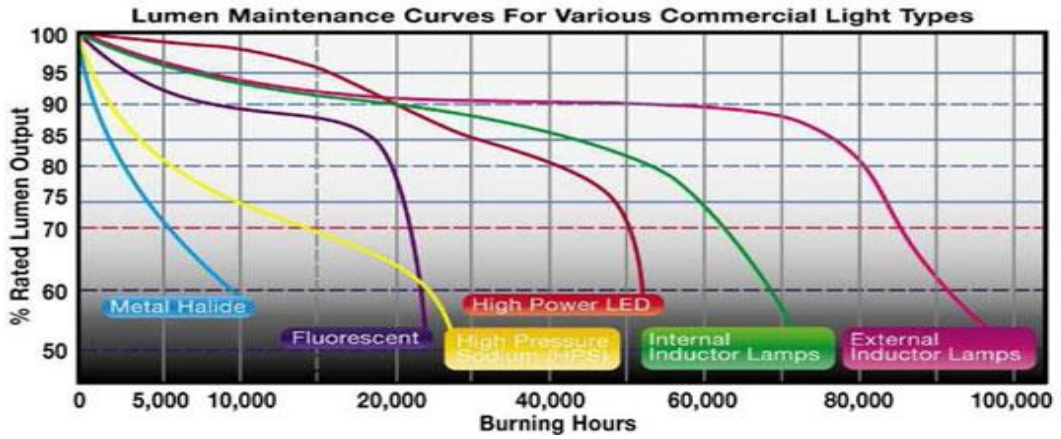


Fig 12: Lumen maintenance Curve for various commercial light

- The lumen output varies with the burning hours. As the burning hour increases the lumen output decreases.
- Maintainability is the other parameter for lighting design. As the maintainability factor decreases life of the lamp increases.
- For lighting in a hazardous area or for high altitude area its play a vital role.

STARTING TIME

Light source	Starting time (sec)
incandescent	instant
Tungsten halogen	instant
Standard fluorescent	3 to 10
CFL	1 to 3
HPMV	2 to4
HPSV	120 to 240
LPSV	240 to 600
Metal halide	240 to 360
Blended lamp	instant
LED	instant

- Some lamps are achieve their full light output immediately after starting. But some lamps such as MH lamp does not achieve full lumen at starting, they require some time called starting time.

- After a lamp has been on for some time then extinguished. It can't be on immediately; they need some time for turn on. This period of time called restriking time.

COLOUR RENDERING INDEX

colour rendering: Effect of an illuminate on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminate.

Light sources	CRI
Incandescent	Very good (100)
Tungsten halogen	Very good (60-90)
FTL	Good (around 80)
CFL	Good to very good (82)
HPSV	Low to good (30)
LPSV	Poor (- 44)
Metal halide	Very good (96)
LED	Good for white LED (>75)

CORRELATED COLOUR TEMPERATURE

The colour temperature of a light source is the temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source.

- colour temperature is conventionally stated in the unit of absolute temperature, the kelvin, having the unit symbol K.

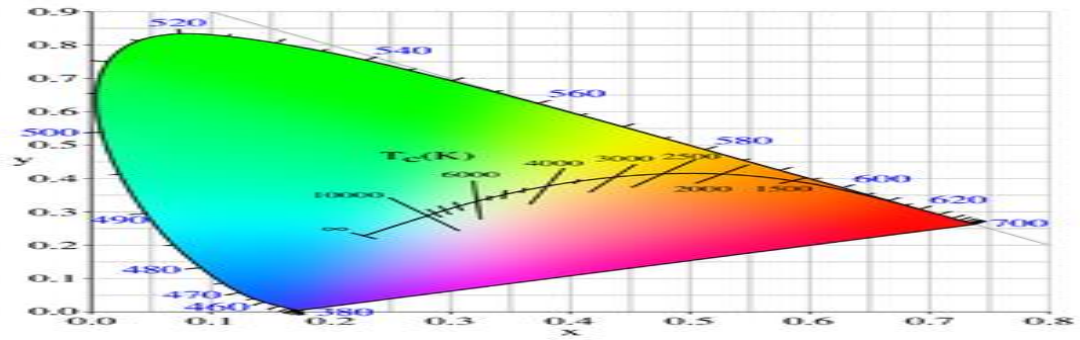


Fig 13: CIE 1931 x,y chromaticity space

HEAT DISSIPATION

- Artificial luminous radiation can be produced from electrical energy according to two principles:
- Incandescence
- Luminescence

DIMMING CAPABILITY

- By decreasing or increasing the RMS voltage and, hence, the mean power to the lamp, it is possible to vary the intensity of the light output.

Light sources	Dimming capability
Incandescent	Very good
Halogen lamp	Very good
FTL	fair
CFL	Very low
HPSV	low
LPSV	Very low
LED	No
Metal Halide	low

OPTICAL CONTROL

Optical control is a parameter for choosing the shape and size of light sources. If we choose the size of the lamp little the optical control is easier than the larger sources.

Light sources	Optical control
Incandescent lamp	good
Tungsten halogen	Very good
CFL	fair
FTL	poor
Metal halide	good

COMPARISON OF VARIOUS FTL

QUALITY	CRI Levels	LPW Levels
T12 = old and inefficient	T12=62	T12=78 LPW
T8 = higher efficiency	T8=85 CRI	T8=90 LPW
T5 = highest	T5=85 CRI	T5=99 LPW

LAMP LUMEN DEPRECIATION OF FTL

- As lamps age, they lose a certain amount of output.
- Old T12 fluorescents can lose up to 30% of output over their life.
- New T8 fluorescents maintain up to 95% of original lumens.
- This depreciation must be accounted for when installing new lighting system.

[TABLE 6: COMPARISON OF LED WITH A FLUORESCENT LAMP]

	Cool white LED	Popular T8 Brand Fluorescent
Watt Rating, typical B.F. = 0.8	22W	34W
Lumens, initial	2800	2850
CRI	85	85
Color Temperature	5000K	5000K

Life Expectancy 12 hrs per start	10 years	20000 hours 16000 hours
Light output at 0° C	20% increase	50%decrease

2.4 Benefits of LED Lighting for Offices & Workplaces [15]

LED lighting in the workplace is more than a passing trend; it's a strategic investment that enhances both health and productivity. This advanced lighting solution, embraced by forward-thinking organizations globally, leverages modern technology to light workspaces in ways that traditional lighting simply can't replicate. However, while LED lighting offers clear advantages, it's wise to consider potential drawbacks as well. Beyond energy efficiency, LED lighting has the potential to completely transform the workplace environment. Understanding these benefits reveals how this shift can be a valuable decision, positively impacting employee satisfaction, productivity, and your bottom line. Let's dive into these benefits in detail.

Office Productivity

Human beings are deeply influenced by their psyche, both conscious and subconscious, which is shaped by the environment around them. Interior design and surroundings directly affect how people feel, and given the amount of time spent in workspaces, these factors have a significant impact.

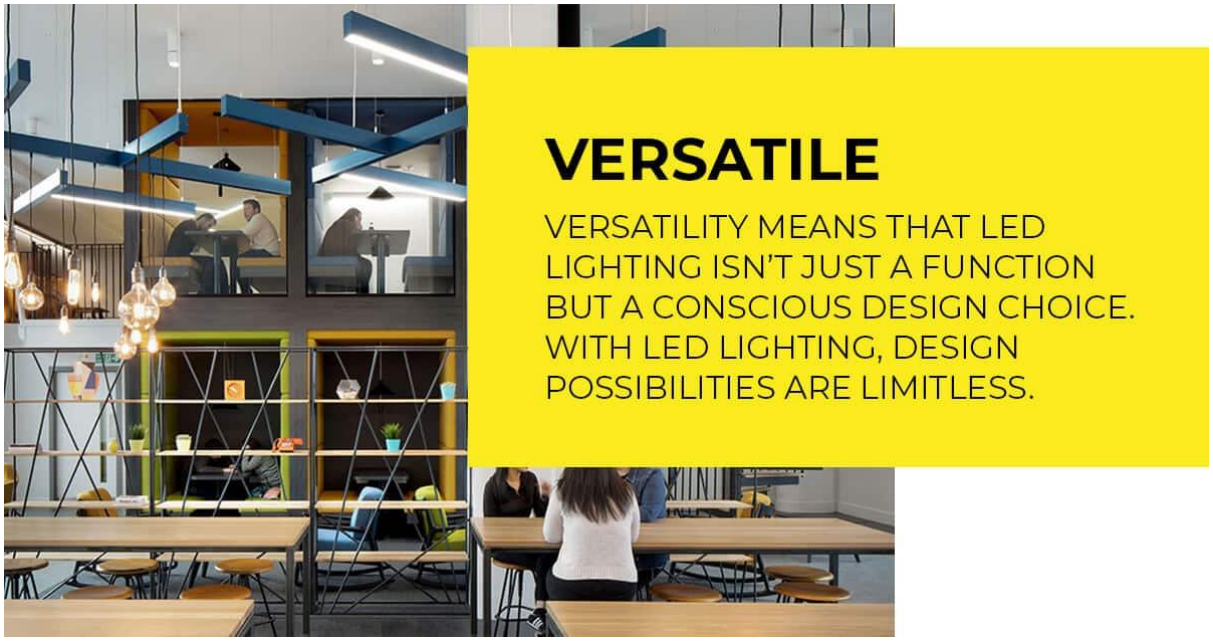
In Britain, where people work nearly 2,000 hours annually on average, the workspace environment greatly affects their mental state. During these hours, employers seek to keep employees motivated and engaged, and lighting plays a key role in supporting this.

A critical element of promoting productivity is aligning office lighting with the circadian lighting system. Circadian rhythms are daily cycles of physical, mental, and behavioural changes, and circadian lighting aims to replicate these natural fluctuations in workplace lighting. While natural

light is ideal for fostering positivity and productivity, it isn't always available or consistent throughout the day.

This is where artificial lighting that mimics the color and shifts of natural light becomes invaluable. LED lighting can effectively simulate natural light to keep employees energized without disrupting their body's natural rhythms. Exposure to natural light promotes alertness, reduces stress, and enhances overall happiness—making it an excellent productivity booster if recreated with a simple lighting adjustment.

LEDs provide a brighter, more natural appearance, and smart technology allows employees to adjust lighting intensity to mirror natural light changes throughout the day. By integrating smart LED controls, whether through spotlights or pendant lighting, employees can maintain peak mental performance and avoid the negative effects of poor lighting when they leave the office.



Versatile

LED luminaires come in a vast array of shapes and sizes. Leveraging the light-emitting diode's innovative technology, lighting companies like Mount Lighting have created luminaires that range from ultra-compact to impressively large. This wide size range, without sacrificing brightness or output, allows you to illuminate any space to meet both task and general lighting needs.

From sleek LED linear systems like the M-Line to sturdy bulkhead lighting, LED solutions can provide high-quality illumination across every corner of a commercial space. Whether it's stairwells, canteens, or reception areas, LED lighting offers unparalleled versatility.

For example, in a warehouse where uniform lighting is crucial for safety, LED office lighting delivers clear, even visibility to support safe and efficient work. In office spaces, functional and

aesthetic luminaires can be seamlessly integrated into each zone, with controls available to employees to boost their mood and motivation.

Gone are the days of rigid, one-size-fits-all lighting solutions. Embrace the flexibility of LEDs to shape your design to any functional or aesthetic requirement.

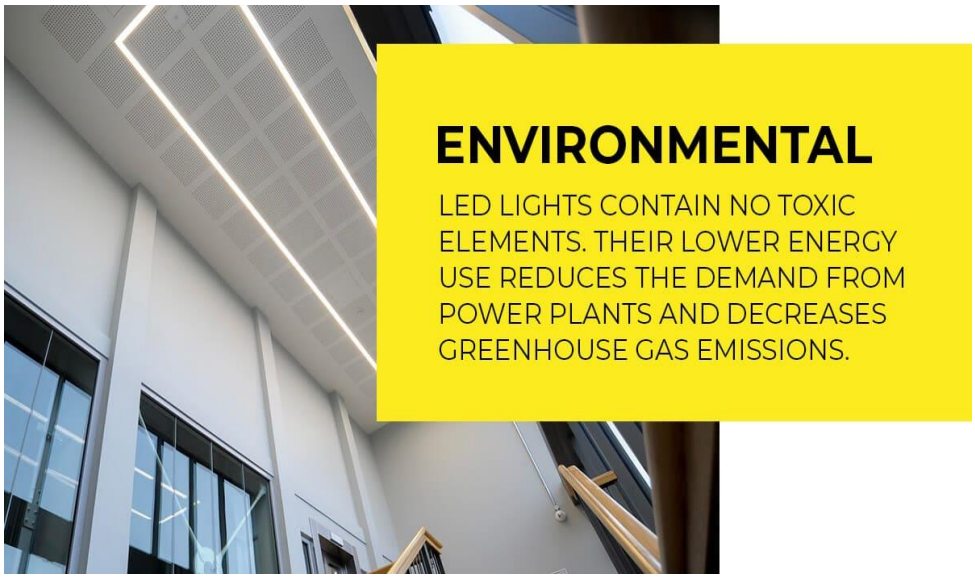
Casambi-controlled LED lights are especially suited for multi-purpose spaces, combining flexibility with energy efficiency. Their striking designs also make them perfect for geometric lighting themes, such as hexagonal or circular luminaires.

Energy Efficiency

Businesses are constantly seeking ways to reduce utility expenses, and LED lighting offers a substantial cost advantage over traditional lighting options.

LEDs can last up to 20 times longer than standard incandescent or halogen lamps. Their superior efficiency and lifespan are due to minimal energy wasted on heat, focusing power on light production instead.

Among lighting options, LEDs provide the highest return on investment, making them an ideal choice for businesses aiming to optimize both cost and performance.



Environmentally Friendly

In today's world, environmental responsibility is a priority for most businesses. By incorporating LEDs into your workspace, you're choosing a sustainable alternative to traditional lighting.

LEDs are free from pollutants like mercury, lead, glass, and other toxic materials, making them 100% recyclable and a long-term eco-friendly choice.

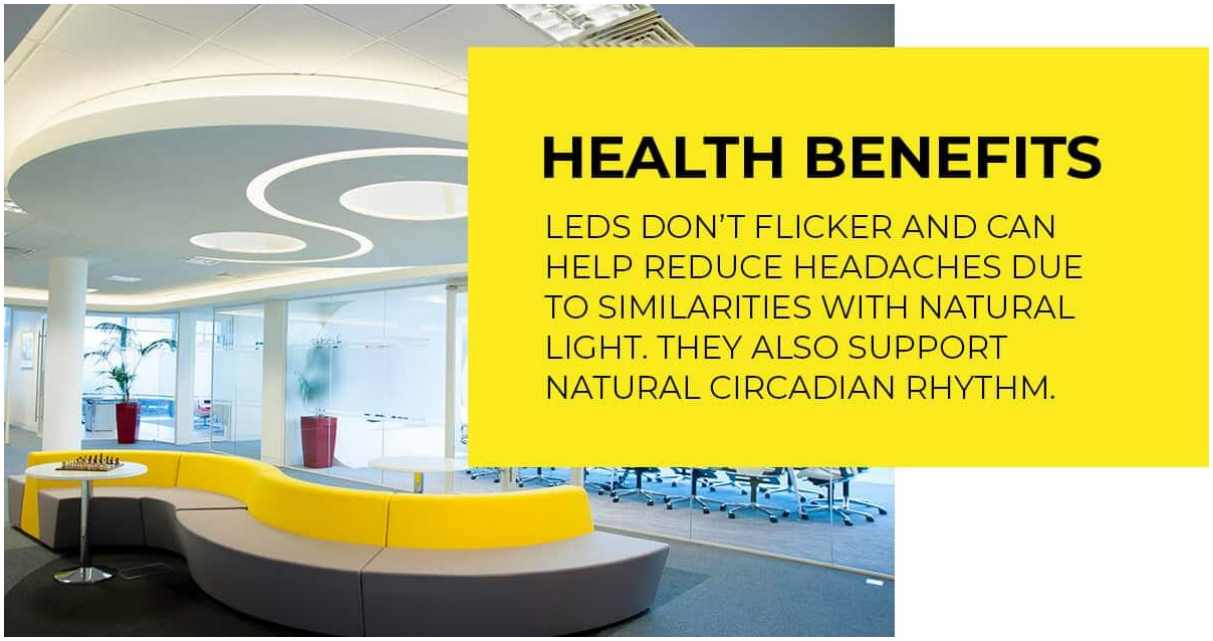
Because LEDs consume less power per unit, they help reduce greenhouse gas emissions and keep carbon dioxide output low. Using LED lighting not only lowers utility costs but also supports

environmental efforts, making it a smart, responsible choice for business owners.

Tough and Durable

LEDs are made with very sturdy materials and components. As mentioned above, LEDs are versatile and their durability means they can be used throughout various areas of the business to meet the demands of different types of workspaces.

A key secret to the durability of the LED lamp is that it contains no filament and without a filament, there's not one to break. Physical shock in alternative forms of lighting such as incandescent lamps can lead to shattered glass and interrupted lighting. LEDs can withstand much more shock during operation and won't suffer from adverse effects.



No Flickering

Flickering lamps can significantly impact employees' health. For individuals prone to migraines or headaches, flickering lighting can be particularly painful, but it can also cause issues like eye strain and other visual discomforts for others. High-quality LEDs do not flicker and can even help reduce headaches due to their similarity to natural light.

Headaches triggered by the work environment can lead to reduced productivity and downtime. When an employee can't comfortably focus on their screen due to pain, it becomes a serious barrier to productivity.

LED office lighting can be instrumental in enhancing productivity. By reducing stress, minimizing discomfort, and enabling better focus, LED lighting supports employees in performing at their best. It's an effective way to invest in workforce well-being, creating an environment where employees feel good and can work to their full potential.

Outstanding aesthetics

Architectural linear lighting should do more than perform well; it should look exceptional. In business, first impressions are vital, and attractive LED lighting is a powerful way to showcase your workplace to clients, visitors, and potential employees.

Aesthetic luminaires can serve as a stunning focal point in a large office or be thoughtfully woven throughout a workspace to create beautifully layered lighting. With Mount Lighting's outstanding range of products, you can elevate any space, ensuring it leaves a memorable impression.

Don't compromise on the perfect ambiance and working environment—let the unmatched aesthetics and luminous quality of LED luminaires bring your design vision to life.

2.5. Codes and Standards of Office Lighting:

2.5.1: IS 3646 (Part 1): 1992 (Code of Practice for Interior Illumination) [9]

The primary object of this code is to indicate the factors which should be considered to achieve good lighting. This code (Part 1) covers the principles and practice governing good lighting in buildings and relates to the lighting of working areas in industrial, commercial and public buildings, hospitals and schools keeping two objects in mind, namely, to make the task easy to see and to create a good visual environment.

Because circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity, a range of illuminances is recommended for each type of interior or activity intended of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminances. For working interiors, the middle value of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below apply.

The higher value of the range should be used when:

- Unusually low reflectance or contrasts are present in the task;
- Errors are costly to rectify,
- Visual work is critical,
- Accuracy or higher productivity is of great importance and
- the visual capacity of the worker makes it necessary.

The lower value of the range may be used where reflectance or contrasts are unusually high, speed and accuracy are not important and the task is executed only occasionally.

Table 06 gives the recommended illuminance ranges for different tasks and activities. The values are related to the visual requirements of the task, to user's satisfaction, to practical experience and to the need for cost effective use of energy. The values in the table are service values, which are obtained as an average during the maintenance cycle. They apply to the average illuminance at the reference surface/working plane.

[Table 06: Recommended Illuminance]

Table 1 (*continued*)

Type of Interior or Activity	Range of Service Illuminance in Lux	Quality Class of Direct Glare Limitation
17 COMMERCE		
17.1 Offices		
17.1.1 General offices	300-500-750	1
17.1.2 Deep plan general offices	500-750-1 000	1
17.1.3 Computer work stations	300-500-750	1
17.1.4 Conference rooms, executive offices	300-500-750	1
17.1.5 Computer and data preparation rooms	300-500-750	1
17.1.6 Filing rooms	200-300-500	1
17.2 Drawing Offices		
17.2.1 General	300-500-750	1
17.2.2 Drawing boards	500-750-1 000	1
17.2.3 Computer aided design and drafting	—	—
17.2.4 Print rooms	200-300-500	1
17.3 Banks and Building Societies		
17.3.1 Counter, office area	300-500-750	1
17.3.2 Public area	200-300-500	1
18 SERVICES		
18.1 Garages		
18.1.1 Interior parking areas	20-30-50	3
18.1.2 General repairs, servicing, washing, polishing	200-300-500	2
18.1.3 Workbench	300-500-750	1
18.1.4 Spray booths	300-500-750	1
18.1.5 External apron		
18.1.5.1 General	30-50-100	—
18.1.5.2 Pump area (retail sales)	200-300-500	—
18.2 Appliance servicing		
18.2.1 Workshop		
18.2.1.1 General	200-300-500	2
18.2.1.2 Workbench	300-500-750	2
18.2.1.3 Counter	200-300-500	2
18.2.1.4 Stores	200-300-500	3

2.5.2: Energy Conservation Building Code 2017 [16]

The **Energy Conservation Building Code** (**ECBC**), was launched by Ministry of Power, Government of India in May 2007, as a first step towards promoting energy efficiency in the building sector. The ECBC was developed by an Expert Committee, set up by India's Bureau of Energy Efficiency, with support and guidance from United States Agency for International Development (USAID).

2.5.2.1Building Area Method: Determination of interior lighting power allowance (watts) bythe building area method (Table-04) shall be in accordance with the determination of the allowed lighting power density for each appropriate building area type from Table.

(a) Calculation of the gross lighted carpet area for each building area type.

(b) The interior lighting power allowance is the sum of the products of the gross lighted floor area of each building area times the allowed lighting power density for that building area type.

[Table -07: Interior Lighting Power-Building Area Method]

Building Area Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Automotive Facility	9.7	Multifamily Residential	7.5
Convention Center	12.9	Museum	11.8
Dining: Bar Lounge/Leisure	14.0	Office	10.8
Dining: Cafeteria/Fast Food	15.1	Parking Garage	3.2
Dining: Family	17.2	Performing Arts Theater	17.2
Dormitory/Hostel	10.8	Police/Fire Station	10.8
Gymnasium	11.8	Post Office/Town Hall	11.8
Health care-Clinic	10.8	Religious Building	14.0
Hospital/Health Care	12.9	Retail/Mall	16.1
Hotel	10.8	School/University	12.9
Library	14.0	Sports Arena	11.8
Manufacturing Facility	14.0	Transportation	10.8
Motel	10.8	Warehouse	8.6
Motion Picture Theater	12.9	Workshop	15.1

2.5.2.2 Space Function Method: Determination of interior lighting power allowance (watts) by the space function method shall be in accordance with the following:

(a) Determination of the appropriate building type and the allowed lighting power density from Table. In cases where both a common space type and building specific space type are listed, building specific space type LPD shall apply.

(b) For each space, enclosed by partitions 80% or greater than ceiling height, determination of the gross carpet area by measuring to the face of the partition wall. The area of balconies or other projections is also to be included. Retail spaces do not have to comply with the 80% partition height requirements.

(c)The interior lighting power allowance is the sum of the lighting power allowances for all spaces. The lighting power allowance for a space is the product of the gross lighted carpet area ofthe space times the allowed lighting power density for that space

[Table -08: Interior Lighting Power-Space Function Method]

Lounge/Recreation*	12.9	• For Detailed Manufacturing	22.6
• For Hospital	8.6	• For Equipment Room	12.9
Dining Area*	9.7	• For Control Room	5.4
• For Hotel	14.0	Hotel/Motel Guest Rooms	11.8
• For Motel	12.9	Dormitory – Living Quarters	11.8
• For Bar Lounge/Leisure Dining	15.1	Museum	
• For Family Dining	22.6	• For General Exhibition	10.8
• Food Preparation	12.9	• For Restoration	18.3
Laboratory	15.1	Bank Office – Banking Activity Area	16.1
Restrooms	9.7	Retail	
Dressing/Locker/Fitting Room	6.5	• For Sales Area	18.3
Corridor/Transition*	5.4	• For Mall Concourse	18.3
• For Hospital	10.8	Sports Arena	
• For Manufacturing Facility	5.4	• For Ring Sports Area	29.1
Stairs-active	6.5	• For Court Sports Area	24.8
Active Storage*	8.6	• For Indoor Field Area	15.1
• For Hospital	9.7	Warehouse	
Inactive Storage*	3.2	• For Fine Material Storage	15.1
• For Museum	8.6	• For Medium/Bulky Material Storage	9.7
Electrical/Mechanical Facility	16.1	Parking Garage – Garage Area	2.2
Workshop	20.5	Transportation	
Convention Center – Exhibit Space	14.0	• For Airport – Concourse	6.5
Library		• For Air/Train/Bus – Baggage Area	10.8
• For Card File & Cataloging	11.8	• For Ticket Counter Terminal	16.1
• For Stacks	18.3		

Space Function	LPD (W/m^2)	Space Function	LPD (W/m^2)
Office-enclosed	11.8	• For Reading Area	12.9
Office-open plan	11.8	Hospital	
Conference/Meeting/Multipurpose	14.0	• For Emergency	29.1
Classroom/Lecture/Training	15.1	• For Recovery	8.6
Lobby*	14.0	• For Nurse Station	10.8
• For Hotel	11.8	• For Exam Treatment	16.1
• For Performing Arts Theater	35.5	• For Pharmacy	12.9
• For Motion Picture Theater	11.8	• For Patient Room	7.5
Audience/Seating Area*	9.7	• For Operating Room	23.7
• For Gymnasium	4.3	• For Nursery	6.5
• For Convention Center	7.5	• For Medical Supply	15.1
• For Religious Buildings	18.3	• For Physical Therapy	9.7
• For Sports Arena	4.3	• For Radiology	4.3
• For Performing Arts Theater	28.0	• For Laundry – Washing	6.5
• For Motion Picture Theater	12.9	Automotive – Service Repair	7.5
• For Transportation	5.4	Manufacturing Facility	
Atrium-first three floors	6.5	• For Low Bay (<8m ceiling)	12.9
Atrium-each additional floor	2.2	• For High Bay (>8m ceiling)	18.3

2.5.2.3 National Lighting Code 2010: This code covers the principles and practices governing good lighting of offices. It recommends the levels of illumination [17] to be achieved by general principles of lighting.

The provision made for lighting will depend on the type of office, for example, general office, executive office, drawing office, etc. and the subdivision of the floor space. Where the layout of partitioning is unknown or subject to alteration, provision should be made for a flexibleinstallation that will allow luminaires to be placed in proper relation to any arrangement of partitioning. This flexibility may be achieved by either:

a) providing fixed outlets on a modular system enough in number to ensure that luminaires can be located satisfactorily irrespective of how the interior is partitioned; or

b) by using continuous lines of trunking or lighting track along which luminaires can be located as required.

2.6. Lighting Control Devices [19]

Lighting control devices are used to automatically turn or dim lights on and off as needed and to save energy. Of course, energy can be saved by turning off lights when they are not needed, as sometimes the users forget or do not notice that they have left them on. The most common types of lighting controls include:

2.6.1 Dimmers for LEDs: Some light-emitting diode (LED) lightbulbs can be used with dimmers. LED bulbs and fixtures must be designed for dimming, and existing dimmer switches may be needed to replace with ones that are compatible with an LED lighting product. The packaging or accompanying instructions will indicate if the product is dimmable and which dimmer products are compatible. Fully compatible LED dimmers are expected to become more common as the LED industry expands.

2.6.2. Occupancy sensor is an indoor motion detecting device used to detect the presence of a person to automatically control lights or temperature or ventilation systems. The sensors use infrared, ultrasonic, microwave, or other technology. Occupancy sensors are typically used to save energy, provide automatic control, and comply with building codes. They can be extremely cost-effective tools for reducing energy use and costs

Motion Sensor: A motion sensor, also known as a motion detector, is a device that detects movement. While "motion sensor" or "motion detector" is commonly used in residential contexts, the terms "occupancy sensor" or "vacancy sensor" are more often used in commercial or professional settings. These sensors are designed to automatically control lighting, security systems, or other devices based on detected movement, helping to enhance energy efficiency and convenience across various environments.

In lighting applications, occupancy sensors are sometimes referred to as "presence sensors" or "vacancy sensors." Some advanced occupancy sensors, such as LSG's Pixel View, Philips Lumi Motion, and Ecoamicatechs Sirius, can go beyond simple detection. These sensors are capable of classifying the number of occupants, their direction of movement, and other details using image processing technology. For instance, the Pixel View is a camera-based occupancy sensor, where the camera is integrated into each light fixture to monitor and detect activity within its range, enhancing the precision and functionality of the system.

Occupancy Sensor Types:

1. **PIR Sensors (Passive Infrared Sensors)**: PIR sensors detect heat differences by measuring infrared radiation. Inside the device is a pyroelectric sensor that detects the sudden presence of objects, such as humans, that emit a temperature difference compared to the surrounding environment, like the room temperature or the temperature of walls. When a person enters the detection area, their body heat creates a noticeable difference from the background, triggering the sensor to activate the lighting or other systems.

Fig No- 14: PIR Sensor

2. **Environmental Sensors**: These sensors, including temperature, humidity, and CO2 sensors, detect changes in the environment that occur due to human presence. For example, a rise in temperature, increase in humidity, or elevated CO2 levels can indicate that a person is in the area, prompting the sensor to activate lighting or other systems.
3. **Ultrasonic Sensors**: Ultrasonic sensors, working on the Doppler shift principle, function similarly to radar. These sensors emit high-frequency sound waves within a given area and monitor the reflected sound patterns. If the reflected pattern changes continuously, it indicates movement or occupancy, and the connected lighting load is turned on. If the pattern remains constant for a preset time, the sensor assumes there is no occupancy, and the lighting is switched off.

Fig No- 15: Ultrasonic Sensor

4. **Microwave Sensors**: Like ultrasonic sensors, microwave sensors also operate on the Doppler shift principle. These sensors emit high-frequency microwaves in a designated area and analyze the reflected patterns. If the reflected pattern changes continuously, the sensor detects occupancy and activates the connected lighting. If the pattern remains constant for a set period, the sensor assumes there is no occupancy and turns off the lighting. Microwave sensors offer higher sensitivity and a greater detection range compared to other sensor types, making them highly effective for larger or more complex spaces.

Fig No- 16: Microwave Sensor

5. **Keycard Light Slots**: These are used in hotel energy management systems to detect room occupancy. Guests are required to insert their keycard into a slot to activate the lights and thermostats, ensuring that energy is only used when the room is occupied.
6. **Smart Meters**: Smart meters detect changes in power consumption patterns, identifying distinct characteristics between occupied and vacant states. This allows the system to adjust lighting and other utilities based on occupancy.

7. **Door Operated Switch**: A switch that activates lighting when a door is opened, indicating that the space is occupied.
8. **Audio Detection**: Audio sensors detect sounds, such as voices or movement, to identify occupancy and trigger the lighting or HVAC systems.

The two most common types of occupancy sensors are **Passive Infrared (PIR)** and **Ultrasonic (US)** sensors.

Both sensors rely on the **pyroelectric effect**—a scientific principle that occurs due to the crystal structure of certain materials. When these crystals are warmed, their atoms shift slightly, generating a voltage. This voltage is then translated into an electrical signal, which triggers the lighting to turn on.

Passive Infrared Sensors are "waiting" sensors that detect changes in infrared radiation from objects, typically human bodies, as they emit heat. However, these sensors rely on a direct line of sight. If an individual is behind an obstacle like an office partition, the sensor may not detect them.

Ultrasonic Sensors, on the other hand, are more versatile. They emit ultrasonic waves and measure the Doppler shift in the reflected sound waves. When these waves bounce off a moving object (like a person), the pitch of the sound changes. This change is detected by the sensor, which then sends a signal to activate the lights. Unlike PIR sensors, ultrasonic sensors can detect motion through and around obstacles, making them ideal for more complex environments.

The **Doppler effect** in ultrasonic sensors refers to the change in frequency (or pitch) of the sound waves as they reflect off moving objects. When a person moves, the frequency of the reflected waves shifts, and this shift is used to determine occupancy and trigger appropriate actions, such as turning the lights on.

$$F2 = \frac{(F1 * C)}{(C + V)}$$

- F1 = The frequency of the sound that the ultrasonic sensor emits.
- F2 = The frequency of the sound that the ultrasonic sensor receives back after reflection.
- C = The speed of sound at sea level, approximately 700 miles per hour.
- V = The speed of the person approaching the sensor, about 3 miles per hour.

The key point to note is that F2 will differ from F1 if there is motion, such as a person moving toward the sensor. When the frequency of the reflected sound (F2) differs from the emitted frequency (F1), the ultrasonic sensor detects this change and triggers the lights to turn on.

2.6.3 Digital Timers

A digital timer, also known as a time switch or timer switch, is a device that controls an electric switch based on a timing mechanism. This switch can be connected to an electric circuit operating from mains power, often through a relay or contactor. The timer can be built into power circuits (e.g., for central heating or water heaters), plugged into a wall outlet with equipment connected to the timer, or integrated into the equipment itself.

The timer can perform several functions:

- Switch equipment on, off, or both at specific times or intervals.
- Countdown timers turn equipment off after a set period.
- Cyclical timers alternate between switching equipment on and off at preset times, usually over a 24-hour or 7-day cycle.

Some timers include additional features such as sensors. For example, a timer might switch on lights only during hours of darkness, using a seasonal algorithm or light sensor. By combining a light sensor with a timer, lights can be programmed to turn on at sundown and off at midnight.

Programmable Timers: These timers offer advanced scheduling capabilities, allowing users to set the switch to turn on and off at specific times. Unlike basic mechanical timers, programmable timers can handle multiple on/off cycles within a 24-hour period and can be scheduled for several days. For example, they can operate on a 7-day schedule, like a programmable thermostat, with exact on/off times for each day.

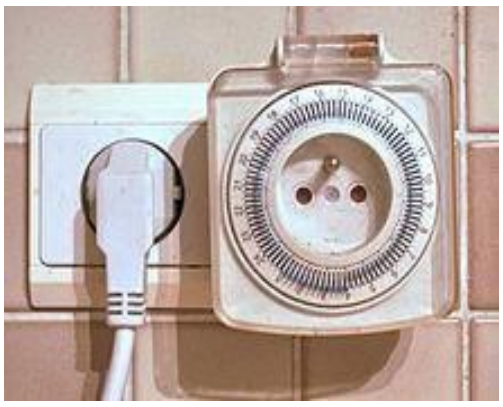


Fig No- 17: Hour Electromechanical Time Switch

Time Switches can be used for a variety of purposes, including:

1. **Energy Conservation**: Time switches help reduce electricity consumption by ensuring that equipment is only powered when needed. This prevents energy waste, as devices are turned off when not in use.
2. **Operational Control**: Time switches can automate the on/off operation of equipment according to specific time schedules, improving efficiency in processes that require precise timing.
3. **Home Security**: Time switches can also enhance security by controlling lights in a pattern that simulates occupancy, making it appear as though the premises are attended. This helps reduce the risk of burglary or prowling when the property is unoccupied.

2.6.4 Photo Sensor

A **photoelectric sensor** (also known as a **photo eye**) is a device used to detect the presence, absence, or distance of an object by using light, typically infrared light. It consists of a light-emitting element and a light-receiving element. The sensor emits a beam of light (either visible or infrared) from the emitting element, and the light is then received by the receiving element.

In a **self-contained photoelectric sensor**, the optics and electronics are housed within a single unit, requiring only a power source. These sensors handle tasks like modulation, demodulation, amplification, and output switching on their own. Some models may include additional features like built-in control timers or counters. With advances in technology, these sensors have become increasingly compact.

There are three main types of photoelectric sensors:

1. **Opposed (Through Beam)**: In this type, the light emitter and receiver are positioned opposite each other, and the sensor detects when the light beam is interrupted by an object.
2. **Retro-Reflective**: Here, both the emitter and receiver are housed together. The sensor detects light reflected from a target back to the receiver.
3. **Proximity-Sensing (Diffused)**: In this type, the emitter and receiver are housed in the same unit, and the sensor detects the presence of an object based on the light that is diffused or scattered by the object.

The **Reflective Model** (often used in retro-reflective sensors) contains both the light-emitting and light-receiving elements within the same housing. It detects light reflected from the target,

allowing for accurate object detection without the need for separate emitter and receiver components.

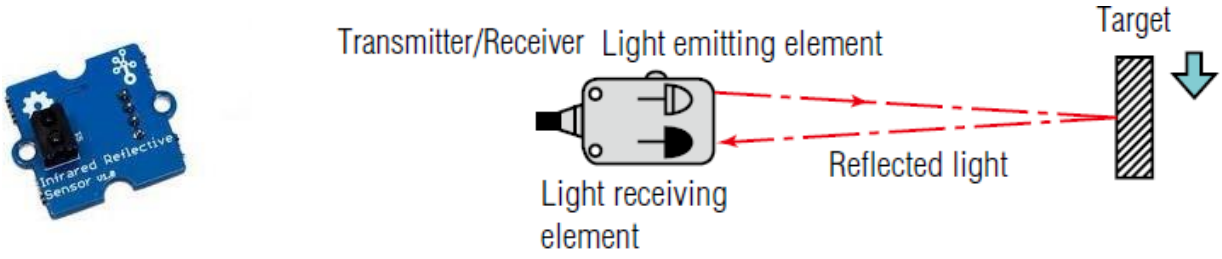


Fig No-18 Reflective Model Photo Sensor

Opposed (Through Beam) Model (Fig No-21): In this model, the transmitter and receiver are positioned separately, facing each other. The sensor detects objects when they pass between the transmitter and receiver, interrupting the light beam. This interruption signals the presence of the target. The opposed (through beam) model is highly effective for detecting objects at greater distances, as the separate positioning of the transmitter and receiver allows for stronger and more reliable detection over longer ranges.

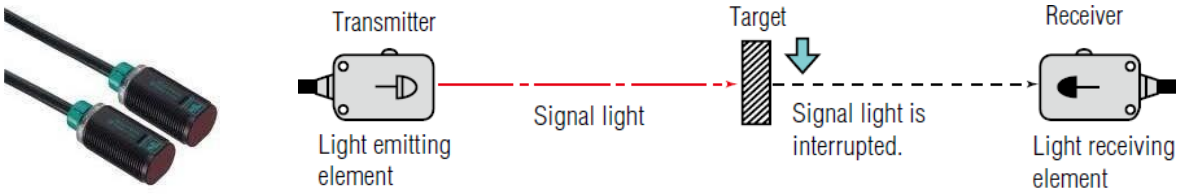


Fig No-19: Through Model Photo Sensor

Proximity-Sensing (Diffused) Model (Fig No-20): In this arrangement, the transmitter and receiver are housed together, and the transmitted light reflects off the target object to reach the receiver. Unlike the through-beam model, where detection occurs when the light beam is interrupted, in the diffused model, an object is detected when the receiver picks up the light reflected from the object. This setup is useful for applications requiring close-range detection, as the object itself acts as the reflector.

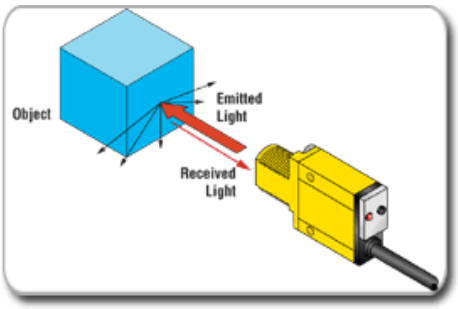


Fig No-20: Diffused Photo Sensor

In Retro-Reflective Sensors (Fig No-23), similar to diffuse sensors, both the emitter and receiver are located within the same housing. However, instead of using a fixed reflector, the target object itself serves as the reflector.

The emitter sends out a beam of light—typically pulsed infrared, visible red, or laser—those spreads across a detection area. When an object enters this area, it reflects part of the light beam back to the receiver. Detection is triggered, and the output is switched on or off when enough reflected light reaches the receiver. This model is effective for sensing objects in a specific area and can be used in various applications requiring proximity detection within a defined range.

Fig No. -21: Retro Reflective Sensor

2.6.4.1 Comparison of photo sensors:

[Table 9: Comparison of Photo Sensors]

Different models	Advantages	Disadvantages
Through-beam	Most accurate, Very reliable Longest sensing range	Must install at two points on system: emitter and receiver
Reflective	Only slightly less accurate than through-beam. Sensing range better than diffuse, very reliable	Must install at two points on system: sensor and reflector Slightly more costly than diffuse Sensing range less than through-beam
Diffuse	Only install at one point Cost less than through-beam or reflective	Less accurate than through-beam or reflective More setup time involved

2.7 Lighting Design Methodology [20]

Here are the key steps in the lighting design process:

1. **Identification of Requirements**: Begin by thoroughly understanding the objectives of the lighting installation. This includes:
    - Task requirements (illuminance and glare levels)
    - Desired mood of the space
    - Relation to the shape of the space
    - Elements to emphasize or conceal
    - Direction and quality of light
    - Integration with natural daylight
2. **Determination of Lighting Method**: Decide how the light will be delivered. Options include recessed or surface-mounted fixtures, direct or indirect lighting, or up-lighting. Also, consider characteristics like prismatic, low-brightness, or mellow light. Factor in daylight utilization to reduce artificial lighting needs.

3. **Selection of Lighting Equipment**: After choosing the lighting method, select the most suitable light source and luminaire based on:
    - Light output (lumens)
    - Total input wattage
    - Efficacy (lumens per watt)
    - Lifetime
    - Physical size Surface brightness / glare
    - Colour characteristics
    - Electrical characteristics
    - Requirement for control gear
    - Compatibility with existing electrical system
    - Suitability for the operating environment

4. Several factors also affect luminaire choice:

- Characteristics of the Light Source and Control Gear: Ensure compatibility with the chosen light source and any necessary control gear for smooth operation.
- Luminaire Efficiency: Look for fixtures that maximize light output while minimizing energy consumption.
- Light Distribution: Choose luminaires that provide the desired spread of light, whether focused or widespread, for effective illumination.
- Glare Control: Opt for designs that reduce glare, promoting visual comfort.
- Finish and Appearance: Consider the fixture's finish and design to match the space's aesthetic.
- Size: Select appropriate sizes for the intended space and scale.
- Accessibility of Components for Maintenance: Ensure parts are easy to access for repairs or replacements.
- Ability to Handle Adverse Operating Conditions: Check that the luminaire can withstand specific environmental conditions, such as moisture or dust.
- Aesthetics: Choose luminaires that align with the visual design and overall style of the environment.
- Thermal Management: Ensure effective heat dissipation to prolong the fixture's lifespan and maintain performance.

2.7.1 Lighting calculations are essential for designing effective and efficient lighting installations, and they generally fall into three categories: **Manual Calculation Methods**, **Three-Dimensional Modelling**, and **Visualisation**.

2.7.1.1 Manual Calculation Methods

Manual methods are a traditional approach, though most have been replaced by computer software for greater efficiency and accuracy. However, one commonly used manual method is the **Lumen Method**, which is especially effective for interior lighting design and can give quick estimates of average illuminance.

The **Lumen Method** allows for calculating the average illuminance or the number of luminaires required for a target illuminance. This method relies on certain assumptions for accuracy:

- All luminaires in the room are identical and uniformly oriented.
- The luminaires do not have a specific directional distribution and are directed towards the floor.
- They are arranged in an even grid pattern on the ceiling.
- Spacing between luminaires does not exceed the maximum spacing-to-mounting-height ratio in utilization tables.

Calculation Formula

The formula to find the **average illuminance (E)** using the Lumen Method is:

$$E=(\phi \times n \times N \times UF \times MF) / A$$

Where:

- **ϕ** = Initial bare lamp luminous flux (in lumens)
- **n** = Number of lamps per luminaire
- **N** = Total number of luminaires
- **UF** = Utilization Factor, which accounts for the efficiency of light directed onto a surface
- **MF** = Maintenance Factor, which adjusts for light loss due to factors like dust accumulation
- **A** = Area of the surface to be illuminated (in m^2)

Utilization Factors (UF)

Utilization factors vary by luminaire design, room layout, and the reflection characteristics of room surfaces. They can be broken down into specific factors based on room regions:

- **UF(C)** for the **ceiling cavity**, which is an imaginary plane at the luminaires' height.
- **UF(W)** for **wall surfaces** between the ceiling and floor levels.
- **UF(F)** for the **floor cavity**, typically at a working height of 0.85 meters above the floor.

Manufacturers often provide tables of utilization factors for their luminaires under standard conditions, allowing designers to select the correct utilization factor based on room reflectance and configuration. These tables are keyed to the **Room Index** and the **effective reflectance** of the surfaces involved (such as the floor, walls, and ceiling).

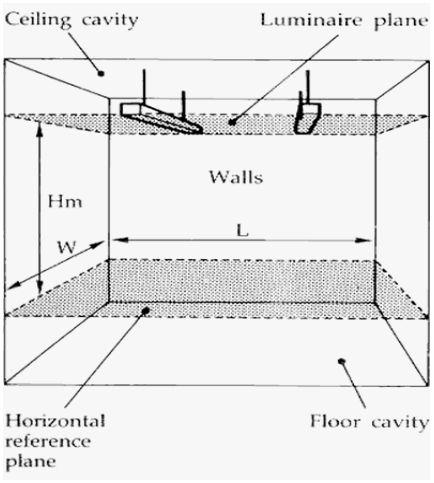


Fig No.22: Room Index and Effective Room Reflectance

2.7.1.2 Three-dimensional modelling

Although it was possible to calculate the luminance of all the surfaces in a room, the calculations were extremely laborious and could only be justified in the most special cases. However, the advent of computer modelling (Fig No-25) enabled a more flexible approach to lighting design and significantly increased the information available to the designer.

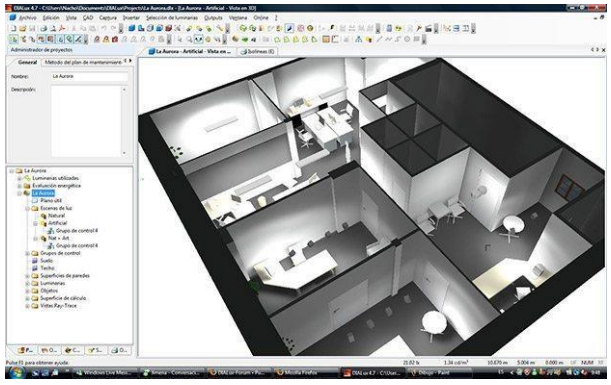


Fig No-23: DIALux work plane

2.7.1.3 Visualisation

Visualisation programs create a rendered perspective of the space, varying from basic block representations to high-quality, photorealistic images, depending on the program's sophistication and the interior's detail level. These visualisations allow designers to simulate how light will appear within a given space, offering a tangible preview of the lighting's impact.

Two Basic Types of Visualisation Calculations:

- **Flux Transfer (Radiosity) Calculations**: Focus on how light is distributed and diffused across surfaces, ideal for analyzing the spread of light in a room with highly reflective surfaces.
- **Ray Tracing Calculations**: Emulate the path of individual light rays, capturing reflections, refractions, and shadows, which is useful for detailed visualisation where surface details impact light interaction.

Using visualisation, lighting designers can explore a room’s potential lighting effects in greater depth, moving beyond assumptions of uniformity and allowing for irregular luminaire arrangements, directional lighting, and enhanced surface calculations. This results in a richer understanding of the room's lighting dynamics.

2.7.1.4 Determination of the Control System

The choice of a control system is critical for achieving an effective and efficient lighting installation, affecting performance as much as the selected light sources and fixtures. Control systems, as previously discussed, regulate lighting based on occupancy, daylight, time schedules,

or energy-saving requirements, enhancing the functionality and sustainability of the lighting design.

2.7.1.5 Choice of Luminaire

A well-chosen luminaire offers better long-term value than a low-quality unit. Essential qualities of a high-quality luminaire include:

- Robust mechanical and electrical construction with a durable finish
- Effective glare control, ensuring comfort in the illuminated space
- Efficient heat dissipation, preventing damage to lamps and electrical components
- High light output ratio with suitable distribution
- Ease of installation, maintenance, and cleaning

2.7.1.6 Inspection of the Installation Upon Completion

Final inspection ensures that the lighting installation matches the design specifications, verifying correct fixture placement, performance, control systems, and overall functionality.

2.8 Software for Lighting Design

Lighting design software enhances accuracy and presentation in design by providing powerful tools for calculation, analysis, and visualisation. Key advantages over manual calculations include:

- Faster calculations for illuminance and uniformity
- Improved accuracy in determining light levels
- 3D and 2D visualisation of spaces
- Importing of luminaires' photometric data
- Enhanced object, texture, and surface color integration
- Detailed layout planning for luminaires
- Viewing of illuminance isolines for even distribution
- Energy evaluation capabilities

Lighting design software streamlines complex tasks, provides higher accuracy, and supports creative visualization, making it an invaluable tool for both planning and presenting effective lighting designs for indoor environments.

DIFFERENT TYPES OF LIGHTING SIMULATION SOFTWARES

There are different types of lighting simulation Software available as appended below.

[Table -10: Lighting design Software]

Sl. No.	Title	Description
1	DIALux	DIALux is a free light planning software for both indoor and outdoor lighting with daylight and artificial light scenarios.
2	Trace Pro	A software tool for modelling the propagation of light in imaging and non- imaging opto-mechanical systems. The models are created by importing from a design or CAD program, or through directly creating the solid geometry in Trace Pro. Designers can analyse from the model: Light distributions in illumination and imaging systems Lumens exiting, absorbing, and incident at the component and system levels Candela distributions Optical efficiency, luminance, and radian cemeteries Photorealistic rendering
3	Lite Star 4D	A software for interior and exterior lighting design
4	MA Lighting software	Lighting design software for indoor and outdoor stage lighting
5	Relux	Free lighting design software for indoor, outdoor and tunnel lighting.

6	Radiance	Radiance is a free open-source suite of programs for the analysis of lighting in design. Its input files specify the scene geometry, luminaires, time, date, and sky conditions. Calculated values include illuminance values, luminance values include glare indices.
7	Ray front	This type of software is used for lighting design in educational institutions and industries with daylight to compute daylight factors, work-plane illuminance and evaluate glare distribution.
8	Microlux	Lighting design software for indoor stage lighting
9	Lighting Reality	Lighting software for street and outdoor area lighting

Out of the above-mentioned lighting design Software, **DIALux 4.13** software has been adopted for present study.

CHAPTER 3

LIGHTING DESIGN WITH LED LAMPS

Introduction:

The lighting design for the Hi-Tech System office was carried out using energy efficient LED luminaires. The design is simulated in DIALux 4.13 considering all the factors like, dimension of the room, light loss factor, reflectance factor, height of work plane over which the illumination level is calculated and output data like average level of illuminance, overall uniformity, energy consumption. While carrying out the lighting design parameters all the recent standards for indoor lighting design was considered. The Aim is to observe the maintained average illuminance (E_{avg}) value of the new design using energy efficient luminaires if it is better than the existing design or as per the recent guidelines. The costing and return of investment will be calculate.

3.1 Room Details:

All the rooms proposed by the office admin were considered for calculation for various photometric data and tabulated below (Table-08). According to the prescribed guidelines for indoor lighting for an office space and software available the design was finalized.

Table-11: Room Details with Visual Task and Illuminance

Sl. No.	Name of the Room	Visual Task to be Performed	Age Group of the Working Personal (years)	Required Average Illuminance (lux)
1	Inside Sales area (Document Room)	Task related to document verification, authorization, Tendering.	25 - 40	200-300
2	Work Space, Divisional Room	Tasks related to issuing and deposit of various miscellaneous stock (Stationary) items required for day to day office requirement.	21 - 50	300-500
3	Small Conference Room	Task related to document verification, authorization	25 – 60.	300-500

		and important meeting with delegates of other offices		
4	Manager's Room	Generic	40 – 60.	300-500
5	Cubicles Gen 2 & TnD	Task related to works for employees, Sales & Marketing.	50 – 60	300-500
6	Corridor	Generic	30 – 60	200-300
7	Main Conference Room	For every ex-house meeting, presentations etc	20 – 60	300-500
8	AHU Room	Service & maintenance team area.	20 - 40	300-500

3.2 Luminaire Details:

Table-12: Luminaire Details with area of usage

Sl No	Name of Luminaire	Optic type	Specifications	Area of Usage
1	Philips BN308C LED40S-6500 L12O PSU WH (Fig No-)	Beam angle 120°	Luminous flux (Luminaire):4350 lumens Luminous flux(Lamps): 4350 lumens Luminaire Wattage: 35.1 WLuminaire classification according to CIE: 93 Fitting: 1 X LED (Correction Factor 1.000).	AHU Room

2	Philips DN590B M LED15S-6500 PSD WH WB (Fig No-)	Facetted reflector with beam angle 60°	Luminous flux (Luminaire):1560 lumen Luminous flux(Lamps): 1560 lumen Luminaire Wattage: 13.0 W Luminaire classification according to CIE: 100 Fitting:1 X LED (Correction Factor 1.000).	Work Space-Divisional Room, Small Conference Room, Manager's Room, Cubicles Gen 2 & TnD, Corridor, Main Conference Room
3	Philips DN590B M LED20S-6500 PSU WH WB (Fig No-)	Facetted reflector with beam angle 60°	Luminous flux (Luminaire):2172 lumen Luminous flux(Lamps): 2170 lumen Luminaire Wattage: 18.9 W Luminaire classification according to CIE: 100 Fitting:1 X LED (Correction Factor 1.000).	Inside Sales area
4	Philips RC600B LED40S840 PSD W60L60 /3950K (Fig No-)	Beam angle 100°	Luminous flux (Luminaire):4001 lumens Luminous flux(Lamps): 4000 lumens Luminaire Wattage: 32.0 W Luminaire classification according to CIE: 100 Fitting:1 X LED Ra85/3950K (Correction Factor 1.000).	Work Space-Divisional Room, Small Conference Room, Manager's Room, Cubicles Gen 2 & TnD, Main Conference Room

PHILIPS
Lighting

Endura Next Batten

BN308C LED40S-6500 L120 PSU WH

With Philips Endura Next, customers have an industrial batten lighting solution that makes a valuable contribution to the profitability of their business, providing both operational and maintenance cost savings.By significantly reducing the energy consumption, this solution contributes to a lower carbon footprint. At the same time, the luminaire design ensures flicker free, consistent light output for the lifetime (50K hrs.), thereby guaranteeing the optimal working conditions for employees. It enhances productivity as well as takes care of safety of the employees. This unique solution comes with a wide range of intelligent (DALI, PIR movement detection) and networkable options such as Interact IoT enabled platform (both in Wired & Wireless options).No matter what your requirement is "Endura Next" comes with endless possibilities in this era of connected lighting and is specifically designed to minimize downtime in operations.

Warnings and Safety

- Meant for use in Indoor environment only

Product data

General Information	
Beam angle of light source	120 °
Light source color	865 cool daylight
Driver included	Yes
Optic type	120 [Beam angle 120°]
Optical cover/lens type	Polycarbonate
Luminaire light beam spread	120°
Control interface	-
Protection class IEC	Safety class I (I)
Flammability mark	F [For mounting on normally flammable surfaces]
Warranty period	2 years

Material	Steel
Light source engine type	LED
Operating and Electrical	
Input Voltage	140-270 V
Input Frequency	50 Hz
Power Factor (Min)	0.95
Controls and Dimming	
Dimmable	No

Datasheet, 2020, March 19

data subject to change

Fig No 22: BN308C LED40S-6500 L12O PSU WH Specifications

LuxSpace G4

DN591B LED20/840 PSU C D200 WH WB WP GM

LuxSpace G4, 18 W, 2040 lm, 4000 K, Facetted reflector with beam angle 60°, Textured, IP20/54 | Finger-protected; dust accumulation-protected, splash-proof

LuxSpace Gen4 is the a new LED downlight range combining light comfort and leading performance with luxury looking

Product data

General Information	
Light source replaceable	No
Number of gear units	1 unit
Driver included	Yes
Light source engine type	LED
Warranty period	3 years

Light Technical	
Luminous Flux	2,040 lm
Correlated Color Temperature (Nom)	4000 K
Luminous Efficacy (rated) (Nom)	113 lm/W
Color rendering index (CRI)	>80
Light source color	840 neutral white
Optic type	Facetted reflector with beam angle 60°

Operating and Electrical	
Input Voltage	220 to 240 V
Line Frequency	50 or 60 Hz
Inrush current	6.1 A
Inrush time	0.31 ms
Power Consumption	18 W
Power Factor (Fraction)	0.9
Connection	Push-in connector and pull relief
Number of products on MCB of 16 A type B	34
Protection class IEC	Safety class II

Controls and Dimming	
Dimmable	No
Driver/power unit/transformer	Power supply unit external (On/Off)
Control interface	-
Constant light output	No
Maximum dim level	Not applicable

Mechanical and Housing	
Housing Material	Aluminum die cast
Reflector material	Polycarbonate aluminum coated
Optic material	Polycarbonate
Optical cover material	Polycarbonate
Fixation material	Steel
Housing Color	White and black

Datasheet, 2024, September 26

data subject to change

Fig No 23: Philips DN590B M LED15S-6500 PSD WH WB Specifications

PHILIPS

Lighting

LuxSpace G4

DN591B LED20/840 PSU C D200 WH WB WP GM

LuxSpace G4, 18 W, 2040 lm, 4000 K, Facetted reflector with beam angle 60°, Textured, IP20/54 | Finger-protected; dust accumulation-protected, splash-proof

LuxSpace Gen4 is the a new LED downlight range combining light comfort and leading performance with luxury looking

Product data

General Information	
Light source replaceable	No
Number of gear units	1 unit
Driver included	Yes
Light source engine type	LED
Warranty period	3 years

Light Technical	
Luminous Flux	2,040 lm
Correlated Color Temperature (Nom)	4000 K
Luminous Efficacy (rated) (Nom)	113 lm/W
Color rendering index (CRI)	>80
Light source color	840 neutral white
Optic type	Facetted reflector with beam angle 60°

Operating and Electrical	
Input Voltage	220 to 240 V
Line Frequency	50 or 60 Hz
Inrush current	6.1 A
Inrush time	0.31 ms
Power Consumption	18 W
Power Factor (Fraction)	0.9
Connection	Push-in connector and pull relief
Number of products on MCB of 16 A type B	34
Protection class IEC	Safety class II

Controls and Dimming	
Dimmable	No
Driver/power unit/transformer	Power supply unit external (On/Off)
Control interface	-
Constant light output	No
Maximum dim level	Not applicable

Mechanical and Housing	
Housing Material	Aluminum die cast
Reflector material	Polycarbonate aluminum coated
Optic material	Polycarbonate
Optical cover material	Polycarbonate
Fixation material	Steel
Housing Color	White and black

Datasheet, 2024, September 26

data subject to change

Fig No 24: Philips DN590B M LED20S-6500 PSU WH WB Specifications

PHILIPS
Lighting

PowerBalance RC600B

RC600B LED40S/840 PSD W60L60 CAU

PowerBalance RC600B, 125 lm/W, 840 neutral white, DALI

When it comes to lighting an office space with LED luminaires, people are willing to invest in sustainability, but only at reasonable cost. At the same time, the system should comply with office lighting norms to ensure a comfortable working environment. PowerBalance is an attractively priced LED luminaire specially developed to meet all office requirements. It consumes significantly less energy while offering longer life of the light source, resulting in lower operational cost compared to traditional luminaires.

Product data

General Information	
Light source replaceable	No
Number of gear units	1 unit
Driver included	Yes
Light source engine type	LED
Service tag	Yes
Glow-wire test	Temperature 650 °C, duration 30 s
Flammability mark	-
CE mark	CE mark
ENEC mark	ENEC mark
Warranty period	3 years
EU RoHS compliant	No

Light Technical	
Luminous Flux	4,000 lm
Correlated Color Temperature (Nom)	4000 K
Luminous Efficacy (rated) (Nom)	125 lm/W
Color rendering index (CRI)	>80
Beam angle of light source	- degree(s)
Light source color	840 neutral white
Optic type	Beam angle 100°
Optical cover type	Opal
Luminaire light beam spread	120°

Operating and Electrical	
Input Voltage	220/240 V
Line Frequency	50 to 60 Hz
Inrush current	14.7 A
Inrush time	250 ms
Power Consumption	32 W

Datasheet, 2023, September 4

data subject to change

Fig No 25: Philips RC600B LED40S840 PSD W60L60 /3950K Specifications

3.3 Design Calculations:

The lighting design is simulated in DIALux 4.13 and the various photometric results summary carries all the necessary input data like overall dimensionof the room, light loss factor and reflectance factor, height of work plane over which theillumination level is calculated and output data like average level of illuminance, overall uniformity, LPD value. Details of luminaires used for simulation is also obtained from the summary report pertaining to the application area is appended below.

The lighting design parameters to be maintained according to the recent standards IS 3646(Part I and II), 1992: Code of practice for indoor illumination [09], National Lighting code [17], 2010, Energy Conservation Building Code (ECBC): 2017 [16] etc. are:

- Maintained Average Illuminance (in lux)
- Overall Uniformity of Illuminance (U0)
- Energy consumption.

3.3.1 Inside Sales area (Document Room:

Design Aim: Document rooms require average illuminance of 200-300 lux for the working area ofroom. The room was fitted with 12 nos. LED luminaires. Fig No 26-gives the 3D view of the room. Fig No 27,28 and 29 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: Philips DN590B M LED20S-6500 PSU WH WB

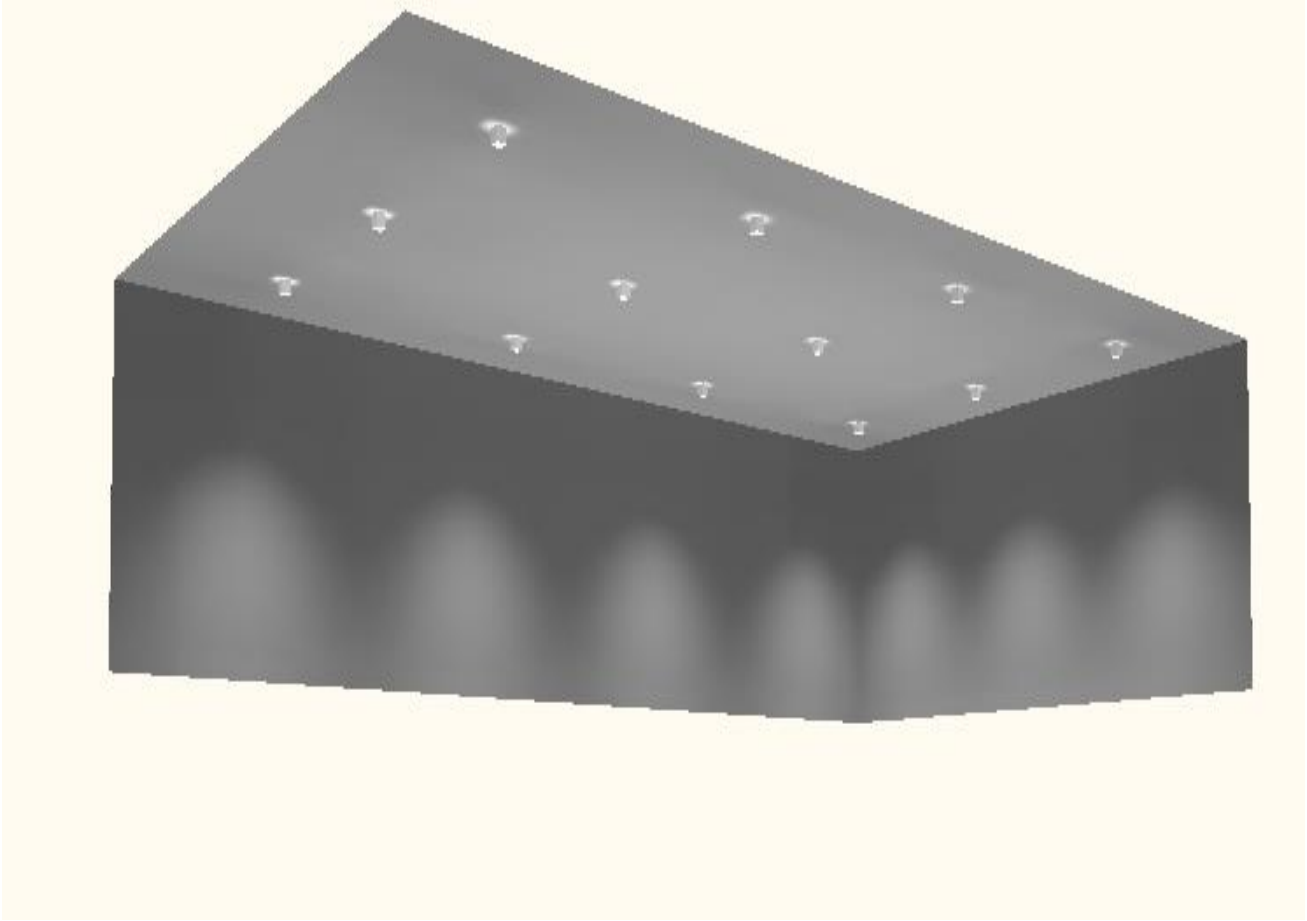
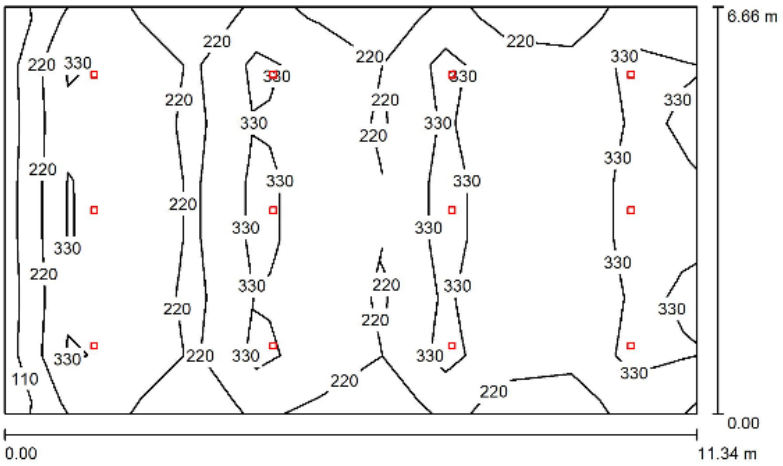


Fig No 26-: Document Room 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:86

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	278	73	601	0.263
Floor	20	260	76	365	0.292
Ceiling	50	35	22	797	0.623
Walls (4)	30	52	20	126	/

Workplane:
Height: 0.760 m
Grid: 11 x 7 Points
Boundary Zone: 0.000 m

UGR (CIE, SHR = 1.00.)

	Lengthways-	Across
Left Wall	/	/
Lower Wall	/	/

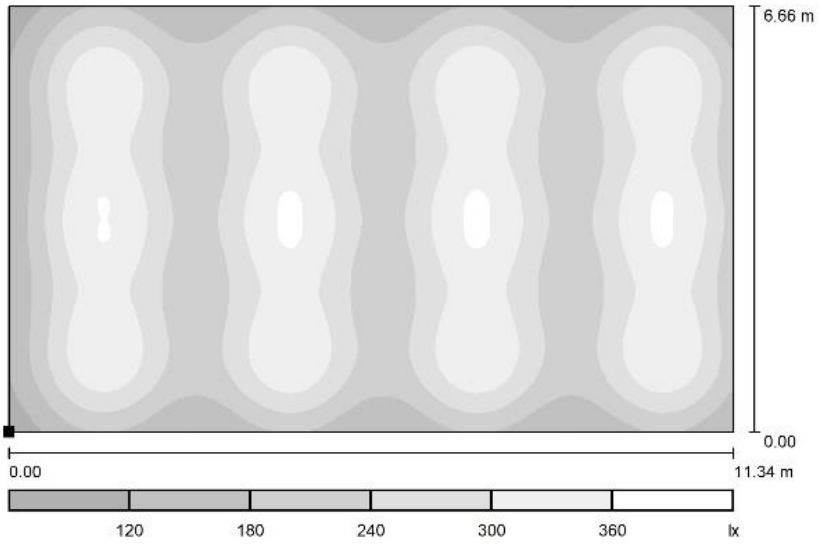
to luminaire axis

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.143, Ceiling / Working Plane: 0.126.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	Philips DN590B M LED20S-6500 PSU WH WB (1.000)	2172	2170	18.9
			Total: 26061	Total: 26040	226.2

Fig No 27: Summary of Document Room



Scale 1 : 82

Position of surface in room:
Marked point: (12.259 m, 29.700 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
260	76	365	0.292	0.208

Fig No 28: Grey scale [E]

109	171	220	214	167	143	160	206	227	193	152	147	183	224	217	170	143	160	205	226	188
138	230	299	290	222	188	211	280	307	261	197	191	246	303	293	226	187	210	278	305	254
158	265	336	331	257	214	243	322	343	301	227	218	283	341	334	261	214	241	321	341	294
160	268	349	338	261	217	246	327	357	305	229	222	287	353	342	265	217	245	325	356	298
157	256	332	321	248	208	237	309	340	290	222	215	273	335	325	252	208	235	307	339	283
155	251	321	311	246	205	236	300	329	282	220	212	268	324	315	250	205	234	298	328	276
161	264	345	333	255	214	242	321	353	299	226	219	281	347	337	259	214	240	319	352	293
165	279	358	349	269	224	254	339	364	316	237	228	297	361	353	273	223	252	337	363	309
166	278	358	348	267	222	253	338	364	315	236	227	296	361	352	272	222	251	335	363	308
158	262	341	329	253	212	241	317	349	297	224	218	279	344	333	257	212	239	316	348	290
156	250	320	310	246	205	236	299	328	281	220	212	267	323	314	250	205	234	297	327	275
157	257	335	324	249	210	238	312	343	292	223	216	274	338	328	254	210	236	309	342	285
162	269	349	339	261	218	247	328	357	306	230	223	288	353	343	265	218	245	326	356	299
156	262	333	328	254	211	241	319	340	298	223	216	281	338	331	258	211	239	318	338	291
136	223	290	281	216	182	205	272	298	253	192	186	239	294	285	220	182	204	270	297	246
106	167	213	207	162	139	156	199	219	186	148	143	178	217	210	166	139	157	197	219	182

6.66 m

0.00

0.00

11.34 m

Values in Lux, Scale 1 : 82

Not all calculated values could be displayed.

Position of surface in room:
Marked point: (12.259 m, 29.700 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
260	76	365	0.292	0.208

Fig No 29: Value Chart [E]

3.3.2 Work Space, Divisional Room:

Design Aim: It requires average illuminance of 300-500 lux for the working area of room. The room was fitted with 58 nos. LED luminaires. Fig No 31,32,33 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: 1) Philips DN590B M LED15S-6500 PSD WH WB
  2) Philips RC600B LED40S840 PSD W60L60 /3950K

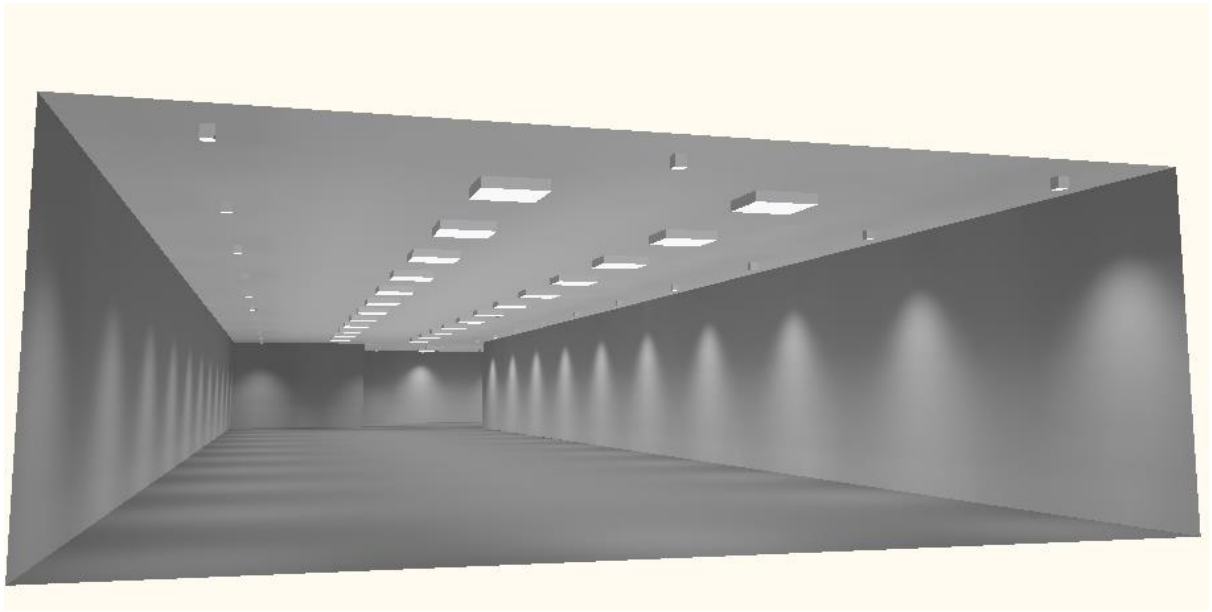
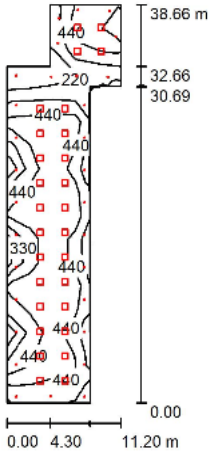


Fig No 30-: Workspace 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:497

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	425	124	627	0.292
Floor	20	378	103	517	0.272
Ceiling	50	58	27	75	0.471
Walls (8)	30	108	30	373	/

Workplane:

Height:	0.760 m
Grid:	5 x 17 Points
Boundary Zone:	0.000 m

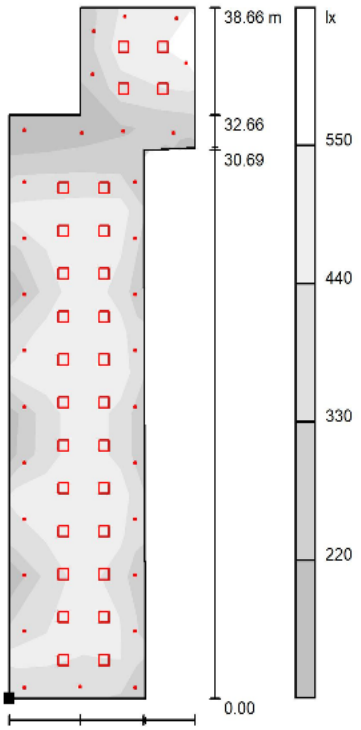
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.232, Ceiling / Working Plane: 0.143.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	30	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	1560	1560	13.0
2	28	Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)	4001	4000	32.0
			Total: 158849	Total: 158800	1286.0

Specific connected load: 4.10 W/m² = 0.96 W/m²/100 lx (Ground area: 313.40 m²)

Fig No 31: Summary of Workspace; Divisional Room



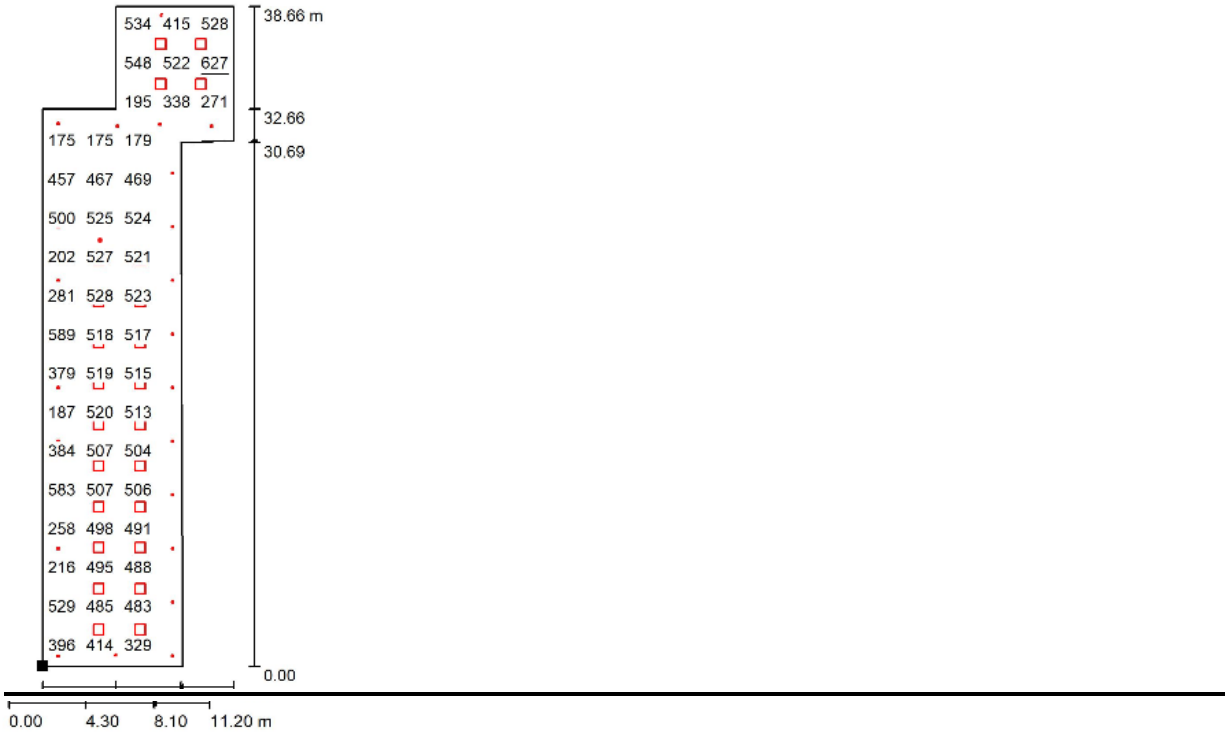
Scale 1 : 303

Position of surface in room:
Marked point: (12.026 m, 42.140 m, 0.760 m)

Grid: 5 x 17 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
425	124	627	0.292	0.198

Fig No- 32: Grey scale [E]



Values in Lux, Scale 1 : 303

Not all calculated values could be displayed.

Position of surface in room:
Marked point: (12.026 m, 42.140 m, 0.760 m)

Grid: 5 x 17 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
425	124	627	0.292	0.198

Fig No 33: Value Chart [E]

3.3.3 Small Conference Room (Eden):

Design Aim: Small Conference rooms require average illuminance of 300-500 lux for the working area ofroom. The room was fitted with 09 nos. LED luminaires. Fig No 34 gives the 3D view of the room. Fig No 35,36 and 37 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: 1) Philips DN590B M LED15S-6500 PSD WH WB
  2) Philips RC600B LED40S840 PSD W60L60 /3950K

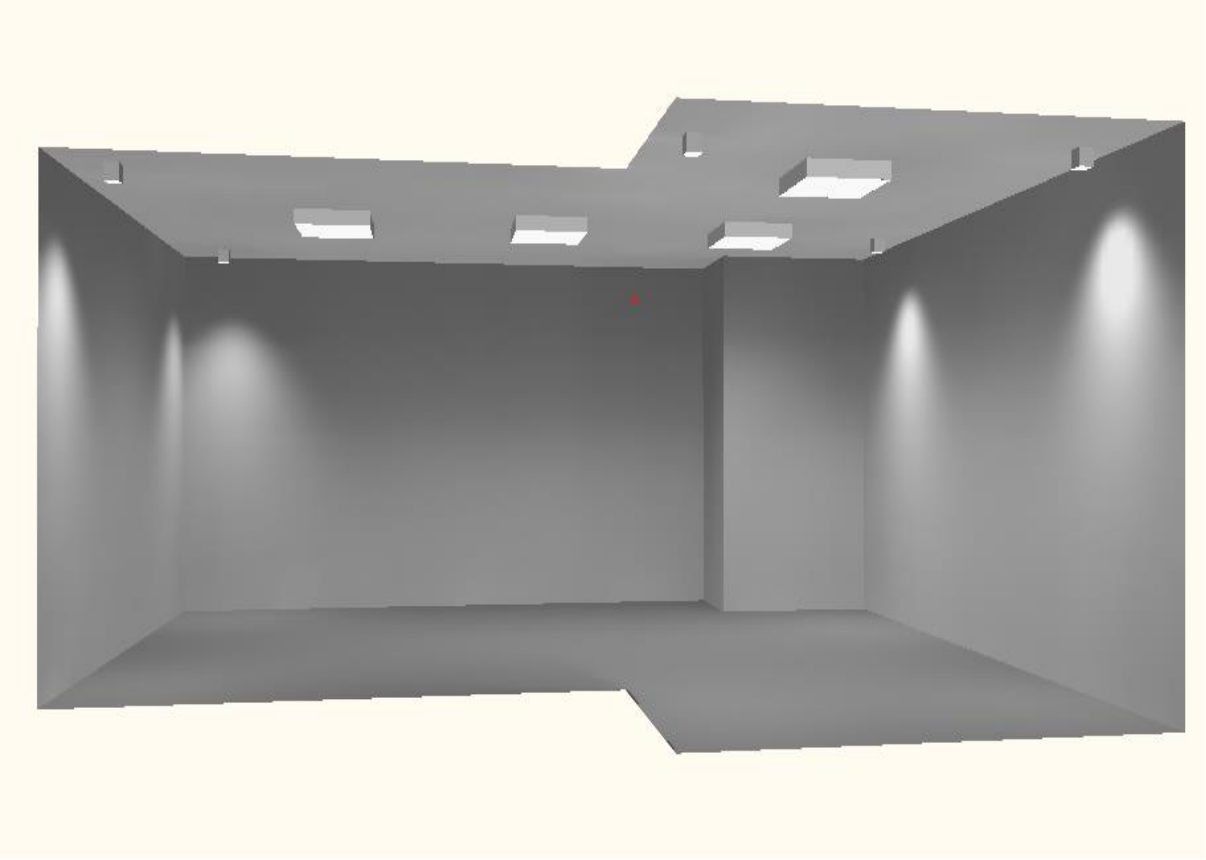
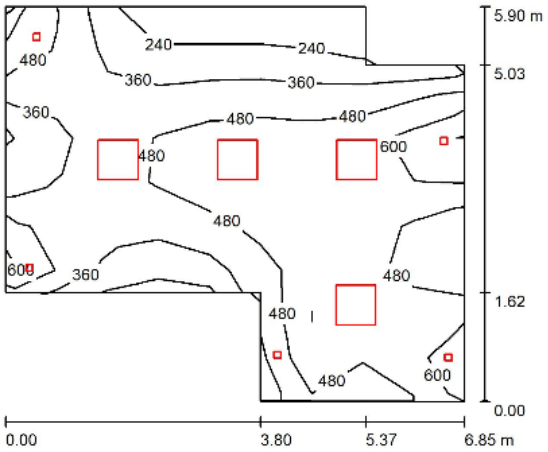


Fig No 34: Workspace 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:76

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	441	160	730	0.363
Floor	20	380	165	530	0.433
Ceiling	50	51	36	71	0.703
Walls (8)	30	158	35	1349	/

Workplane:

Height:	0.760 m
Grid:	9 x 9 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.336, Ceiling / Working Plane: 0.114.

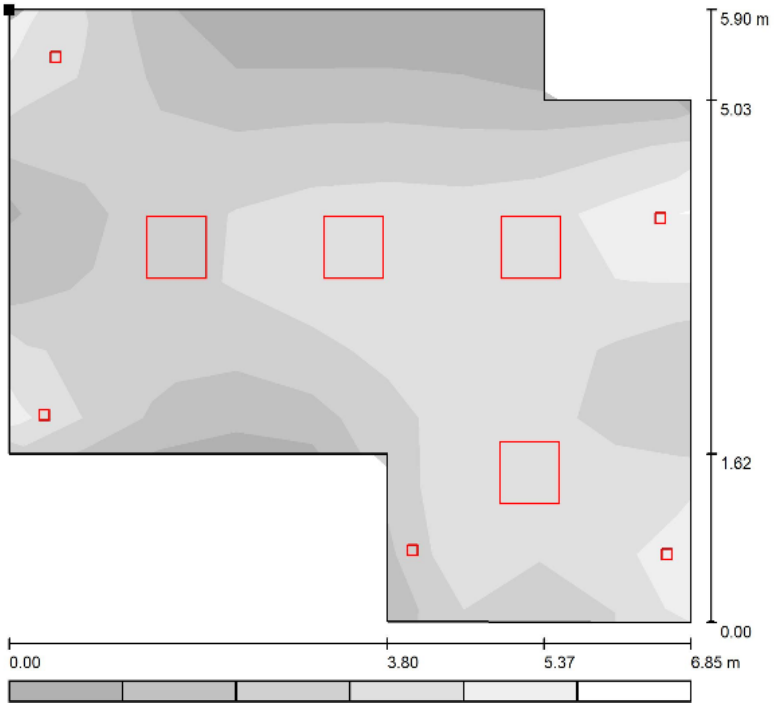
Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	5	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	1560	1560	13.0
2	4	Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)	4001	4000	32.0
			Total: 23807	Total: 23800	193.0

Specific connected load: 5.86 W/m² = 1.33 W/m²/100 lx (Ground area: 32.94 m²)

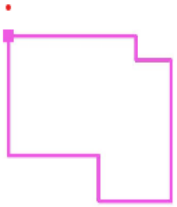
Fig No 35: Summary of Small Conference Room

Small Conference Room East Side / Workplane / **Greyscale (E)**



Scale 1 : 51

Position of surface in room:
Marked point: (45.846 m, 69.702 m, 0.760 m)

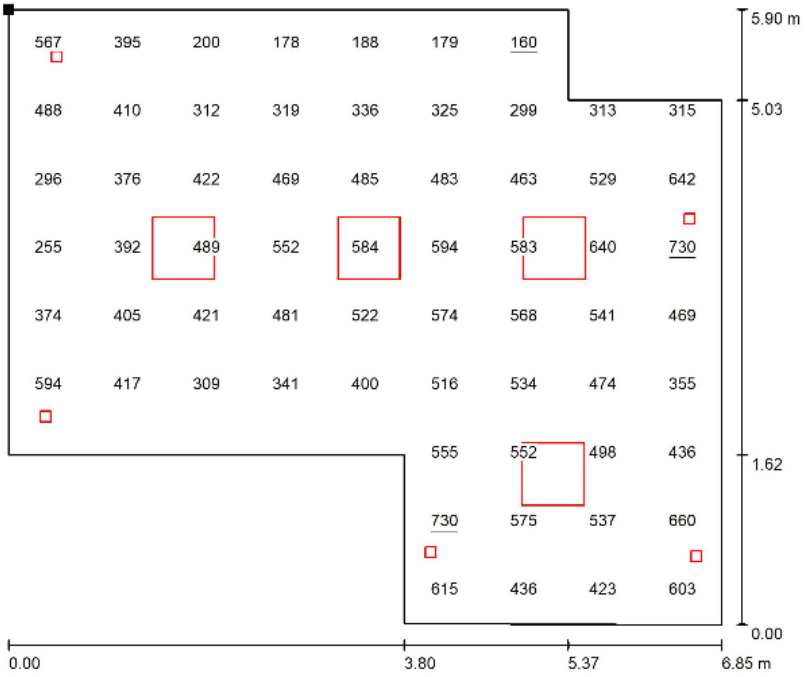


Grid: 9 x 9 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
441	160	730	0.363	0.219

Fig No 36: Grey scale [E]

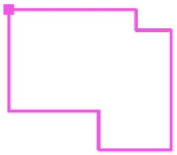
Small Conference Room East Side / Workplane / Value Chart (E)



Values in Lux, Scale 1 : 49

Not all calculated values could be displayed.

Position of surface in room:
Marked point: (45.846 m, 69.702 m, 0.760 m)



Grid: 9 x 9 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
441	160	730	0.363	0.219

Fig No 37: Value Chart [E]

3.3.4 Manager's Room:

Design Aim: Manager's rooms require average illuminance of 300-500 lux for the working area ofroom. The room was fitted with 06 nos. LED luminaires. Fig No 38 gives the 3D view of the room. Fig No 39,40 and 41 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: 1) Philips DN590B M LED15S-6500 PSD WH WB
  2) Philips RC600B LED40S840 PSD W60L60 /3950K

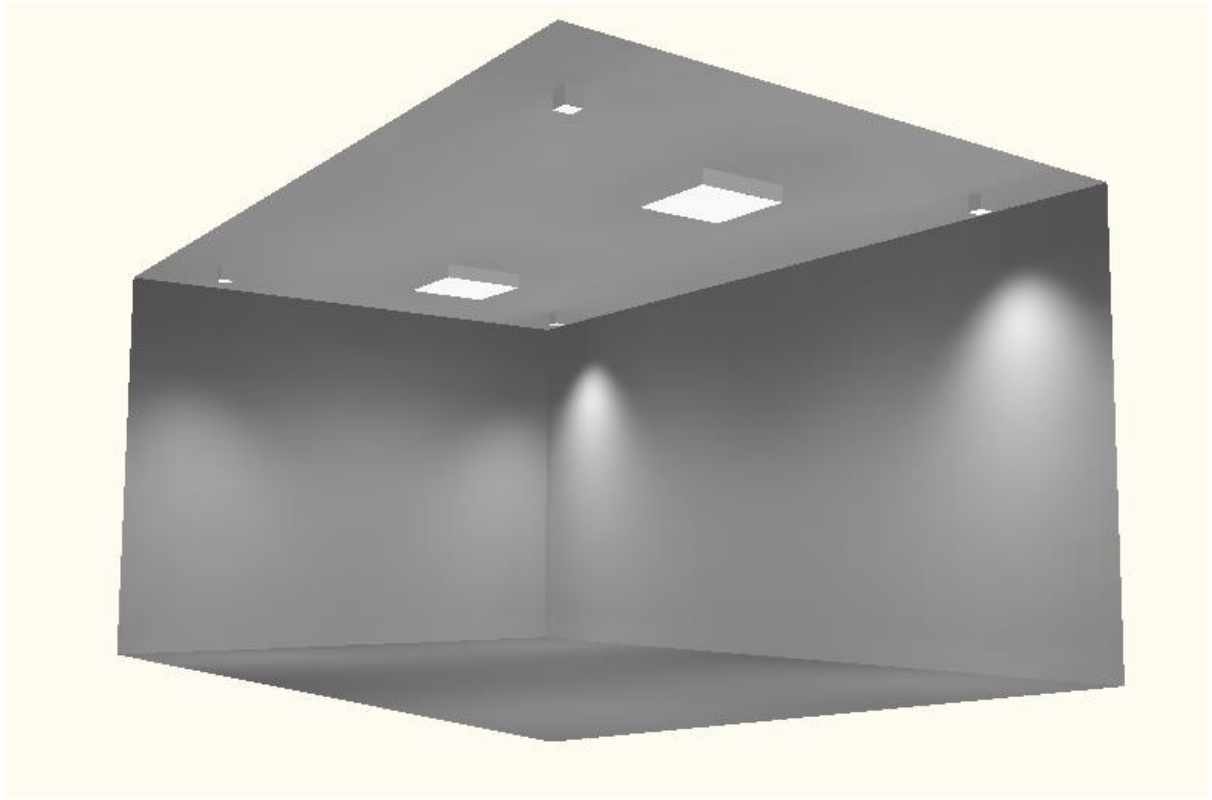
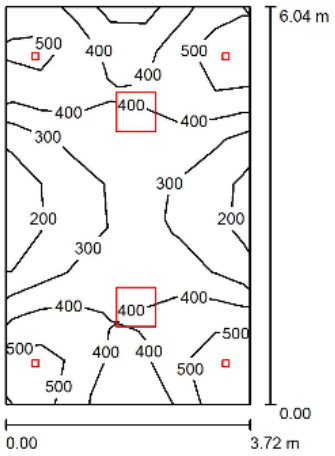


Fig No 38: Manager's Room 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:78

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	383	156	624	0.406
Floor	20	309	169	412	0.547
Ceiling	50	41	30	47	0.742
Walls (4)	30	135	29	644	/

Workplane:

Height:	0.760 m
Grid:	7 x 9 Points
Boundary Zone:	0.000 m

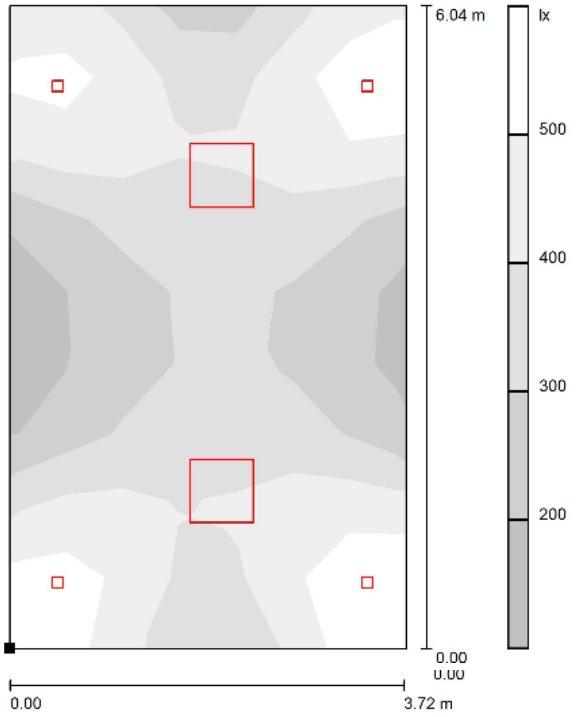
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.340, Ceiling / Working Plane: 0.109.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	1560	1560	13.0
2	2	Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)	4001	4000	32.0
			Total: 14244	Total: 14240	116.0

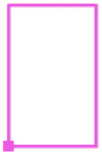
Specific connected load: 5.16 W/m² = 1.35 W/m²/100 lx (Ground area: 22.48 m²)

Fig No 39: Summary of Manager's Room



Scale 1 : 48

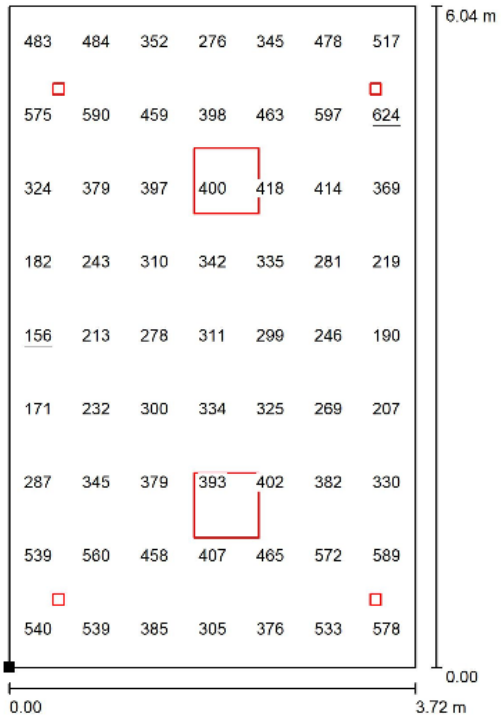
Position of surface in room:
Marked point: (29.376 m, 74.910 m, 0.760 m)



Grid: 7 x 9 Points

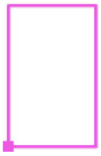
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
383	156	624	0.406	0.250

Fig No 40: Grey scale [E]



Values in Lux, Scale 1 : 48

Position of surface in room:
Marked point: (29.376 m, 74.910 m, 0.760 m)



Grid: 7 x 9 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
383	156	624	0.406	0.250

Fig No 41: Value Chart [E]

3.3.5 Cubicles Gen 2 & TnD:

Design Aim: This rooms require average illuminance of 300-500 lux for the working area ofroom. The room was fitted with 43 nos. LED luminaires. Fig No 42 gives the 3D view of the room. Fig No 43,44 and 45 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: 1) Philips DN590B M LED15S-6500 PSD WH WB
  2) Philips RC600B LED40S840 PSD W60L60 /3950K

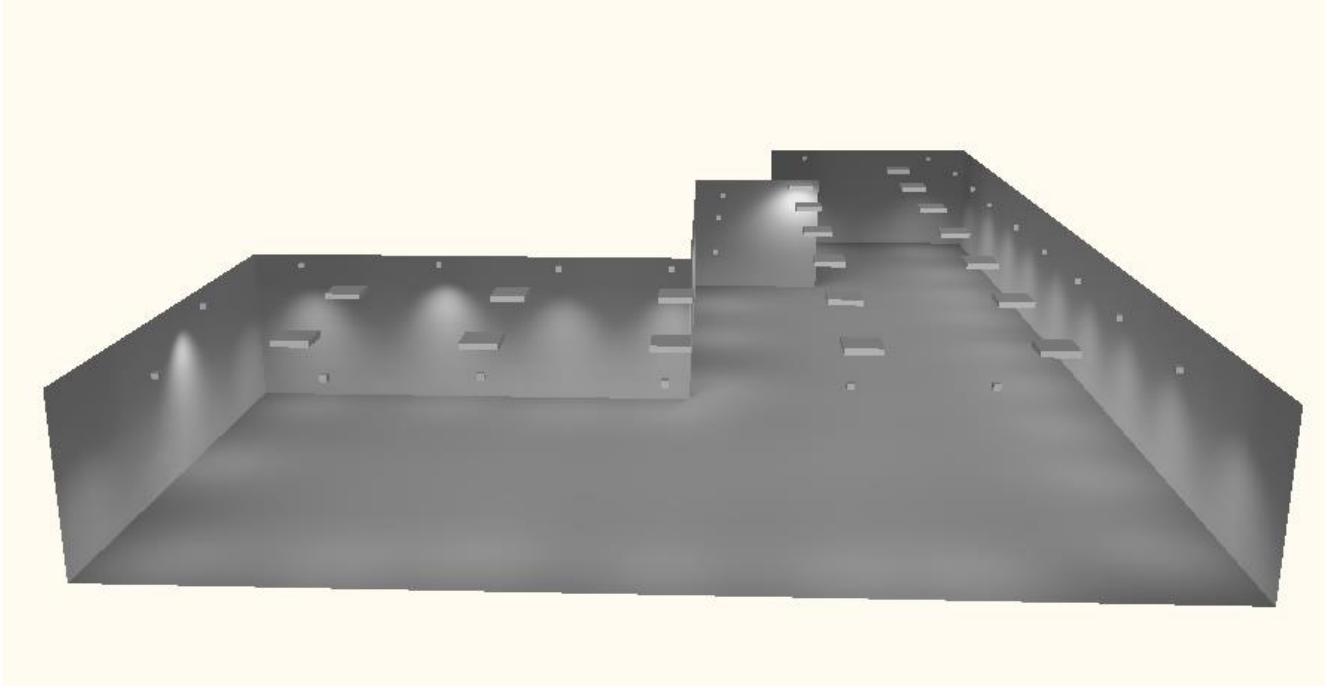
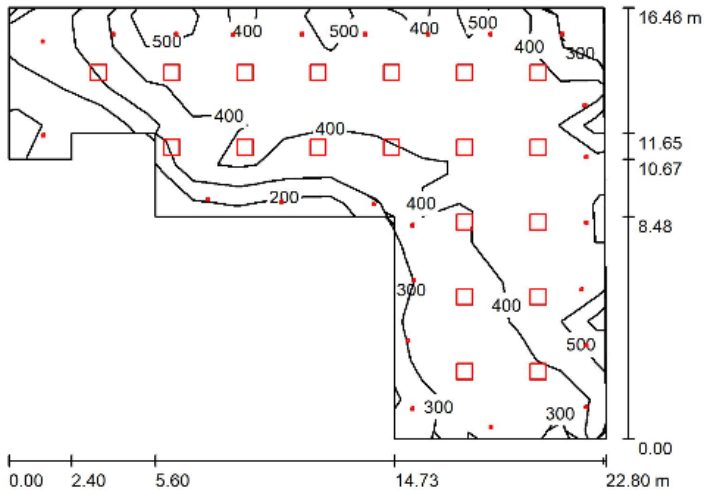


Fig No 42: Cubicles 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:212

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	388	126	624	0.324
Floor	20	359	70	529	0.194
Ceiling	50	54	21	70	0.393
Walls (10)	30	100	15	779	/

Workplane:

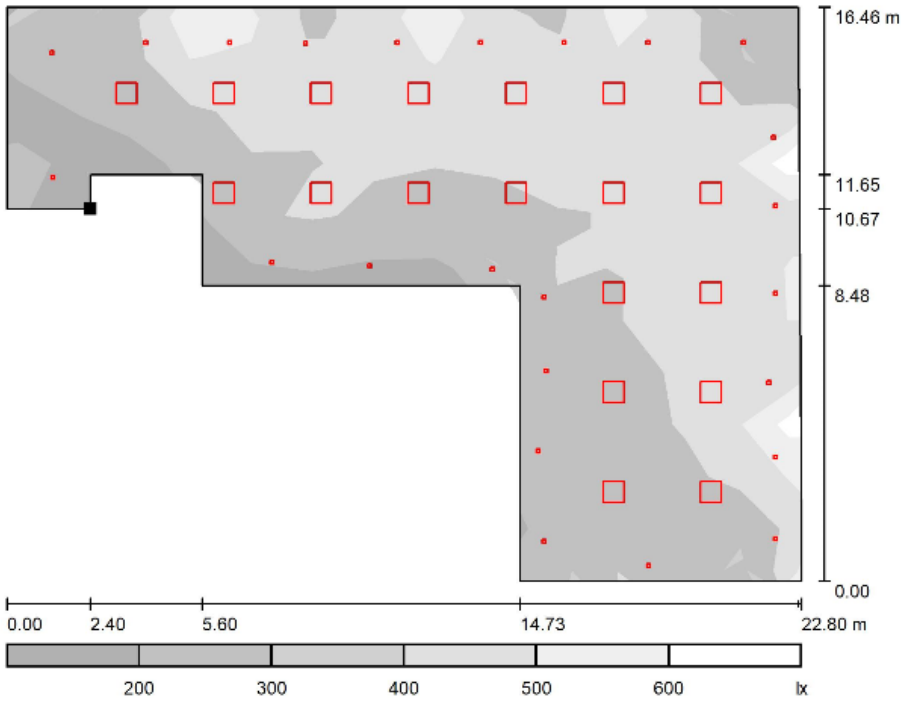
Height:	0.760 m
Grid:	11 x 13 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.217, Ceiling / Working Plane: 0.140.

Luminaire Parts List

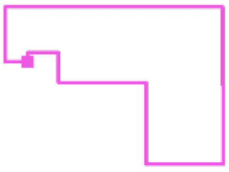
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	24	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	1560	1560	13.0
2	19	Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)	4001	4000	32.0
			Total: 113474	Total: 113440	920.0

Fig No 43: Summary of Cubicles



Scale 1 : 164

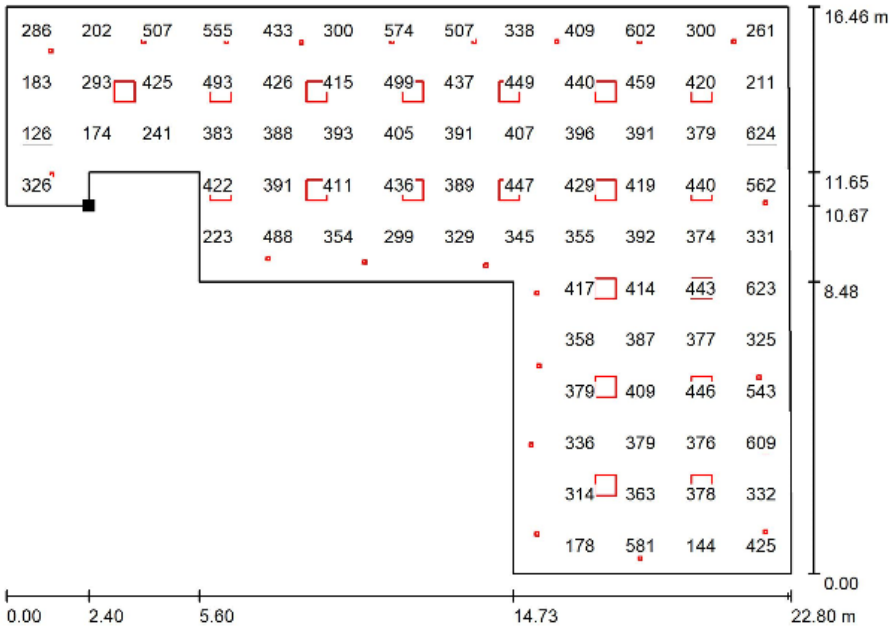
Position of surface in room:
Marked point: (51.896 m, 75.027 m, 0.760 m)



Grid: 11 x 13 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
388	126	624	0.324	0.202

Fig No 44: Grey scale [E]



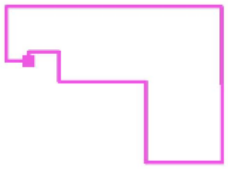
Values in Lux, Scale 1 : 164

Not all calculated values could be displayed.

Values in Lux, Scale 1 : 164

Not all calculated values could be displayed.

Position of surface in room:
Marked point: (51.896 m, 75.027 m, 0.760 m)



Grid: 11 x 13 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
388	126	624	0.324	0.202

Fig No 45: Value Chart [E]

3.3.6 Corridor:

Design Aim: Corridor requires average illuminance of 200-300 lux for the working area ofroom. The room was fitted with 56 nos. LED luminaires. Fig No 46 gives the 3D view of the room. Fig No 47,48 and 49 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: 1) Philips DN590B M LED15S-6500 PSD WH WB (1.000)

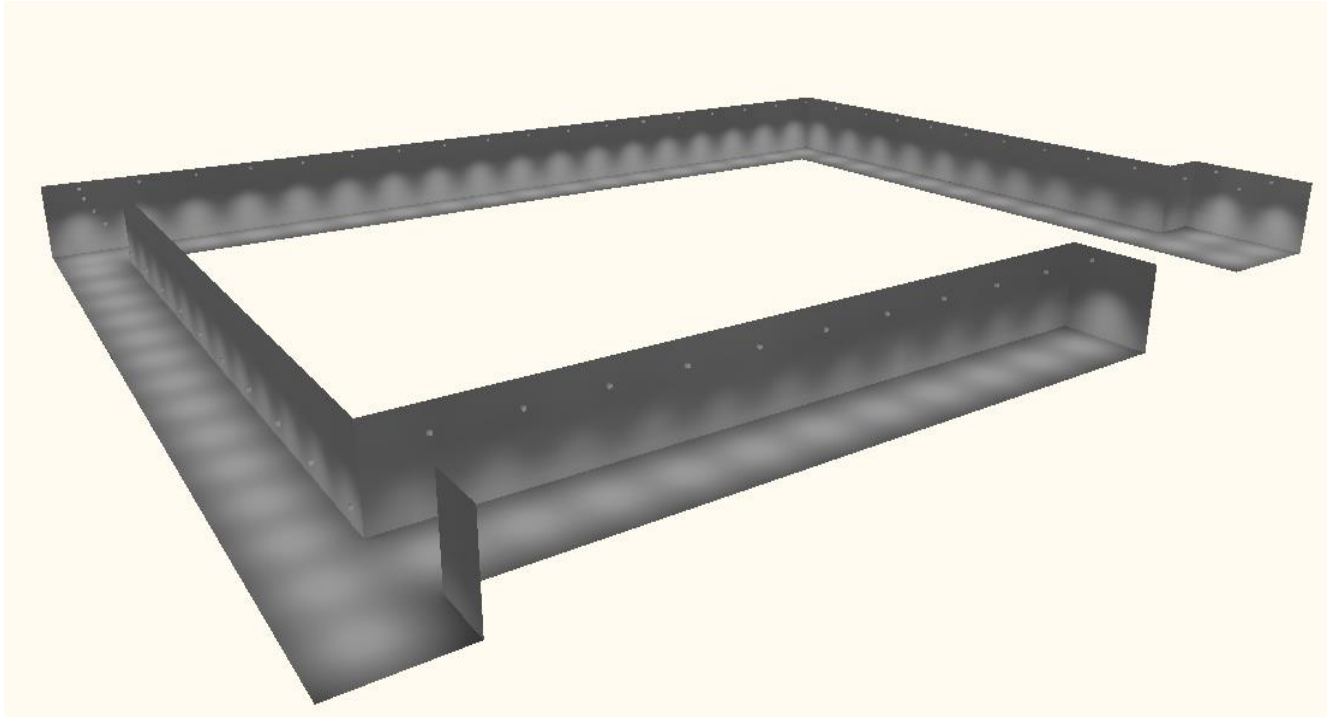
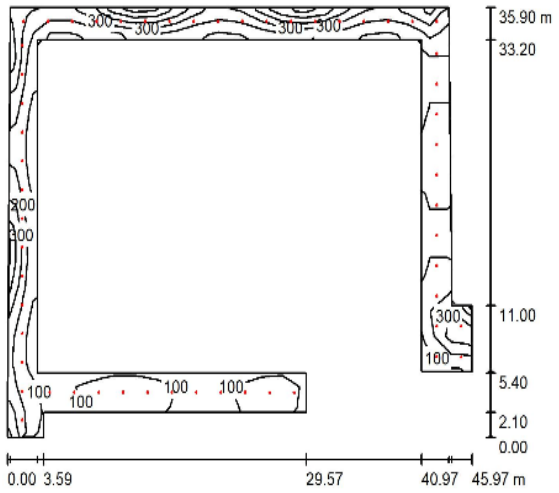


Fig No 46: Corridor 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:461

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	226	17	469	0.074
Floor	20	166	13	289	0.078
Ceiling	50	18	11	23	0.631
Walls (14)	30	26	9.04	89	/

Workplane:

Height:	0.760 m
Grid:	22 x 17 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.099, Ceiling / Working Plane: 0.098.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	56	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	1560	1560	13.0
			Total: 87378	Total: 87360	728.0

Fig No 47: Summary of Corridor

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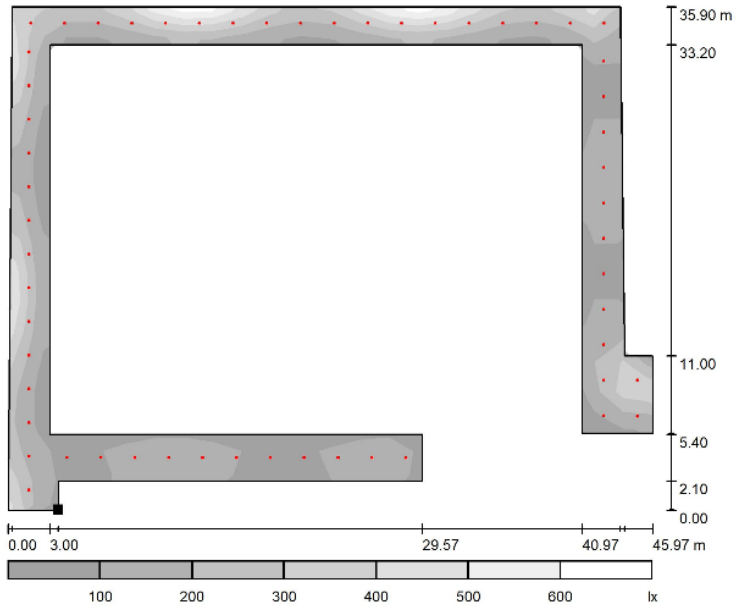


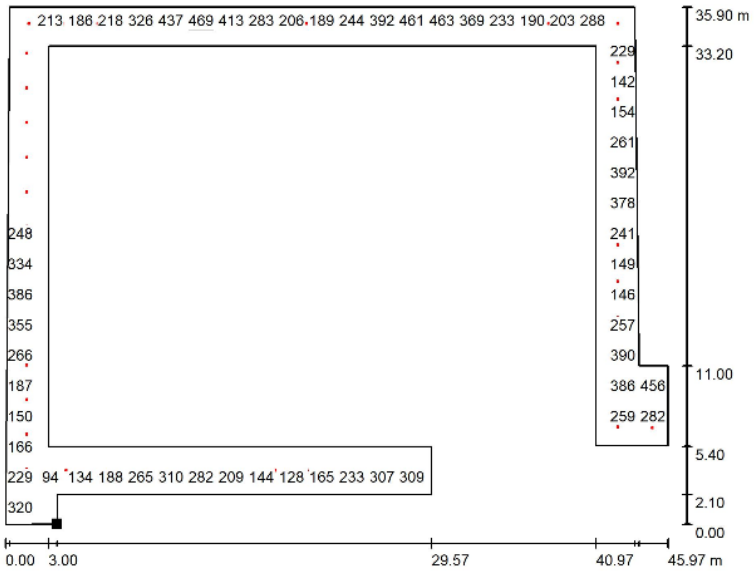
Scale 1 : 329

Position of surface in room:
Marked point: (23.817 m, 36.640 m, 0.760 m)

Grid: 22 x 17 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
226	17	469	0.074	0.036

Fig No 48: Grey scale [E]



Values in Lux, Scale 1 : 329

Not all calculated values could be displayed.

Position of surface in room:
Marked point: (23.817 m, 36.640 m, 0.760 m)

Grid: 22 x 17 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
226	17	469	0.074	0.036

Fig No 49: Value Chart [E]

3.3.7 : Main Conference Room

Design Aim: Main Conference rooms require average illuminance of 300-500 lux for the working area ofroom. The room was fitted with 18 nos. LED luminaires. Fig No 50 gives the 3D view of the room. Fig No 51,52 and 53 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: 1) Philips DN590B M LED15S-6500 PSD WH WB (1.000)
  2) Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)

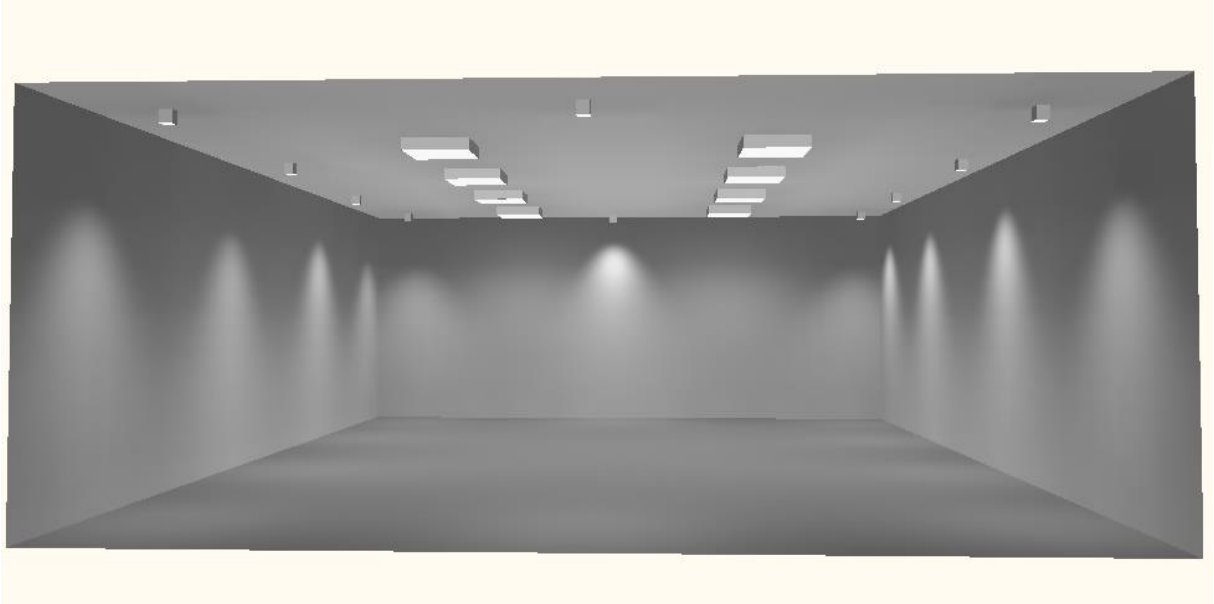
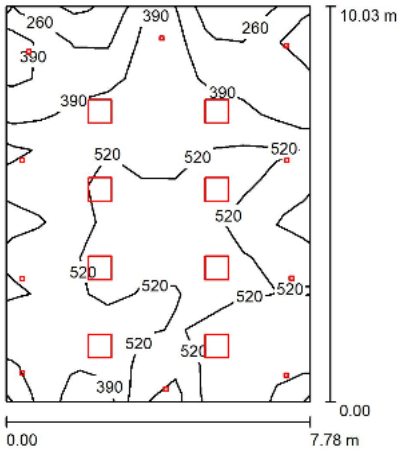


Fig No 50: Main Conference Room 3D View



Height of Room: 2.850 m, Mounting Height: 2.850 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	455	117	751	0.256
Floor	20	410	157	555	0.384
Ceiling	50	59	35	78	0.582
Walls (4)	30	137	34	817	/

Workplane:

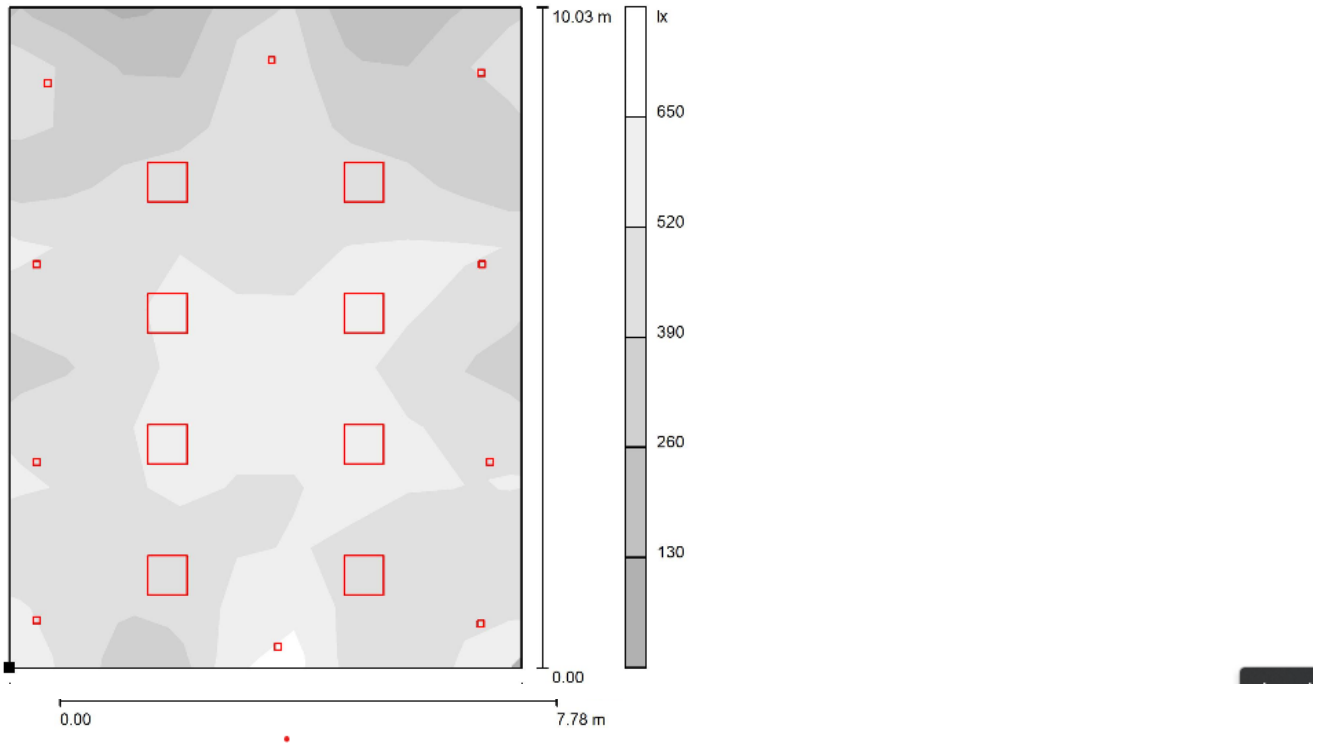
Height:	0.760 m
Grid:	9 x 11 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.272, Ceiling / Working Plane: 0.132.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	10	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	1560	1560	13.0
2	8	Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)	4001	4000	32.0
			Total: 47614	Total: 47600	386.0

Fig No 51: Summary of Main Conference Room



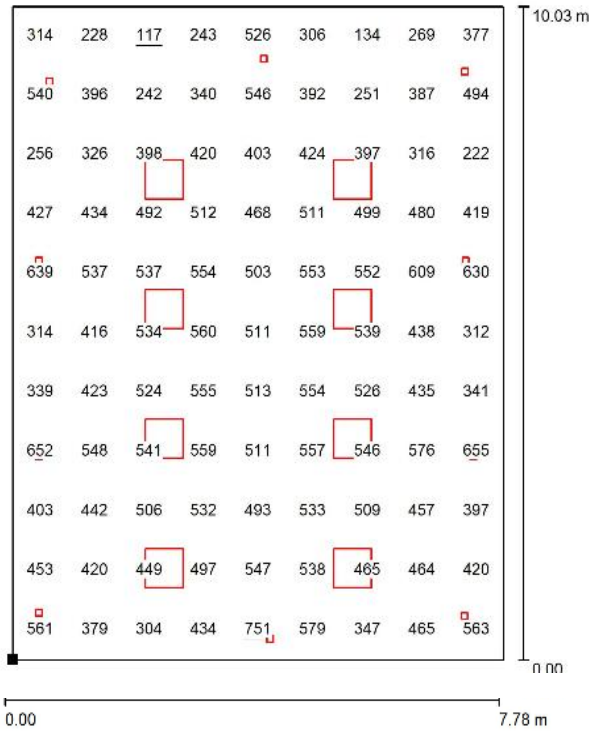
Scale 1 : 79

Position of surface in room:
Marked point: (64.316 m, 47.977 m, 0.760 m)

Grid: 9 x 11 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
455	117	751	0.256	0.155

Fig No 52: Grey scale [E]



Values in Lux, Scale 1 : 79

Position of surface in room:
Marked point: (64.316 m, 47.977 m, 0.760 m)

Grid: 9 x 11 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
455	117	751	0.256	0.155

Fig No 53: Value Chart [E]

3.3.8: AHU Room

Design Aim: AHU rooms require average illuminance of 200-300 lux for the working area ofroom. The room was fitted with 4 nos. LED luminaires. Fig No 54 gives the 3D view of the room. Fig No 55,56 and 57 give the design results of average illuminance, grey scale and Value chart respectively for the document room using energy efficient LED luminaires.

Design Considerations:

- Height of Room: 2.850 meter
- Maintenance Factor: 0.80
- Reflection Factor (%): 50/30/20(ceiling/wall/floor)
- Work Plane Height: 0.760 m
- Luminaire Used: Philips BN308C LED40S-6500 L12O PSU WH (1.000)

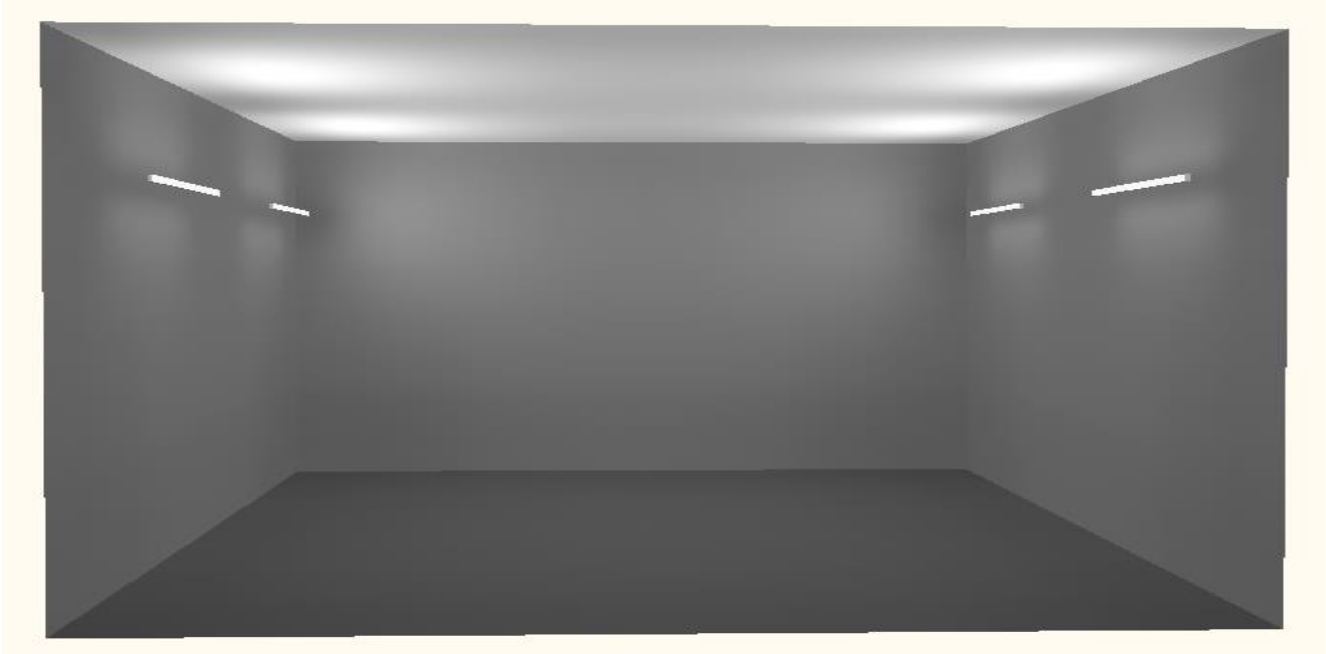
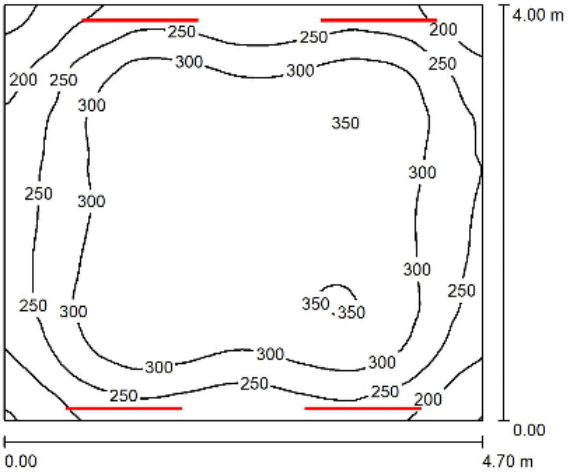


Fig No 54: AHU Room 3D View



Height of Room: 2.850 m, Mounting Height: 2.200 m, Maintenance factor: 0.80 Values in Lux, Scale 1:52

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	287	138	356	0.482
Floor	20	218	128	281	0.588
Ceiling	50	325	97	707	0.297
Walls (4)	30	215	107	502	/

Workplane:

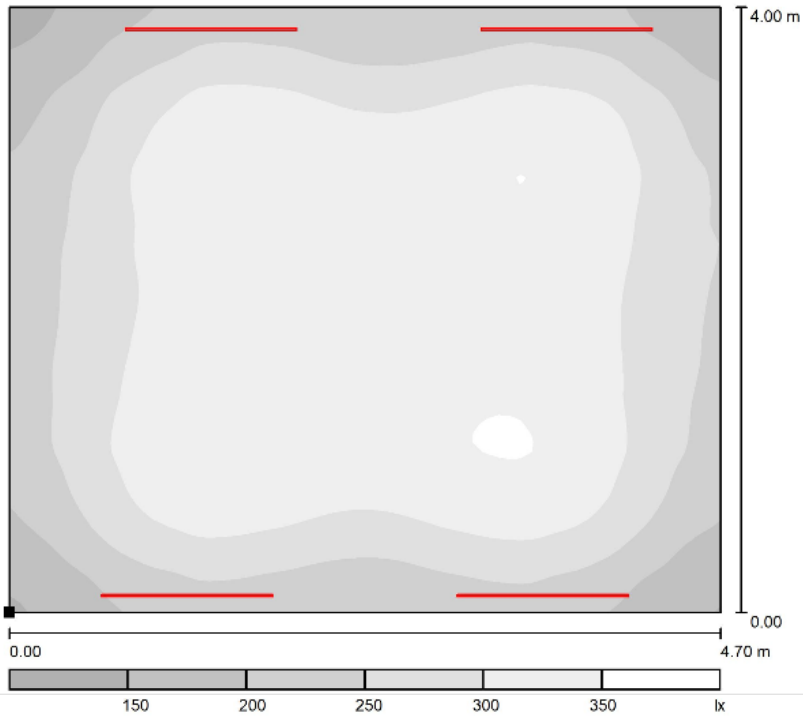
Height:	0.760 m
Grid:	64 x 64 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.839, Ceiling / Working Plane: 1.132.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	Philips BN308C LED40S-6500 L12O PSU WH (1.000)	4350	4350	35.1
			Total: 17401	Total: 17400	140.2

Fig No 55: Summary of AHU Room



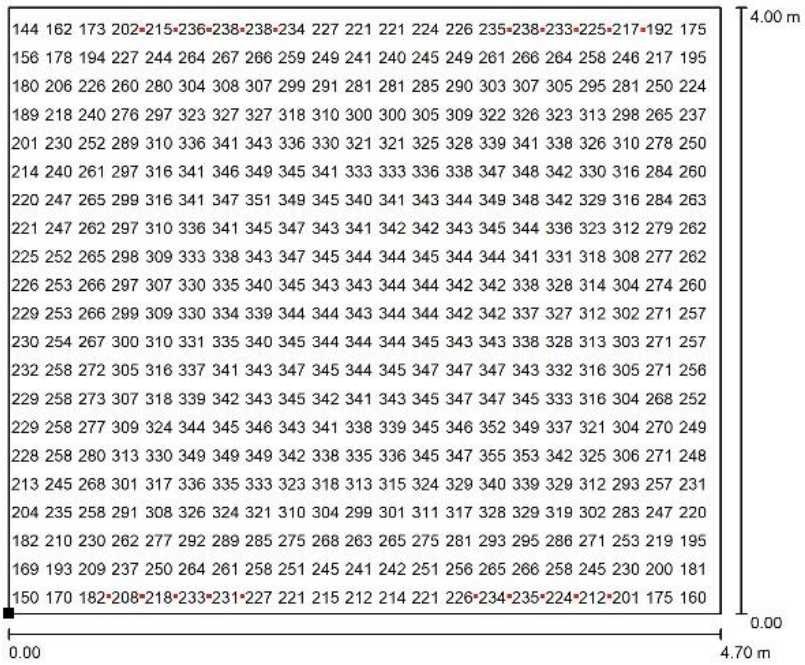
Scale 1 : 34

Position of surface in room:
Marked point: (56.300 m, 52.702 m, 0.760 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
287	138	356	0.482	0.388

Fig No 56: Grey scale [E]



Values in Lux, Scale 1 : 34

Not all calculated values could be displayed.

Position of surface in room:
Marked point: (56.300 m, 52.702 m, 0.760 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
287	138	356	0.482	0.388

Fig No 57: Value Chart [E]

CHAPTER 4

RESULT ANALYSIS

[Table 13: Lighting Design Summary Using Energy Efficient (LED) Luminaires]

Sl. No.	Name of the Room	Type of Luminaire Used	Quantityy of Luminaire	Average Illuminance (lux)		Overall Uniformity
				Required	Designed	
	Inside Sales area (Document Room)	Philips DN590B M LED20S-6500 PSU WH WB	12	200-300	278	0.3
	Work Space, Divisional Room	1) Philips DN590B M LED15S-6500 PSD WH WB 2) Philips RC600B LED40S840 PSD W60L60 /3950K	58	300-500	425	0.3
	Small Conference Room	1) Philips DN590B M LED15S-6500 PSD WH WB 2) Philips RC600B LED40S840 PSD W60L60 /3950K	09	300-500	441	0.4
	Manager's Room	1) Philips DN590B M LED15S-6500 PSD WH WB 2) Philips RC600B LED40S840 PSD W60L60 /3950K	06	300-500	383	0.4

	Cubicles Gen 2 & TnD	1)Philips DN590BM LED15S-6500 PSD WH WB 2)Philips RC600B LED40S840 PSD W60L60 /3950K	43	300-500	388	0.5
	Corridor	Philips DN590B M LED15S-6500 PSD WH WB (1.000)	56	200-300	226	0.6
	Main Conference Room	1) Philips DN590B M LED15S-6500 PSD WH WB (1.000) 2) Philips RC600B LED40S840 PSD W60L60 /3950K (1.000)	18	300-500	455	0.5
	AHU Room	Philips BN308C LED40S-6500 L12O PSU WH (1.000	4	200-300	287	0.48

The lighting design for the Hi-Tech System & Services ltd office was implemented using energy-efficient LED luminaires. This design was simulated in DIALux 4.13, incorporating key factors such as room dimensions, light loss factor, reflectance factor, and the height of the work plane used to calculate illumination levels. The output data included essential metrics like average illuminance, overall uniformity and energy consumption. During the design process, all recent standards for indoor lighting design were taken into consideration. The results indicate that the maintained average illuminance (Eavg) value of the new design using energy-efficient luminaires is superior to the existing setup and aligns with current guidelines. Key metrics analyzed with lighting control devices are as follows:

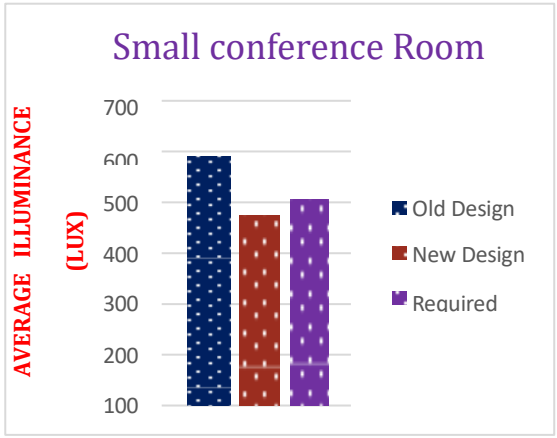
Maintained Average Illuminance (lux)

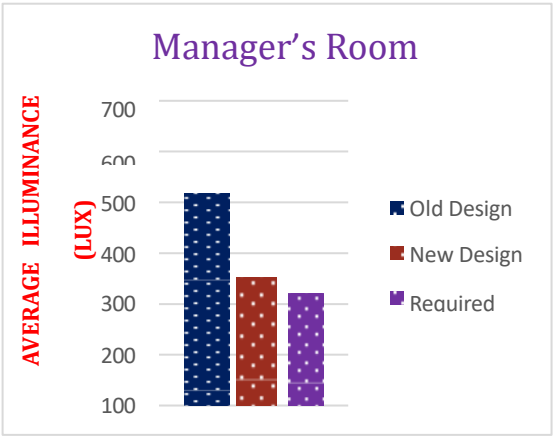
Energy Consumption

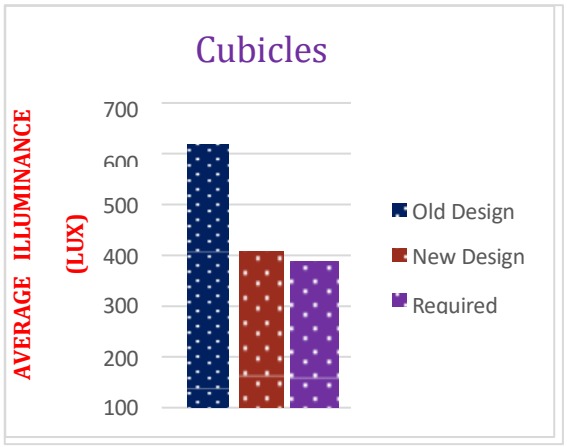
7.1 Average Illuminance:

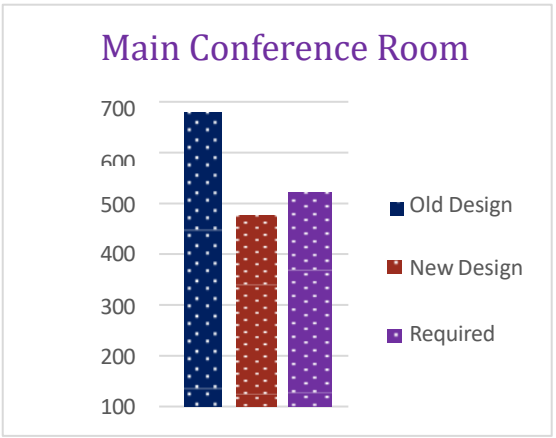
The average illuminance required for various areas and rooms in the office was designed according to the current guidelines outlined in IS 3646 (Part 1): 1992 (Code of Practice for Interior Illumination) [9]. The design aimed to facilitate visual tasks and create a comfortable visual environment. Since conditions vary across different interiors or even within the same type of interior, a range of illuminance values was applied for each area instead of a single fixed illuminance level. This approach ensures adaptability to diverse interior or activity-specific needs.

Fig. No 58: Average Illuminance for Document Room & Work Space









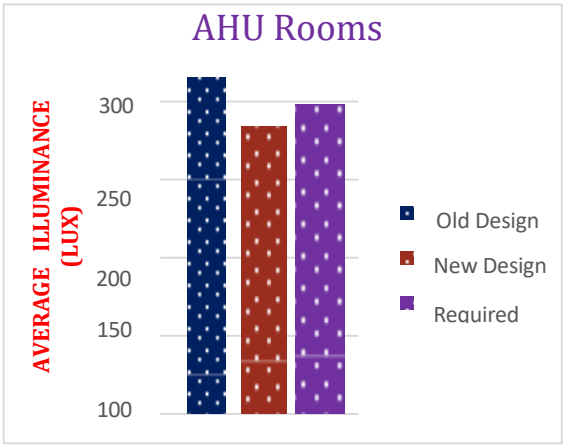


Fig. No 59: Average Illuminance for Small Conference Room, Manager's Room, Cubicles, Main Conference Room, Corridors, AHU Room

Energy Consumption:

Energy consumption data was calculated for all rooms and areas in the specified region under both lighting designs. The results show that energy consumption in the new design, using energy-efficient luminaires, is significantly lower than in the existing design with conventional luminaires. Figures below compares energy consumption for various rooms, with the X-axis representing both lighting designs and the Y-axis showing annual energy consumption in kWh.

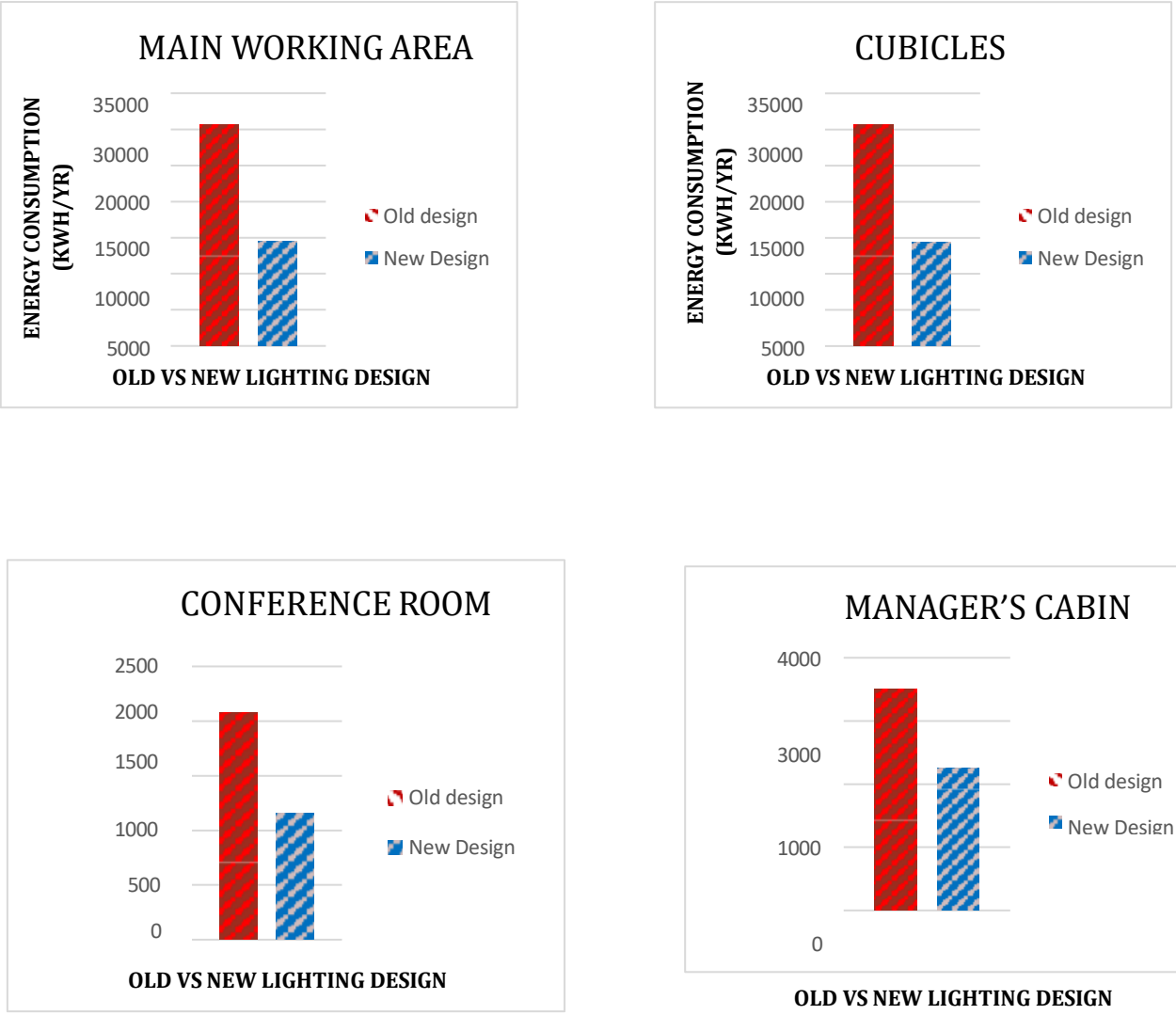


Fig. No 60: Energy Consumption for Main Working Area, Cubicles, Conference Room, Manager's Cabin

Total energy saving comparison for one year: the energy consumption corresponding to the usage of both type of luminaries is appended below. From the results it was observed that, the total energy saving/year using energy efficient luminaires will be 39600 units less than the conventional luminaires. The comparison data is paced in Fig. No 61.

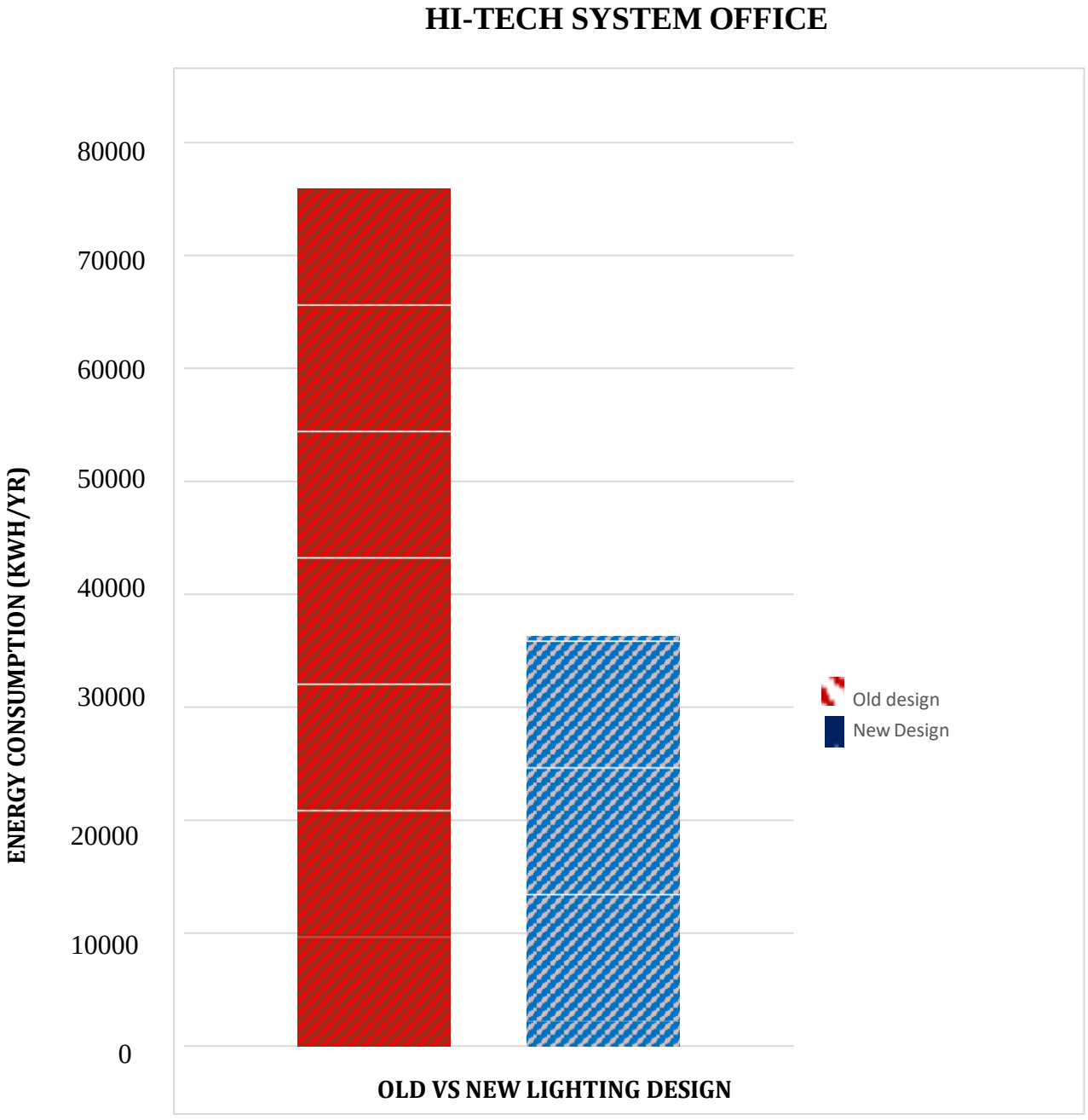


Fig. No 61: Energy Consumption Data for 01 Year

CHAPTER 5

RETURN ON INVESTMENT

5.1 Pay Back Period / Return on Investment:

This study presents the potential energy saving, life cycle cost analysis and Return on investment of the lighting system in Hi-Tech systems & Services Ltd, Kolkata office building. As briefed earlier, the existing luminaires fitted in the Hi-Tech system building were more than 15 years old and the new energy efficient fittings were installed at the same places without much changing to the false ceiling area. Cost benefit analysis of retrofitting with more efficient lighting system in terms of potential energy saving, life cycle cost analysis and payback period have been conducted. Comparison of existing and retrofitting of lighting system based on the energy consumption is presented.

The Payback Period is the amount of time it will take you to recoup your original investment in the project. The Return on Investment (ROI) is a ratio of the total savings from the project to the total project cost and it will demonstrate how profitable the project is. Forcalculating the payback period and justification that, the investment is viable, the following process was adopted.

- **STEP 1 -** Determine the type, number and operation schedule of the existing luminaires.
  - Total power consumed by the existing luminaires = power consumed by individual luminaire X No. of luminaires= 26 X 49 Watt + 19 X 44 Watt + 233 X 89 watt = 22,847 Watt = 23 KW (approx.)
  - Average working Hours / Day – 10 hours
  - Average working Hours / Year – 3300 Hours (Approximately 330 working days)

- **STEP 2** – Estimate the total operating cost as energy consumption (KWH) of the existing luminaires. and maintenance cost for 01 year.
  - Total energy consumption /Year for old fittings – 3300 X 23 KW = 75900 KWH.
  - Total operating cost / Year for old fittings - Rs. 8.00 X 75900 KWH = **Rs. 6,07,200.00.**
  - Maintenance Cost for one year: Total no. of lamps (Old) to be replaced in one year = Quantity of lamps * Average working Hours in one year / average life of lamp = Rs. 300.00 X 280 X 3300/7000 = **Rs. 39,600.00**
  - Total cost for the old fittings will be = Total operating cost / Year + maintenance cost= Rs. 6, 07,200.00 + Rs. 39,600.00 = **Rs. 6, 46,800.00**

- **STEP 3** - Determine the type, number and operation schedule of the LED luminaires.
  - Total power consumed by the LED luminaires - power consumed by individual luminaire X No. of luminaires = 53 X 21 Watt + 60 X 33 Watt + 235 X 33 Watt + 38 X 15 watt = 11148 Watt = 11 KW (Approx.)
  - Average working Hours / Day – 10 hours
  - Average working Hours / Year – 3300 Hours (Approximately 330 working days)

- **STEP 4** – Estimate the total operating cost as energy consumption (KWH) of the LED and maintenance cost for 01 year.
  - Total energy consumption /Year for old fittings – 3300 X 11 KW = 36300 KWH
  - Total operating cost / Year for old fittings - Rs. 8.00 X 363000 KWH = = **Rs. 2,90,400.00**
  - Maintenance Cost for one year: The LED lamps are having 50000 hours of rated life, so no maintenance cost for first two years
  - Total cost for the LED fittings will be = Total operating cost / Year + maintenance cost= Rs. = **Rs. 2, 90,400.00** + 0.00 = **Rs. 2, 90,400.00**

- **STEP 5** – Calculate the annual savings in regard to operation and maintenance of both the type of luminaires.
  - Total savings(cost) in replacement and operation using LED luminaires= Total replacement and operation of old luminaires - Total replacement and operation of LED luminaires = Rs. 6,46,800.00 - Rs. 2,90400.00 = **Rs. 3,56,400.00** / Year
- **STEP 6** – Calculate the capital investment for replacement to LED luminaires.
  - Total Supply cost of the new luminaires =Cost of 21-watt Luminaire X 53 No's X Rs. 700.00 + Cost of 15-watt Luminaire X 38 No's X Rs. 550.00 + Cost of 2 ft X 2 ft Luminaire X 60 No's X Rs. 3500.00 + Cost of 01 ft X 04 ft Luminaire X 245 No's X Rs. 1500.00 = Rs. 6, 60,000.00
  - Installation cost for the new Luminaires – Rs. 100 X 396= Rs. 39, 600.00
  - Cost for modification of false ceiling and other accessories during the replacement of new luminaire at the building – Rs. 1, 50,000.00
  - Total cost for new luminaires – Rs. 6, 60,000.00 + 39, 600.00 + Rs. 1, 50,000.00 = Rs. 8, 49,600.00 = **Rs. 8, 50,000.00** (Approx.)

- **STEP 7** – Calculate the payback period and Return on Investment.
  - **Payback period** = Total capital investment / Total annual savings(cost)

    = Rs. 8, 50,00.00 / Rs. 3,56,400.00

    = 2.389 Years = 2.5 years after installation.
  - Return on Investment (%)=(Total annual savings(cost)/Total capital investment) * 100

    = (Rs. 3,56,400.00 / Rs. 8, 50,00.00) * 100

    = 42 %

  :- Hence the Investment is **Viable.**

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion:

Lighting design plays a crucial role in achieving energy efficiency during the design phase, particularly through the use of modern energy-saving lamps, luminaires, and control systems. Careful planning, combined with effective operational practices, further enhances energy savings. Lighting design is not only essential for office functionality but also offers a high-return, low-risk investment opportunity. By integrating advanced lighting technologies, offices can significantly reduce both electricity consumption and lighting-related energy costs.

Given that many current lighting systems are outdated and inefficient, the introduction of modern light control systems is now common in the market. Studies confirm that energy-efficient lighting design, paired with the use of appropriate light sources, is vital. In this project, LEDs in suitable luminaires were utilized to meet workplace requirements, including:

- Replacement with energy-efficient lamps to achieve energy savings and reduce operational costs.
- Reducing excess light levels to meet necessary standards while maintaining good uniformity and minimizing glare.
- Creating a healthy, well-lit environment for office staff.
- Lowering annual energy consumption.
- Using low-maintenance lamps with extended lifespans to improve overall illuminance.

A comparison of different lighting schemes across various office areas was conducted, evaluating average illuminance, Lighting Power Density (LPD), and energy consumption. Bar charts were used to recommend optimal values for illuminance and LPD by area, while a payback period analysis supported the proposal for a new energy-efficient LED lighting design.

6.2 Future Scope:

The current lighting system is controlled manually via buttons and switches. As technology advances, future lighting control may leverage automated systems. Smart lighting, controlled via smartphone or PC through Bluetooth and Wi-Fi, is one of the simplest ways to save energy. With every light point connected to an intelligent system, smart lighting provides high-quality, reliable illumination, offering significant value beyond just light. In the future, smart lighting will play a key role in the Internet of Things (IoT), facilitating real-time data integration and artificial intelligence to optimize energy usage and enable informed consumer decisions, leading to cost savings.

IoT connects computers and networks to monitor and control devices with minimal human intervention. Both general and specialized lighting systems could be managed through visible light control systems instead of radio-frequency controllers. LEDs can also be precisely dimmed by integrating daylight sensors, optimizing lighting based on available natural light and further reducing energy use. Additionally, lighting load could be offset using solar energy from rooftop panels, especially in regions with extended daylight hours.

Emerging technologies such as OLEDs (Organic LEDs) also hold promise, utilizing organic semiconductors to generate light and further contribute to energy savings.

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